การเปรียบเทียบการเจริญเติบโตและการตอบสนองทางสรีรวิทยาของ *Globba marantina* L. และ *G. schomburgkii* Hook. f. ในวัสดุปลูกและระบบไฮโดรโปนิกส์

นางสาวปิยะมาศ ปานทอง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2560

COMPARISON OF GROWTH AND PHYSIOLOGICAL RESPONSES OF *GLOBBA MARANTINA* L. AND *G. SCHOMBURGKII* HOOK. F. IN GROWING SUBSTRATE AND HYDROPONIC SYSTEMS

Piyamart Phantong

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Biology

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COMPARISON OF GROWTH AND PHYSIOLOGICAL RESPONSES OF *GLOBBA MARANTINA* L. AND *G. SCHOMBURGKII* HOOK. F. IN GROWING SUBSTRATE AND HYDROPONIC SYSTEMS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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ปิยะมาศ ปานทอง : การเปรียบเทียบการเจริญเติบโตและการตอบสนองทางสรีรวิทยาของ *Globba marantina* L. และ *G. schomburgkii* Hook. f. ในวัสดุปลูกและระบบไฮโดรโปนิกส์ (COMPARISON OF GROWTH AND PHYSIOLOGICAL RESPONSES OF *GLOBBA MARANTINA* L. AND *G. SCHOMBURGKII* HOOK. F. IN GROWING SUBSTRATE AND HYDROPONIC SYSTEMS) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.หนูเดือน เมืองแสน, 79 หน้า.

Globba (Zingiberaceae) เป็นไม้ล้มลุกที่นิยมใช้เป็นไม้ประดับ อย่างไรก็ตามการเพาะปลูกมีข้อจำกัด เนื่องจากอัตราการขยายพันธุ์ต่ำและขึ้นอยู่กับฤดูกาลเท่านั้น งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบการเจริญเติบโตและการตอบสนองทางสรีรวิทยาของ *Globba marantina* L. และ *G. schomburgkii* Hook. f. ในวัสดุปลูกและระบบไฮโดรโปนิกส์ ในการศึกษาวิจัยนี้ใช้ต้นกล้าของ *G. marantina* และ *G. schomburgkii* ที่เพิ่มจำนวนในหลอดทดลอง (ความสูง 8 ซม.) ย้ายไปปลูกในระบบไฮโดรโปนิกส์ด้วยเทคนิค NFT ส่วนในวัสดุปลูกต้นกล้าถูกย้ายปลูกในกระถางขนาดเล็กที่มีส่วนผสมของทราย: แกลบเผา: พีทมอส (1: 1: 1 โดยปริมาตร) โดยใช้สารละลายสูตร SUT และสารละลายสูตร Hoagland วัดลักษณะการเจริญเติบโตของพืช ได้แก่ จำนวนต้น ความสูง เส้นผ่านศูนย์กลางลำต้น จำนวนใบและขนาดของใบ ที่ระยะเวลา 15 30 45 และ 60 วันหลังย้ายปลูก วัดพารามิเตอร์ทางด้านการเติบโตที่เกี่ยวข้องกับการสืบพันธุ์ ได้แก่ จำนวนช่อดอก ความยาวของช่อดอก จำนวนดอกและพารามิเตอร์ทางสรีรวิทยา ได้แก่ อัตราการสังเคราะห์ด้วยแสง อัตราการคายน้ำและค่าการนำไฟฟ้าในปากใบที่ระยะ 60 วันหลังย้ายปลูก ผลการศึกษาพบว่าต้นพืชมีการรอดชีวิต 100% ในการเจริญเติบโตทั้งสองสภาพ พืชทั้งสองชนิดที่ปลูกในระบบไฮโดรโปนิกส์ มีความยาวของใบ พื้นที่ใบและเส้นผ่านศูนย์กลางลำต้นมากกว่า ยกเว้นจำนวนต้นที่น้อยกว่าเมื่อเทียบกับพืชที่ปลูกในวัสดุปลูก นอกจากนี้พืชทั้งสองชนิดที่ปลูกในระบบไฮโดรโปนิกส์เกิดช่อดอกก่อนและมีจำนวนดอกมากกว่าซึ่งแสดงให้เห็นว่าพืชเหล่านี้สามารถออกดอกนอกฤดูกาลได้ นอกจากนี้พืชที่ปลูกในระบบไฮโดรโปนิกส์ทั้งสองชนิดมีอัตราการสังเคราะห์ด้วยแสง อัตราการคายน้ำและค่าการนำไฟฟ้าในปากใบสูงกว่าพืชที่ปลูกในวัสดุปลูก ผลจากการทดลองยังชี้ให้เห็นว่าการใช้สารอาหารสูตร Hoagland ส่งผลให้ความยาวช่อดอก (13.92 ซม.) จำนวนช่อดอก (8.33 ช่อดอกต่อกระถาง) และจำนวนดอกย่อย (18.11 ดอกต่อช่อดอก) มากกว่าพืชที่ปลูกในสารละลายสูตร SUT ดังนั้นการศึกษาครั้งนี้แสดงหลักฐานว่า *G. marantina* และ *G. schomburgkii* มีความสามารถใน

การปรับตัวให้เข้ากับสภาพไฮโดรโปนิกส์ และไฮโดรโปนิกส์อาจเป็นวิธีการหนึ่งที่เหมาะสมสำหรับการขยายพันธุ์ *Globba* และพืชอื่น ๆ ที่เกี่ยวข้องต่อไปในอนาคต

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา P. Phantong

ปีการศึกษา 2560 ลายมือชื่ออาจารย์ที่ปรึกษา N. Muangsan

PIYAMART PHANTONG : COMPARISON OF GROWTH AND PHYSIOLOGICAL RESPONSES OF *GLOBBA MARANTINA* L. AND *G. SCHOMBURGKII* HOOK. F. IN GROWING SUBSTRATE AND HYDROPONIC SYSTEMS. THESIS ADVISOR : ASSOC. PROF. NOODUAN MUANGSAN, Ph.D. 79 PP.

HYDROPONIC/ NUTRIENT FILM TECHNIQUE (NFT)/ SOILLESS CULTURE/ STOMATATAL CONDUCTIVITY/ ZINGIBERACEAE

Globba (Zingiberaceae) are attractive herbaceous plants which are widely used as ornamental plants. However, cultivation is limited due to low propagation rate and dependence on the season. The objective of this research was to compare growth and physiological responses of *Globba marantina* L. and *G. schomburgkii* Hook. f. in growing substrate and hydroponic systems. *In vitro* plantlets (8 cm in height) of both species were transplanted to a hydroponic culture with the nutrient film technique (NFT). In growing substrate, the plantlets were transplanted to small pots containing sand: burned rice husk: peat moss (1:1:1 by volume). SUT nutrient solution (SUT's solution) and Hoagland's solution were used in this study. Vegetative growth characteristics including the surviving plantlets, number of shoots, height of shoots, stem diameter, number of leaves and length of leaves were measured at 15, 30, 45 and 60 days after transplanting (DAT), whereas reproductive growth parameters including number of inflorescences, length of inflorescences, number of flowers, and physiological parameters of photosynthetic rate, transpiration rate, and stomatal conductivity were measured at 60 DAT. The results showed that there was 100%

survival in both growth conditions. Plants of both species grown in hydroponic system had higher shoot length, leaf area and stem diameter than those plants propagated in growing substrate, except number of shoots. Moreover, both species grown in hydroponics had earlier inflorescences and more flowers, indicating that they can be flowering out of season. In addition, in hydroponic condition for both species had higher photosynthetic rates, transpiration rates, and stomatal conductivity. Additionally plants grown in Hoagland's solution had longer inflorescences (13.92 cm), more inflorescence (8.33 inflorescence per pot) and more flowers (18.11 flowers per inflorescence) than those plants grown in SUT's solution. Therefore, our study provides evidence that *G. marantina* and *G. schomburgkii* are capable of adapting to hydroponic condition and that hydroponics may be a suitable method for propagating *Globba* and other Zingiberaceae.

School of Biology

Academic Year 2017

Student's Signature P. Phantong

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Piyamart Phantong

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LIST OF ABBREVIATION

%	=	percentage
TDZ	=	thidiazuron
MS medium	=	murashige and skoog medium
BA	=	benzyladenine
mg/l	=	milligram per liter
NAA	=	naphthaleneacetic
BAP	=	6-benzylaminopurine
GA_3	=	gibberellic acid
g/l	=	gram per liter
cm	=	centimeter
NFT	=	nutrient film technique systems
DFT	=	deep flow technique
DRFT	=	dynamic root fioating technique
EC	=	electrical conductivity
mS/cm	=	milliseimen per centimeter
AM	=	ante meridiem
CRD	=	completely randomized design
DMRT	=	duncan's multiple range test

CHAPTER I

INTRODUCTION

1.1 Background/Problem

Zingiberaceae is a large family of monocotyledons and a very large group of plants in Thailand and throughout Southeast Asia. In Thailand, Zingiberaceae comprises about 26 genera and 300 species (Larsen and Larsen, 2006). Many species are used as food and medicines such as *Zingiber officinale* Rosco used as food and a medicinal herb, *Z. rubens* Roxb. used for medicinal and ornamental purposes, *Z. zerumbet* Smith used as a medicinal herb, *Curcuma soloensis* used as a potted plant and for cut flowers, *C. attenuata* used for medicinal and ornamental purposes.

The genus *Globba* is usually small herbs. This genus is widely distributed from India eastwards through southern China, Indochina and the Malaysian region. Thailand, Laos, and Myanmar harbor high diversity (Larsen and Larsen, 2006). *Globba* species are ornamental plants, known as "Dancing Girls". At present, it is getting more attention with high demand in the international markets due to its magnificent shape and extraordinary flower. In Thailand, *Globba* plants are used as cut flowers or potted plants, but it is not widespread because the commercial varieties have little variation. In Saraburi Province, Thailand, during Buddhist Lent the flowers of *Globba* bound together with candles are sold in markets near temples for merit making ceremony called "Tak Bat Dok Mai" (http://www. nationmultimedia.com/).

The conventional propagation of the genus *Globba* is propagated using the underground rhizomes, fruits and bulbils (Pimmuen et al., 2014). Only some species of the genus *Globba* has bulbils which have low propagation rate. In addition, propagation of this genus depends on season only. In order to satisfy the increased demand for this plant material, hydroponic culture may be applied to produce high plant material all year-round in consideration of the possibility to control growing conditions.

The main objective of this study was to compare growth and physiological responses of two *Globba* species between growing substrate and hydroponic system. The results from this study will provide a useful information for developing a sustained method for propagating of *Globba* species and other related plant species, that we can grow these plants all year-round without dormancy concerns. It is one way to support and develop the genus *Globba* species as cut flowers economically in the near future.

1.2 Research objectives

The objectives of this thesis were:

1.2.1 To compare the growth and physiological responses of *Globba marantina* L. and *G. schomburgkii* Hook. f. in growing substrate and hydroponic system.

1.2.2 To compare the growth and physiological responses of *G. schomburgkii* Hook. f. in growing substrate and hydroponic system between Hoagland's solution and SUT's solution.

1.3 Research hypothesis

In hydroponic condition, nutrients were introduced directly to the plants' roots through the nutrient solution. It was hypothesized that both *G. marantina* and *G. schomburgkii* would have higher growth and physiological responses in hydroponic culture than in growing substrate.

1.4 Scope and limitation of the study

In this research, two culture conditions: growing substrate culture and hydroponic culture were compared. This study compared growth and physiology responses of two *Globba* species, *G. marantina* and *G. schomburgkii* for 2 months or until flowering. The *in vitro* regenerated plantlets with well-developed roots and shoots were transplanted to pots containing sand: burned rice husk: peat moss (1:1:1 by volume) and to hydroponic system. The plants were maintained under greenhouse condition at Suranaree University of Technology farm (SUT farm). The plants were irrigated one time/ day with nutrients solution of SUT's and Hoagland's formula. The percentage of the survival plantlets, number of shoots, plant height, stem diameter, number of leaves, length of leaf, number of flower, photosynthetic rate, transpiration rate and other physiological traits were applied for result analysis.

1.5 Expected results

The expected results from this study were:

5.1 Data of growth and physiological responses of *G. marantina* and *G. schomburgkii* in growing substrate and hydroponic conditions were obtained.

5.2 *Globba* plants grow faster in hydroponic condition than in growing substrate, and produced flowers out of season.

5.3 The results of this study will provide a useful information for cultivators for developing a suitable culture for propagating of *Globba* species and other related plant species in which these plants can grow all year-round without dormancy concerns.

CHAPTER II

LITERATURE REVIEW

2.1 Plant geography of Zingiberaceae

The Zingiberaceae or Ginger Family are monocots containing about 52 genera and more than 1,300 species worldwide. The gingers are all perennials with underground rhizomes and leafless stems (Larsen and Larsen, 2006). All parts of the plant are aromatic, particularly the rhizome. Local residents commonly use these plants as food, herbs and spices. In addition, some species are used to extract essential oils for use in many industries. Some species have beautiful inflorescences used as ornamental plants, or cut flowers (Kanatum, 2008). The Zingiberaceae are found throughout the tropics, very few reach the subtropical zone. In Southern Himalaya the genus *Roscoea*, the most cold tolerant of all Gingers, is found. The majority of genera and species are found in tropical Asia, mostly in Southeast Asia as seen in Table 1 (Larsen and Larsen, 2006).

Table 1 Approximate number of genera and species of Zingiberaceae worldwide (Larsen and Larsen, 2006).

Region	Genera	Species
Tropical America	1	55
Tropical Africa	4	90
Asia	45	1,300
Thailand	26	300

2.2 Life cycle of ginger plants

The life cycle of ginger plants is divided into vegetative and reproductive phases. The vegetative phase begins with the newly emergence of shoot (pseudostem) from the underground rhizome. Shoot has a maximum height of nearly 6 feet. Once growing, the inflorescence emerged from shoot tip. It is considered as reproductive phase. Which, normally in nature one shoot produces only one inflorescence. (Burghardt, 2008; Choon and Ding, 2016).

Vegetative phase: The stems (pseudostem) of ginger plant are formed by the leaf sheaths (Burghardt, 2008). During the growth of plants, new leaf (cigar leaf) emerges from shoot tip and unfolds. The leaves number increases as the stem elongates and leaves are arranged alternately on the stem. Before entering the reproductive phase, it takes about 70 days to a stay in vegetative phase for example Torch Ginger (*Etlingera elatior*) (Choon and Ding, 2016).

Reproductive phase: The reproductive phase of ginger starts when the inflorescence emerged from shoot tip and it can produce inflorescence anytime during the rainy season (Burghardt, 2008). Only some species, flowers emerge from bracts

and produce small yellow flowers such as *Globba marantina* L. and *Globba schomburgkii* Hook. f. (Burghardt, 2008; Larsen and Larsen, 2006). During inflorescence emergence stage, there will be almost no growth of new leaves on the shoot. After all the true flowers has opened, the inflorescence turns brown and dry but the flower stalks persist for several weeks even though flower defoliates (Burghardt, 2008; Choon and Ding, 2016). Once the rainy season ends and it enters the winter, the leaves and old flower stalks die. The plant will stays dormancy in the rhizomes and emerges new foliage again when the rainy season returns (Burghardt, 2008).

2.3 Propagation of Zingiberaceae

In Zingiberaceae, there are several methods of propagation. Traditional propagation uses the division of rhizome, which has slow propagation rate and the risk of disease infection through division by sectioning of the rhizomes (Hamirah et al., 2007). Cultivation by using soil is also risky of infections with root-knot nematodes, insect and pathogen attack, etc. (Saensouk, 2011; Nasirujjaman et al., 2005) and rhizome cannot be stored for a long time, as it is weakened to fungal diseases, which affects the quality of germination (Nalawade et al., 2003). Thus, *in vitro* culture is an alternative method that can be applied to produce disease-free plantlets for commercial and conservation (Saensouk, 2011). The most successful method of propagation of this plant family is through the direct organogenesis using rhizome explants (Saensouk, 2008). Several researchers have been successful in inducing plantlets using the rhizome as explants. Hamirah et al. (2007) cultured rhizome buds of *Zingiber montanum* Koenig on Gamborg B5 medium supplemented with plant growth regulators for inducing new shoots. They found that explants cultured on 0.5 mg/l

Thidiazuron (TDZ) gave the highest shoot formation about 8.14 shoots/explant. Kochuthressia et al. (2012) cultured rhizome of *Kaempferia galanga* L. on MS medium supplemented with 2 mg/l Benzyladenine (BA) and 1 mg/l Kinetin for 2 weeks and obtained 10.85 shoots/explant. Mohanty et al. (2013) used rhizome buds of *Hedychium coronarium* J. Koenig cultured on MS medium supplemented with 2 mg/l BA and 0.5 mg/l Naphthaleneacetic acid (NAA) and obtained an average of 3.6 shoots/explant on this medium after 45 days of culture. Furthermore, different plant organs have been used as explants for *in vitro* propagation such as leaves (Saensouk, 2011), bulbils (Kho et al., 2007), embryo (Jala et al., 2013), anther (Kou et al., 2013) and leaf sheath (Raju et al., 2014).

2.4 General characters of the Genus *Globba*

2.4.1 *Globba* characteristics

The genus *Globba* are usually small herbs, belonging to the family Zingiberaceae. *Globba* plants have tuberous rhizome, storage roots similar to *Boesenbergia rotunda* (L.) Mansf. and aerial stems which are pseudostem approximately 30-70 cm. The leaves are lanceolate oblong with oval base, alternate arraigning, pubescent below, short petioles and approximately 10-25 cm. Inflorescence is racemose panicle arranging on the leafy shoot and usually curve down. Each branch has a 4-5 flowers. Real flowers are yellow like flying swans. The filament and style are long exerted and arched like a bow (Figure 1). The bracts vary in color such as green, white or purplish. Flowering time is from May to September. They can be found in all regions of Thailand (Chanchula, 2012). In many species, some or all flowers are substituted by bulbils such as *G. marantina*, *G. bulbifera* Roxb. and *G. schomburgkii*

(Figure 2). These may also be formed in the leaf axils (Larsen and Larsen, 2006; Williams et al., 2004).

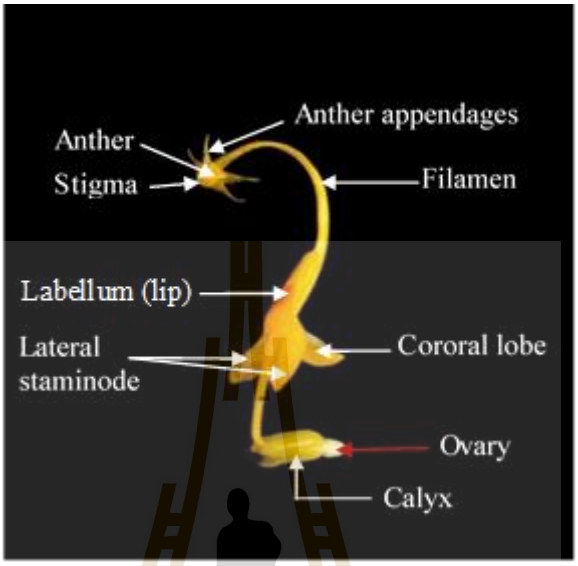

Figure 1 Flower structure of *G. schomburgkii*.

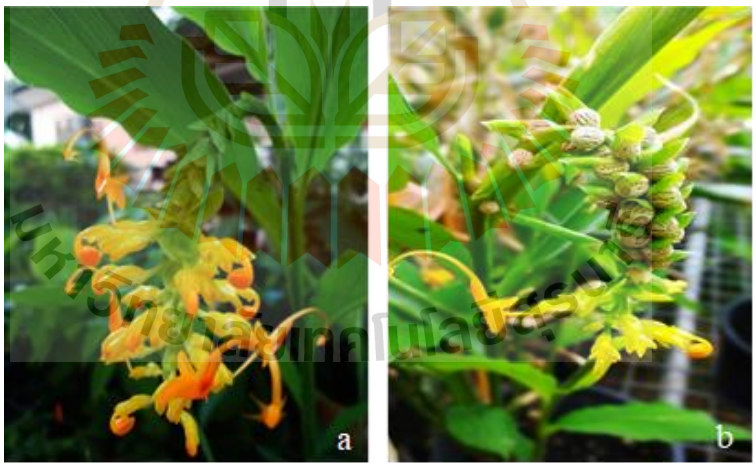

Figure 2 Inflorescence and bubils of *G. schomburgkii*.

a. inflorescence; b. bulbils

2.4.2 Distribution

The genus *Globba* is widely distributed from India and eastwards through southern China, Indochina and the Malaysian region. Monsoon Asia harbors high

diversity, Thailand and neighboring countries such as; Laos, Myanmar are particularly rich in species (Larsen and Larsen, 2006).

2.4.3 Conventional propagation

The genus *Globba* is propagated using the underground rhizome, fruit and bulbil. Only some species of the genus *Globba* have bulbils, such as *G. marantina*, *G. schomburgkii* (Larsen and Larsen, 2006) and *G. bulbifera* Roxb. (Williams et al., 2004).

2.4.4 Propagation by tissue culture technique

The tissue culture technique is one of suitable methods of plant propagation. Only few reports are available that describe *Globba* species propagation. Kho et al. (2007) used bulbils of *Globba brachyanthera* cultured on Gamborg B5 medium supplemented with different concentrations of BAP or combination with NAA hormones, and found that Gamborg B5 medium supplemented with BAP at concentrations of 3.0 mg/l gave the highest number of shoot (6.6 shoots per explants). Chanchula et al. (2013) studied break dormancy by trimming immature *Globba* spp. They divided seeds into six groups as follows; trimmed at the middle seed, trimmed one side of the micropyle, trimmed one side at the base across micropyle, trimmed at the micropyle side, trimmed at the end across micropyle and naked embryo, and then cultured on Murashige and Skoog (MS) (1962) medium supplemented with 10 mg/l BA, 1 mg/l NAA, 10 mg/l Gibberellins (GA_3) and 30 g/l sucrose. They found that cutting of seeds can break dormancy of seeds and germinate new plantlets. Seeds trimmed down to a naked embryo had the highest germination rate, germination index

and speed of emergence, which were 98.03%, 22% and 100% respectively. Jala et al. (2013) studied multiplication of new shoots from embryo culture on *G. schomburkii* cultivar "Burmese Dancing Girl" on MS medium supplemented with different concentrations of BA to stimulate new shoots for eight weeks. They found the highest average number of new shoots cultured on MS medium supplemented with 5 mg/l BA. Pimmuen et al. (2014) studied *G. marantina* propagation *in vitro* using long divided and undivided bubils cultured on MS medium supplemented with 3 mg/l BA and 0.5 mg/l NAA for 8 weeks. The result showed that the long divided bubils produced 20% of plant regeneration, and the average number of shoots was 3.5 shoots per explant. The highest shoot formation was 7.10 shoots per explant obtained on MS medium added with 2 mg/l TDZ.

2.4.5 Planting and maintaining of Genus *Globba*

The propagation of genus *Globba* can be done by separation the underground rhizomes and seeds. The planting depth is about 5 cm and distance 30-30 cm. The plants need moist but not wet soil. If the air is very dry, water should be provided at least once a day in the morning (Chanchula, 2012).

2.5 Hydroponic system

Hydroponics is a system grow plants without soil. The roots are immersed in water or nutrient solution (Michael and Heinrich, 2008) and it's advantages and disadvantages are shown in the Table 2 below. Currently hydroponic devices have been developed on a larger scale for commercial production in many countries around the world. Canada has hydroponic vegetable devices accounted for 90% of the industry

to grow all the vegetables (Tuncho, 2005). In addition, hydroponics has also been successful in countries with arid conditions, such as in Israel and the company called Organitech used hydroponic systems to produce crops in large containers. They can produce large quantities of berries, citrus fruits and bananas, which could not be normally grown in Israel's weather (Van et al., 2002). Hydroponic system has been successfully used for both cut flowers and vegetables. Many crops have been successfully produced by this method such as: *Anthurium andreanum* (Dufour and Guerin, 2005), Alpine strawberry (*Fragaria vesca* L.) (Caruso et al., 2011), carrots (Asaduzzaman et al., 2013), melon (Asao et al., 2013) and *Lactuca sativa* L. (Selma et al., 2012).

Table 2 Advantages and disadvantages of hydroponic culture (Department of Agricultural Extension, 2015).

Advantages	Disadvantages
1. Can be cultivated in unsuitable conditions, used small area and can be produced consistently	1. Supervision requires people with knowledge and experience
2. Reduced labor costs	2. Have water and electricity available
3. Save money on weed and control insects diseases	3. High investment
4. Control environment related to growth such as controlling nutrient and value pH	
5. Harvesting age shorter than plants grown in soil	

2.5.1 Basic types of hydroponic system

Nutrient Film Technique systems (NFT)

Nutrient Film Technique systems have a nutrient solution flows through the plant slowly as seen in Figure 3. The nutrient solution is pumped into the growing tray and flows over the roots of the plants, and then drains back into the reservoir and it's advantages and disadvantages are shown in the Table 3 below (Department of Agricultural Extension, 2015).

Figure 3 Nutrient Film Technique systems (Photo by Department of Agricultural Extension, 2015).

Table 3 Advantages and disadvantages of nutrient film technique systems (Department of Agricultural Extension, 2015).

Advantages	Disadvantages
1. Easy to clean	1. The cost of installation is very high, especially if the stand is made of metal
2. Less water than other systems	2. If the power goes out for a long time, the plants die
3. Can grow crops continuously throughout the year and do not waste time preparing the transplant system	3. The system needs to be closely monitored. It is likely that the system will easy caving and the plants will be severely and rapidly damaged
4. Less risk of disease because of good ventilation	4. There is a rapid spread of certain plant diseases
5. Water will flow through the root of the plant at all times and root of plants does not lack oxygen	5. There are many problems with the accumulation of the solution temperature. Especially in the tropics, the dissolution of oxygen in the solution decreases make the plant susceptible to root damage by plant diseases

Deep Flow Technique systems (DFT)

Deep Flow Technique systems have a plant roots immersed in a nutrient solution container. In this method, there will be a growing gap between the sheets and nutrient solution for approximately 3-5 cm, so that some parts of root touch the air and some parts of root immerse in nutrients as seen in Figure 4 and it's advantages and disadvantages are shown in the Table 4 below (Department of Agricultural Extension, 2015).

Figure 4 Deep Flow Technique systems (Photo by Department of Agricultural Extension, 2015).

Table 4 Advantages and disadvantages of deep flow technique systems (Department of Agricultural Extension, 2015).

Advantages	Disadvantages
1. It is a system of the solution to plants by using rails with a greater depth of solution than NFT system and can be grown with deep roots such as tomatoes, cucumbers	1. This system uses water and fertilizer in large quantities and aeration system is required
2. Water will flow through the root of the plant at all times and root of plants does not lack oxygen	2. The system needs to be closely monitored. It is likely that the system will easy caving and the plants will be severely and rapidly damaged
3. Can grow crops continuously throughout the year and do not waste time preparing the transplant system	3. There is a rapid spread of certain plant diseases
4. The system that uses water and nutrients effectively. It is possible to recycle the solution that flows through the reed rail	4. There are many problems with the accumulation of the solution temperature. Especially in the tropics, the dissolution of oxygen in the solution decreases. To make the plant susceptible to root damage by plant diseases

Dynamic Root Floating Technique systems (DRFT)

Dynamic Root Floating Technique system is developed from Deep Flow Technique systems (DFT) by increasing air circulation and nutrient solution as seen in Figure 5 and it's advantages and disadvantages are shown in the Table 5 below (Department of Agricultural Extension, 2015).

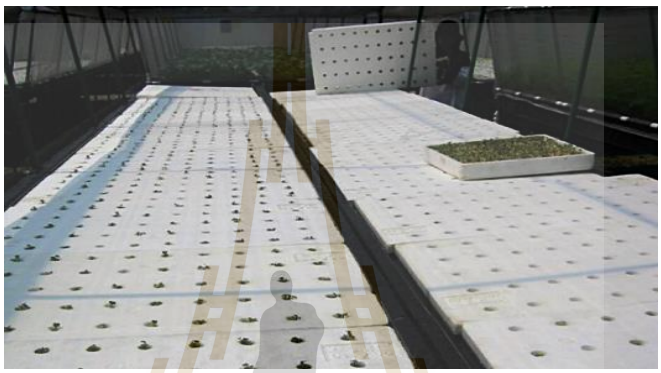

Figure 5 Dynamic Root Floating Technique systems (Photo by Department of Agricultural Extension, 2015).

Table 5 Advantages and disadvantages of dynamic root floating technique systems (Department of Agricultural Extension, 2015).

Advantages	Disadvantages
1. If the power goes out for a long time, the plants will also absorb the solution and the plants do not wilt 2. This system is made of foam, which makes water not hot	1. If there is an insect pest, it is difficult to manage because the distance between the plants are less 2. This system is easy to disease because of heat and poorly ventilated

Table 5 (Continued).

Advantages	Disadvantages
3. This system is inexpensive	3. Cleaning foam is difficult and it accumulates pathogen
4. The system does not require any technical, such as pump failure, cultivators will change slowly or quickly at any time. The plants are not severely affected	4. The system is very heavy, legs, desk, and support must be strong
5. Use a sponge as a growing material, the base of the plants is good same as a perlite	5. Some devices are easily damaged, such as foam pads are easily broken and may be destroyed by ants or mice
	6. Reducing the water level must be done according to the needs of the plants. If reduce the water level is slow, the roots plants may be rotten due to lack of air. If the water level drops faster, the plant's roots may dry out

Therefore I selected NFT system because this system displays less risk of disease because of good ventilation, can grow crops continuously throughout the year and do not waste time preparing the transplant system. In addition, water will flow

through the root of the plant at all times and root of plants does not lack oxygen and it was easy to operate the system.

2.5.2 Nutrients of hydroponic system

Hydroponic formula of Hoagland and Arnon (Tuncho, 2005) is popular from the past. At present, there are many nutrient formulas for hydroponics. For example, Asaduzzaman et al. (2013) used Enshi nutrition solution and studied growth in carrots. Soudek et al. (2011) studied heavy metal uptake and stress response of garlic (*Allium sativum* L.) under hydroponic condition by using half strength Hoagland's liquid solutions. Roosta and Rezaei (2014) used half Hoagland's nutrient solutions in rose cv. "Grand Gala".

2.5.3 Electrical conductivity (EC) and pH of solution

The EC is the electrical conductivity that measures the concentration of the solution. Its unit is milliseimen per centimeter (mS/cm). If the EC value indicates that the solution is highly concentrated, it means that a lot of nutrients are dissolved in it. The EC value in hydroponic crops are different in each areas and types of crops grown such as lettuce in NFT system requires the EC 0.8 to 2.8 mS/cm, the tomato has the EC 2.8 to 3.5 mS/cm (Tuncho, 2005). Generally, when the plants are small, the suitable EC is low, but it should increase when the plant is growing more. Each species of plant needs different EC as shown in the Table 6 below. Samarakoon et al. (2006) have reported that the suitable EC values for hydroponic systems range from 1.5 to 2.5 dS/ m. At previous had to research of other authors who reported that produce reduction when increasing the concentration of nutrient solution. For example, Miceli et al. (2003) reported that when increased EC from 1.6 to 4.6 dS/m fresh weight and

leaf number of lettuce were reduced in coir dust culture. Serio et al. (2001) studied lettuce and found that fresh weights decreased under high EC (range from 1.5 to 3.5 dS/m) and Samarakoon et al. (2006) reported that both fresh and dry weight of lettuce in hydroponics decreased significantly with increased EC of nutrient solution.

pH is a value that indicates the acidity and alkalinity, that the volume is much less dependent on the concentration of hydrogen ions (H^+) or hydroxide ions (OH^-). The pH of the solution ranges from 1-14. Generally the pH should be best in the 5.5-6.5 range. The pH in hydroponic systems needs to be measured regularly for 2-3 times/week (Department of Agricultural Extension, 2015). The pH of nutrient solution has relationship EC values depending on the difference between the concentrations of ions in solution (Libia et al., 2012).

Table 6 EC values of the nutrient solution (Department of Agricultural Extension, 2015).

Type of plants	**EC value (mS/cm)**
Lettuce	0.5-2.0
Cucumber	1.5-2.0
Vegetables, flowers	1.8-2.0
Tomato	2.5-3.5
Cantaloupe	4.0-6.0

CHAPTER III

MATERIALS AND METHODS

3.1 Plant materials

Two *Globba* species were used in the experiments: *Globba marantina* L. and *G. schomburgkii* Hook. f. which were kindly provided by Asst. Prof. Dr. Piyaporn Saensouk.

3.2 Plant growth and preparation

For multiple shoot proliferation, the microshoots of two *Globba* species, *G. marantina* and *G. schomburgkii* were cultured for two months on MS (Murashige and Skoog, 1962) medium supplemented with 3 mg/L BA as described by Pimmuen et al. (2014).

3.3 Research experiments

3.3.1 Experiment I: Comparison of growth and physiology responses of *G. marantina* and *G. schomburgkii* in growing substrate and hydroponic system using SUT's solution

The experiment was carried out in the equipment building F2 and SUT farm. The *in vitro* plantlets (8 cm in height) with well-developed roots and shoots were thoroughly washed with tap water to remove residual agar from roots. In the first set of experiment, the plantlets were then transplanted to small pots (14 cm wide and 12 cm deep) containing sand: burned rice husk: peat moss (1:1:1 by volume). Each plant

was covered with polythene wrap and watered on every alternate day to maintain humidity (Figure 6). Each plant was irrigated one time/day in the morning with 200 ml of nutrients of either SUT's formula (Damna et al., 2017) (Table 7 and Table 8). In the second set of experiment, the plantlets were transplanted to NFT hydroponic system (50 cm wide,×20 cm deep and 150 cm long) (Figure 7) and the system were at 50 cm above ground and grown in small plastic cups (4 cm wide and 4.5 cm deep) containing perlites for 60 days. The nutrient solution was kept by plastic reservoir tank and continuous circulation of the nutrient solution by electric pumps. The experiments were designed using a completely randomized design (CRD) with three replicates with treatment at least 10 plants. The plants were maintained under a greenhouse conditions at SUT farm. EC of nutrient solution is maintained between 1.6- 2.4 mS/cm, and pH is kept between 5.5-6.5. The EC and pH of the nutrient solution were checked daily with manual digital conductivity and pH meters. Growth parameters were examined every 15 days after transplanting (DAT), while physiological parameters were recorded at 60 DAT.

3.3.2 Experiment II: Comparison of growth and physiology responses of *G. schomburgkii* in growing substrate and hydroponic system using Hoagland's solution

In the first set of experiment, the *in vitro* plantlets were transplanted to small pots (14 cm wide and 12 cm deep) containing sand: burned rice husk: peat moss (1:1:1 by volume) and then covered with polythene wrap and watered on every alternate day to maintain humidity. Each plant was irrigated with 200 ml with Hoagland's solutions once daily in the morning (Hoagland and Arnon, 1993) (Table 7 and Table 8). In the

second set of experiment, the plantlets were transplanted to NFT hydroponic system. All the experiments were three replicates with treatment. EC of nutrient solution is maintained between 1.6-2.4 mS/cm, and pH is kept between 5.5-6.5 and all plants were maintained under a greenhouse conditions at SUT farm. Growth parameters were recorded every 15 DAT until the completion of the study and physiological parameters were recorded at 60 DAT.

3.3.3 Measurements of growth and physiological characteristics

3.3.3.1 Growth parameters

The percentage of the survival plantlets, number of shoots, height of shoot, stem diameter, number of leaves, length of leaves, percentage of flowering, number of flower, and length of flower were examined every 15 DAT. In this study, the height of plant was measured from the base up to the shoot tip. The leaves at the first, second and third from the shoot tip, was selected as a representative leaf length measurement because lower leaves often withered. Measurements of leaves; leaf area was measured along the axis of the midrib to base and the width is measured at right-angles to left-angles of the axis, at the point of the greatest width of each leaf. The height, length and width were recorded in centimeter (cm). Reproductive growth parameters including the number of inflorescences, length of inflorescences and number of flowers were determined at 60 DAT. Inflorescence length was measured at the first inflorescence of the shoot tip and recorded in centimeter (cm).

3.3.3.2 Physiological parameters

Physiological parameters including photosynthetic rate, transpiration rate, and stomatal conductivity were measured with LCi-SD portable photosynthesis (ADC Bio Scientific Ltd.) at 60 DAT. Data collection was performed intervals from early 9 to 12 AM. as described by Syros et al. (2004). To measure the rate of photosynthesis, the second and third leaves (fully expanded and healthy) from five plants were choosen from both conditions. The first leaf was avoided because it was newly emergent and would not be representative of the plant.

Figure 6 Plants acclimation in growing substrate.

Table 7 Nutrients of Hoagland's solutions (Hoagland and Arnon, 1993) and SUT's solution (Damna et al., 2017).

Solutions	**Fertilizer**		**Fertilizer**	
	Hoagland's solution	**Value used (g/10L)**	**SUT's solution**	**Value used (g/10L)**
Nutrient solution A	KH_2PO_4	136	$Ca(NO_3)_2•4H_2O$	2,200
	$MgSO_4•7H_2O$	492	Fe-EDTA (12% Fe)	80
	$ZnSO_4•7H_2O$	0.23	KNO_3	1,180
	$CuSO_4•5H_2O$	0.08		
	$MnSO_4•H_2O$	1.61		
	H_3BO_3	2.99		
	$Na_2MoO_4•2H_2O$	0.03		
Nutrient solution B	KNO_3	505	$MgSO_4$	1,180
	$Ca(NO_3)_2•4H_2O$	1180	KH_2PO_4	530
	HNO_3	-	Fe-EDDHA (6% Fe)	4
	Fe-EDTA	18.99	Nicsprey	50

Remark: ratio of 1: 100 fold

Table 8 Comparison of macroelements and microelements between Hoagland's solution and SUT's solution.

	Hoagland and Arnon's solution	**SUT's solution**
Elements	**ppm**	**ppm**
N	210	213.53
P	31	60.31
K	234	304.32
Mg	48	59.81
Ca	200	188.56
S	64	76.49
Fe	2.5	5.87
Mn	0.5	0.48
B	0.5	0.54
Cu	0.02	0.52
Zn	0.05	0.47
Mo	0.01	0.006
Ni	0	0.0125

Figure 7 Plants in hydroponic condition with nutrients of SUT's solution.

3.4 Statistical analysis

The experimental design used a completely randomized design (CRD). The mean values were compared for each variable by applying generalized linear models, using conditions as an independent and number of shoots, the height of shoots, stem diameter, number of leaves, length of leaves, number of inflorescence, inflorescence length and number of flowers as response variables. We tested each variable for normality and homoscedasticity. To test for physiological difference between plants grown in soil and hydroponic condition, we conducted ANOVA. We determined if significant differences between soil and hydroponic conditions as well as the number of days existed with ANOVA and then performed a post-hoc Duncan's multiple range test (DMRT) to identify specific group differences. All tests were considered significant at the 5% level and analyses were done using the SPSS package (version 16).

3.5 Location of research

This study was performed at equipment building F2 at Suranaree University of Technology and Suranaree University Farm.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to compare growth and physiological characters of two *Globba* species between growing substrate and hydroponic system using SUT's solution and Hoagland's solution. Therefore, I compared several factors including growth parameters of the surviving plantlets, number of shoots, height of shoots, stem diameter, number of leaves, length of leaves, reproductive parameters of number of inflorescences, length of inflorescences and number of flowers, and physiological parameters of photosynthetic rate, transpiration rate, and stomatal conductivity.

4.1 Experiment I: Comparison of growth and physiology responses of *G. marantina* and *G. schomburgkii* in growing substrate and hydroponic system using SUT's solution

This study, I conducted an experiment to investigate the growth and physiological characters of two *Globba* species between growing substrate and hydroponic system. SUT's solution was used in this experiment.

4.1.1 Growth responses of *G. marantina*

Plantlets with 3-4 leaves which have been transplanted to small pots containing sand: burned rice husk: peat moss (1:1:1 by volume) and a hydroponic system using the nutrient film technique (NFT) for 2 months under greenhouse

condition at SUT farm plants had 100% survived. A number of shoots (14.33±0.73, $P < 0.05$; Table 9) was significantly higher in growing substrate, However, shoot length (16.06±0.15 cm, $P < 0.05$; Table 9), leaf area (4.93±0.05 cm^2, $P < 0.05$; Table 9), stem diameter (0.46±0.01 cm, $P < 0.05$; Table 9) were significantly higher in hydroponic condition, but a number of leaves (3.72±0.09, $P > 0.05$; Table 9) was not significant.

For reproductive growth of *G. marantina*, the result showed that plants grown in hydroponics condition had earlier inflorescences than those grown in growing substrate (34 DAT in comparison to 36 DAT). The first flower bloomed 8 days after inflorescence (Figure 8 A) and had fewer inflorescences (3.00 per pot) and shorter inflorescences (3.90 cm) than in growing substrate. The inflorescence is curved down and is terminal on the leafy shoot and each branch has 3-4 flowers. However, hydroponic condition had more flowers and the number of flower average was 4.22 flowers per inflorescence. Flowers are yellow like swans that are flying and the bracts are green color and substituted by bulbils which are similar in nature (Table 10). In hydroponic condition, *G. marantina* bulbils have long white papaya seed- like appearance and new plantlets are regenerated from bulbils (Figure 8A and 8E) and the development of plants during different dates are shown in Figure 9.

Table 9 Growth indices of *G. marantina* L.and *G. schomburgkii* using SUT's solution.

Parameters	Treatments	DAT			
		15	**30**	**45**	**60**
No. of shoots ± SE	T1	4.60±0.20^{a}	6.93±0.32^{b}	12.77±0.42^{a}	16.00±0.31^{a}
	T2	4.80±0.15^{a}	8.03±0.44^{a}	13.83±0.69^{a}	14.33±0.73^{a}
	T3	1.43±0.15^{c}	3.97±0.18^{c}	8.77±0.34^{b}	11.07±0.82^{b}
	T4	1.93±0.09^{b}	3.87±0.15^{c}	6.20±0.23^{c}	7.63±0.43^{c}
F-test		**	**	**	**
Shoot length ± SE	T1	6.77±0.29^{d}	8.88±0.20^{c}	11.10±0.35^{c}	11.17±0.50^{c}
	T2	8.48±0.49^{c}	8.62±0.15^{c}	8.98±0.25^{d}	9.22±0.08^{d}
	T3	11.89±0.16^{a}	14.04±0.56^{a}	17.93±0.68^{a}	20.42±0.27^{a}
	T4	10.35±0.34^{b}	12.41±0.20^{b}	15.68±0.30^{b}	16.06±0.15^{b}
F-test		**	**	**	**
No. of leaves ± SE	T1	3.66±0.13	3.86±0.08	3.89±0.08	4.01±0.03
	T2	3.78±0.09	3.78±0.14	3.78±0.08	3.84±0.08
	T3	3.40±0.09	3.52±0.04	3.68±0.12	3.80±0.04
	T4	3.68±0.13	3.68±0.06	3.69±0.09	3.72±0.09
F-test		ns	ns	ns	ns
Leaf area ± SE	T1	2.48±0.23^{b}	3.54±0.12	4.57±0.13^{bc}	4.83±0.08^{b}
	T2	3.24±0.13^{a}	4.05±0.10	4.12±0.18^{c}	4.27±0.14^{c}
	T3	2.40±0.05^{b}	4.16±0.33	5.45±0.06^{a}	5.91±0.10^{a}
	T4	2.70±0.05^{b}	3.77±0.12	4.92±0.21^{b}	4.93±0.05^{b}
F-test		**	ns	**	**

Table 9 (Continued).

Parameters	Treatments	DAT			
		15	30	45	60
Stem diameter ± SE	T1	0.26±0.01	0.38±0.01[b]	0.38±0.01[c]	0.39±0.00[b]
	T2	0.25±0.02	0.26±0.01[c]	0.33±0.00[d]	0.39±0.01[b]
	T3	0.30±0.00	0.45±0.02[a]	0.45±0.00[a]	0.46±0.00[a]
	T4	0.25±0.02	0.34±0.01[b]	0.43±0.01[b]	0.46±0.01[a]
F-test		ns	**	**	**

Means in the same column followed by different letters a-d are significantly different according to the Duncan's multiple range test (DMRT) at $P \leq 0.05$. T1: *G. schomburgkii* grown in growing substrate, T2: *G. marantina* grown in growing substrate, T3: *G. schomburgkii* grown in hydroponic condition, T4: *G. marantina* grown in hydroponic condition. (** indicates significant *P*-value at 0.01 level; ns =not significant)

4.1.2 Physiological responses of *G. marantina*

The physiological responses of *G. marantina* grown in growing substrate and hydroponic condition are shown in Table 11. Plants grown in the hydroponic culture had higher photosynthetic rate (6.12 µmol/(m^2. s)), transpiration rate (2.11 mmol H_2O/(m^2. s)), and stomatal conductivity (0.11 µmol CO_2/mol^-) when compared with growing substrate.

4.1.3 Growth responses of *G. schomburgkii*

Plantlets survived in both growth conditions with 100% survival rate. Results of all data are presented in Table 9. Plants grown in both conditions had growth rate increases with increasing number of days. I detected significant differences between growing substrate and hydroponic condition as well as the number of days with ANOVA. For *G. schomburgkii* at 60 DAT, shoot length (20.42±0.27 cm, $P < 0.05$; Table 9), leaf area (5.91±0.10 cm^2, $P < 0.05$; Table 9) and stem diameter (0.46±0.00 cm, $P < 0.05$; Table 9) were significantly higher in hydroponics than those in growing substrate. However, number of shoots (16.00±0.31 cm, $P < 0.05$; Table 9) was significantly lower in hydroponics and number of leaves was not significantly different. In addition, it was also observed that plants grown in hydroponic condition had earlier inflorescent emergence than those grown in growing substrate (32 DAT in comparison to 34 DAT) (Figure 8B). They had more inflorescences (5.90 per pot), longer inflorescences (5.41 cm) and more flowers than in growing substrate (Table 10). Real flowers has 3-5 flowers and the number of flowers average per inflorescence was 4.74 flowers. In addition, the inflorescence is curved down similar in nature. Similarly, bulbils of *G. marantina* are regenerated into new plantlets (Figure 8F). The development of plants during different dates are shown in Figure 10.

4.1.4 Physiological responses of *G. schomburgkii*

There was no differences in the physiological responses except for stomatal conductivity between growing substrate and hydroponic cultures (Table 11). Plants grown in the hydroponic condition had higher photosynthetic rate (8.38 µmol/(m^2.s)), transpiration rate (3.08 mmol H_2O/(m^2.s)), and stomatal conductivity (0.22 µmol CO_2/mol).

I performed linear regression with days and condition as predictors for number of shoots, shoot length, number of leaves, leaf area and stem diameter. I found that day was a strongly significant predictor for all response variables except number of leaves in the hydroponic *G. marantina* treatment (Figure 11) and *G. schomburgkii* (Figure 12). In general, biweekly most growth measurements indicated a consistently higher growth pattern for hydroponic compared to growing substrate.

Furthermore, it was observed that the roots of plants grown in growing substrate were short and large, tuberous roots. While, the plant roots grown in hydroponics were longer and had more branching roots than those grown in growing substrate (Figure 13).

Figure 8 Growth characteristics of *G. marantina* and *G. schomburgkii* grown in growing substrate and hydroponic condition; (A.) The inflorescence of *G. marantina* grown in hydroponic condition at 41 DAT, (B.) The inflorescence of *G. schomburgkii* grown in hydroponic condition at 38 DAT, (C.) The inflorescence of *G. marantina* grown in growing substrate at 47 DAT, (D.) The inflorescence of *G. schomburgkii* grown in growing substrate at 41 DAT, (E.) New plantlets regenerated from bulbils of *G. marantima* grown in hydroponic condition (red arrow) and (F.) New plantlets regenerated from bulbils of *G. schomburgkii* grown in hydroponic condition (red arrow).

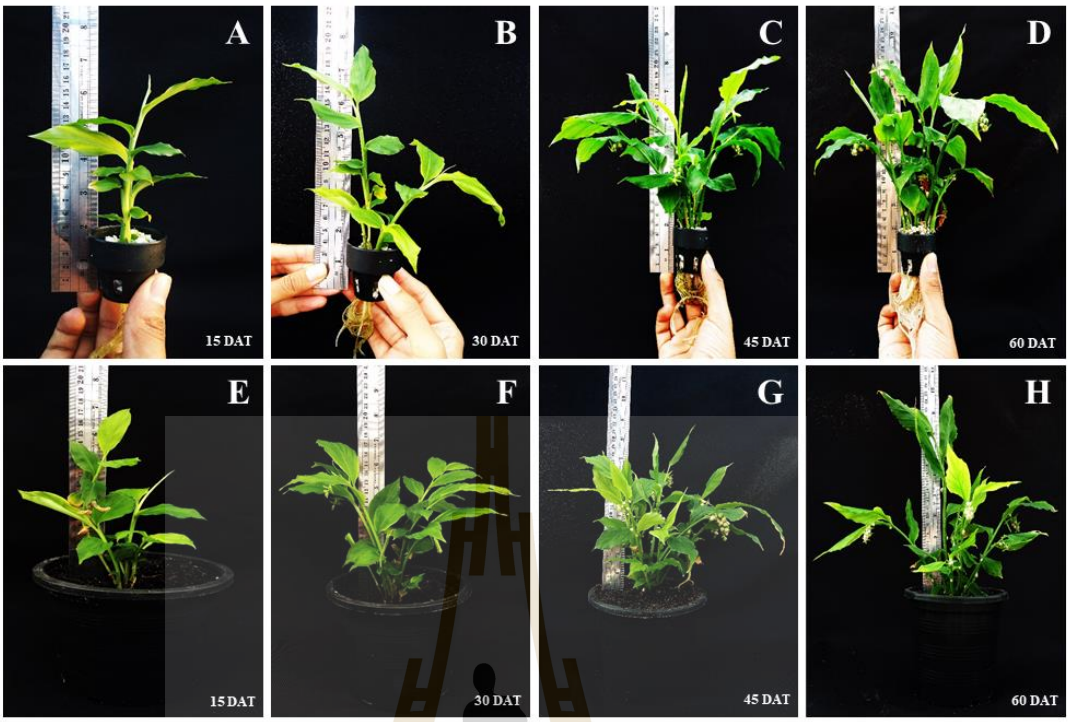

Figure 9 The development of *G. marantina* plants during different dates between growing substrate and hydroponic condition using SUT's solution; A-D plants grown in hydroponic condition, E-H plants grown in growing substrate.

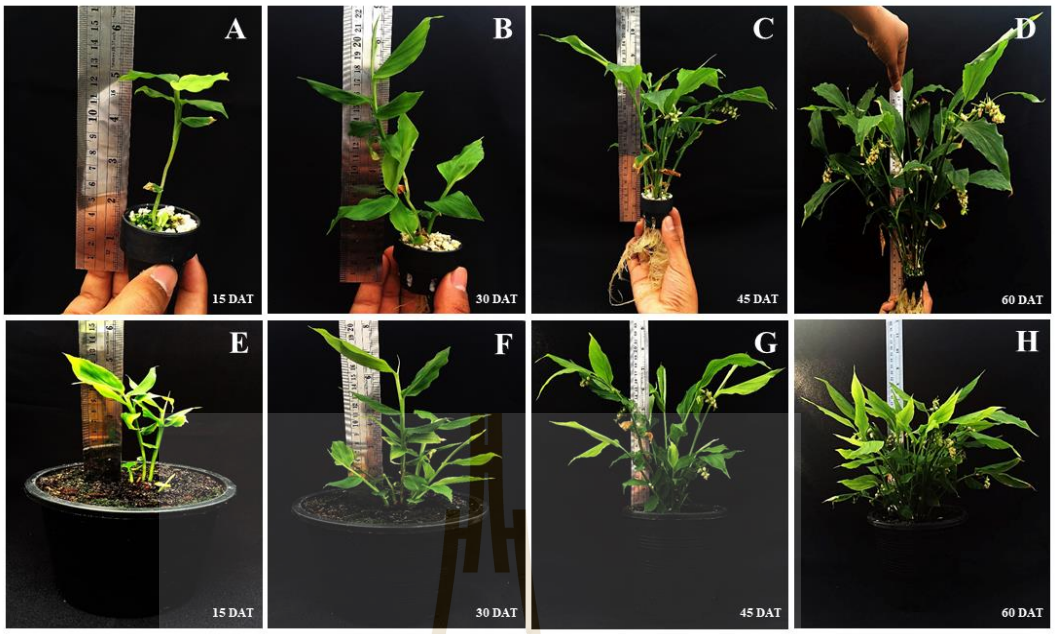

Figure 10 The development of *G. schomburgkii* plants during different dates between growing substrate and hydroponic condition using SUT's solution; A-D plants grown in hydroponic condition, E-H plants grown in growing substrate.

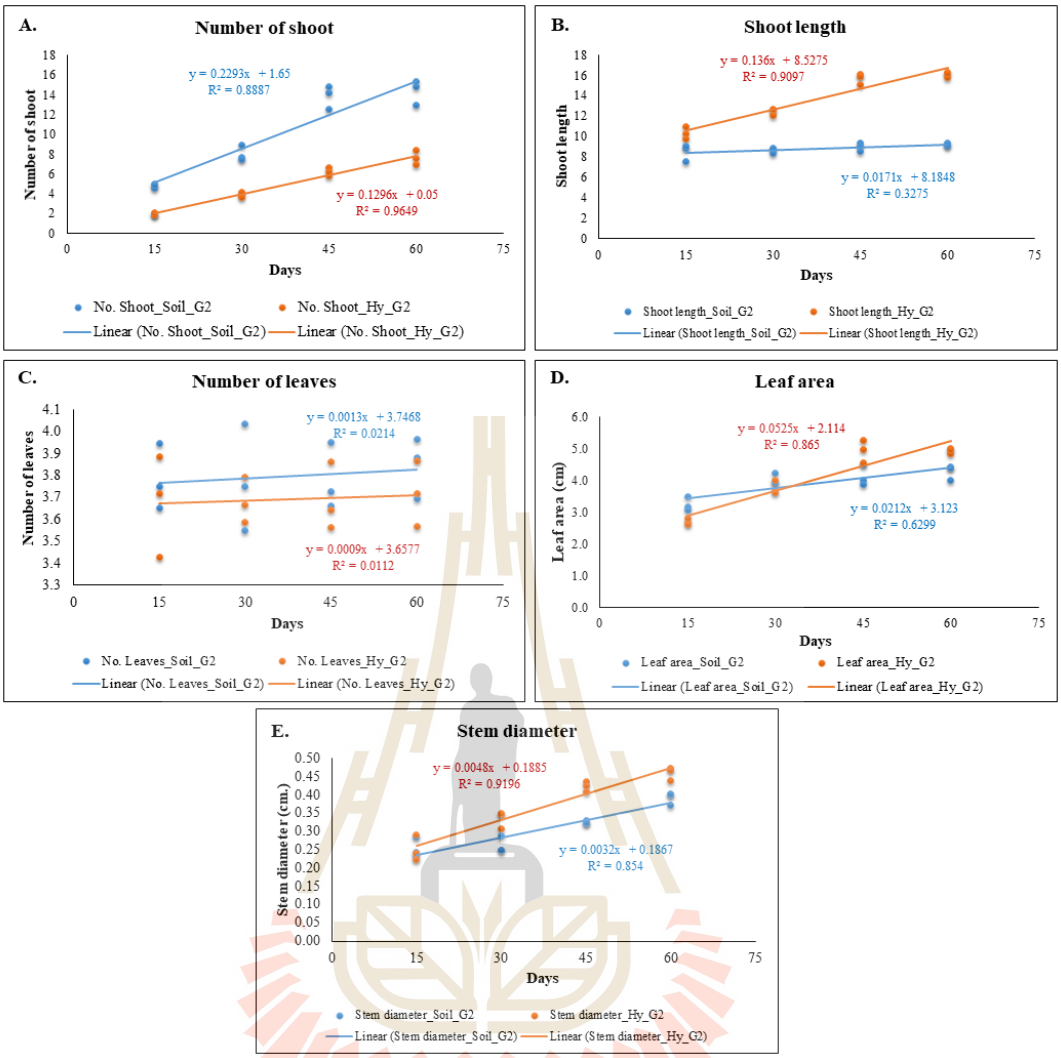

Figure 11 The relationship of *G. marantina* grown between growing substrate and hydroponic system using SUT's solution; (A.) days and number of shoots, (B.) days and shoot length, (C.) days and number of leaves, (D.) days and leaf area and (E.) days and stem diameter. Linear regression fits and associated R^2 values are displayed in each figure.

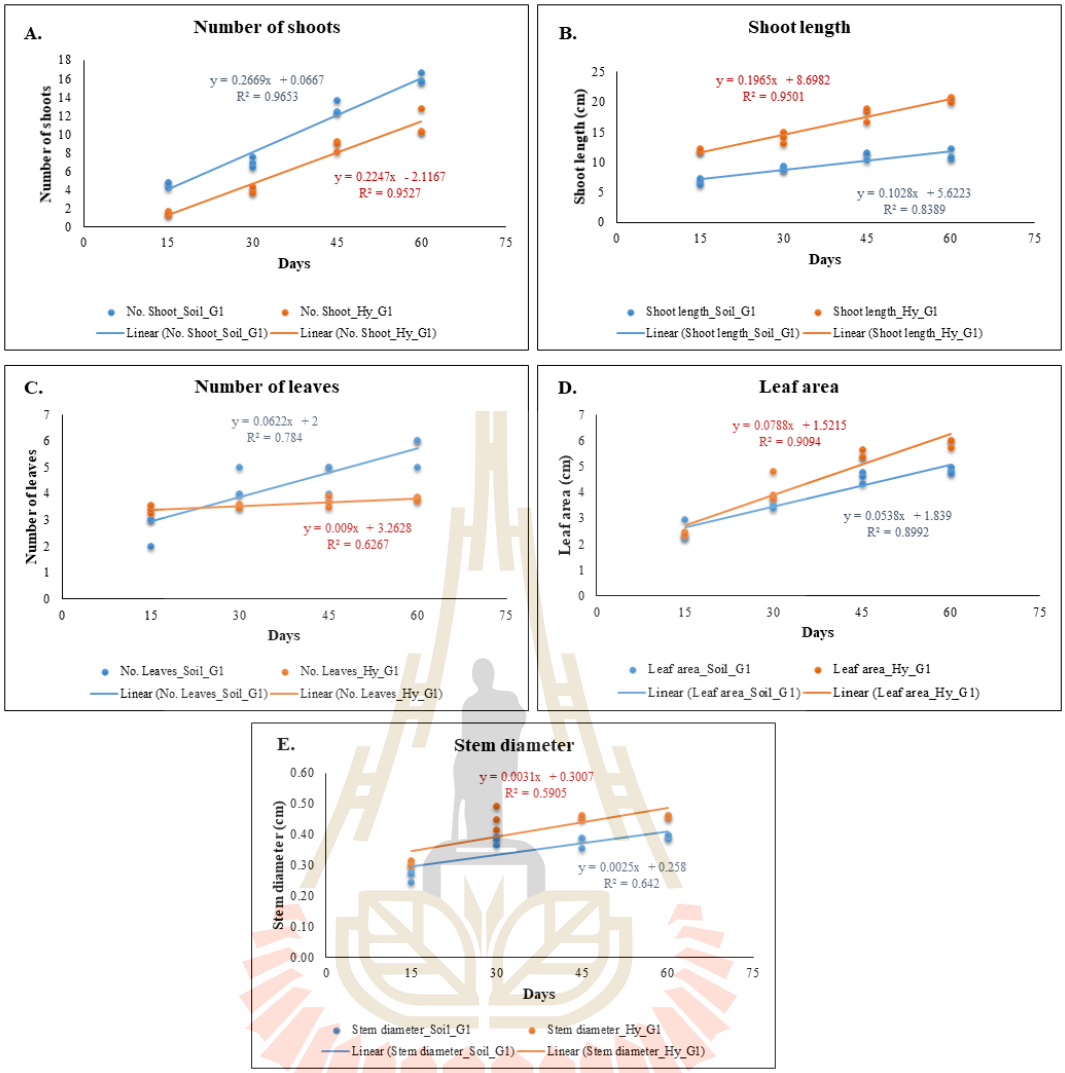

Figure 12 The relationship of *G. schomburgkii* grown between growing substrate and hydroponic system using SUT's solution; (A.) days and number of shoots, (B.) days and shoot length, (C.) days and number of leaves, (D.) days and leaf area and (E.) days and stem diameter. Linear regression fits and associated R^2 values are displayed in each figure.

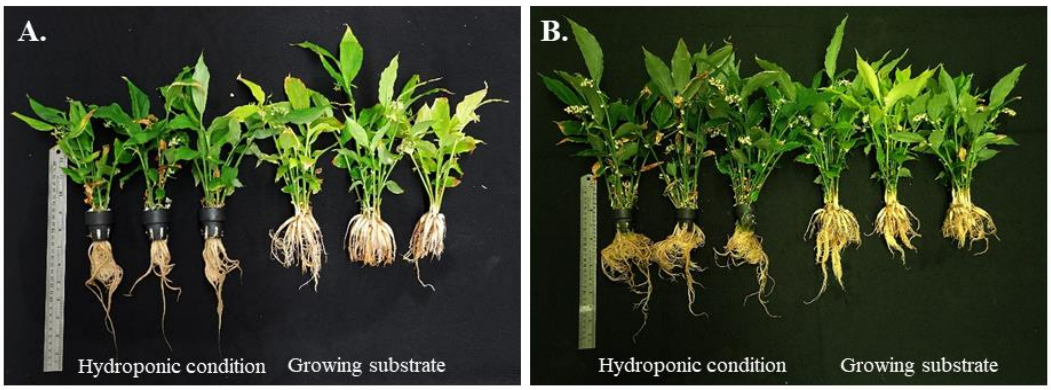

Figure 13 Characteristics of roots of *G. marantina* and *G. schomburgkii* grown in growing substrate and hydroponic condition using SUT's solution at 60 DAT; (A.) Roots of *G. marantina* grown in hydroponic system and growing substrate culture at 60 DAT and (B.) Roots of *G. schomburgkii* grown in hydroponic system and growing substrate culture at 60 DAT.

Table 10 Reproductive growth indices of *G. marantina* and *G. schomburgkii* using SUT's solution at 60 DAT.

Treatments	Parameters		
	No. of inflorescence±SE	**Inflorescence length±SE**	**No. of flowers±SE**
T1	4.633±0.07^{b}	4.89±0.05^{b}	4.05±0.11^{bc}
T2	3.43±0.05^{c}	4.47±0.13^{b}	3.79±0.14^{c}
T3	5.90±0.17^{a}	5.41±0.27^{a}	4.74±0.13^{a}
T4	3.00±0.20^{c}	3.90±0.02^{c}	4.22±0.06^{b}
F-test	**	**	**

Means in the same column followed by different letters a-d are significantly different according to the Duncan's multiple range test (DMRT) at $P \leq 0.05$. a, b, c, and d denote difference between groups soil and hydroponic. T1: *G. schomburgkii* grown in growing substrate, T2: *G. marantina* grown in growing substrate, T3: *G. schomburgkii* grown in hydroponic condition, T4: *G. marantina* grown in hydroponic condition. (** indicates significant *P*-values at 0.01 level)

Table 11 Physiological responses of *G. marantina* and *G. schomburgkii* grown in growing substrate and hydroponic system using SUT's solution at 60 DAT.

Species	Conditions	Photosynthetic rate (A) µmol/(m^2.s)	Transpiration rate (E) mmol H_2O/(m^2.s)	Stomatal conductivity (Gs) µmol CO_2/mol	Leaf temperature (Tci) (°C)
G. schomburgkii	Growing substrate	7.84±0.66	2.96±0.27	0.13±0.01	36.71±1.23
	Hydroponic	8.38±1.20	3.08±0.37	0.22±0.02**	33.70±1.47
G. marantina	Growing substrate	5.57±0.74	1.96±0.26	0.09±0.01	34.24±1.08
	Hydroponic	6.12±0.04	2.11±0.10	0.11±0.01**	33.87±1.58

** $P < 0.01$ statistically significant difference from growing substrate

4.2 Experiment II: Comparison of growth and physiology responses of *G. schomburgkii* in growing substrate and hydroponic system using Hoagland's solution

4.2.1 Growth responses of *G. schomburgkii*

Plantlets transplanted to small pots containing sand: burned rice husk: peat moss (1:1:1 by volume) and a NFT hydroponic system using Hoagland's solution for 2 months under greenhouse condition at SUT farm survived with 100% survival rate. The results of all data are shown in Table 12. There were significant in all parameters between growing substrate and hydroponic condition. *G. schomburgkii* grown in hydroponic culture revealed significantly in shoot length (21.16±0.15 cm, $P < 0.05$; Table 12), a number of leaves (4.22±0.04, $P < 0.05$; Table 12), leaf area (7.44±0.13 cm^2, $P < 0.05$; Table 12) and stem diameter (0.64±0.01 cm, $P < 0.05$; Table 12) were greater than in growing substrate culture. While, a number of shoots (13.07±0.60, $P < 0.05$; Table 12) was significantly higher in growing substrate. The development of plants during different dates are shown in Figure 14.

I performed linear regression with day and condition as predictors for number of shoots, shoot length, number of leaves, leaf area and stem diameter. I found that day was a strongly significant predictor for all response variables in the hydroponic condition of *G. schomburgkii* (Figure 15). In general, the most growth measurements indicated a consistently higher growth pattern for hydroponic compared to growing substrate. Other than this, it was observed that the root characteristics of plants grown in growing substrate were similar to the first experiment in which they were short and

large, tuberous roots. While the plant roots grown in hydroponic condition were longer and had more branching roots than those grown in growing substrate (Figure 16).

In this study, reproductive growth was also observed and the result showed that plants grown in hydroponic culture had earlier inflorescent emergence than those grown in growing substrate (35 DAT in comparison to 40 DAT) (Figure 17). The first flower bloomed 8 days after inflorescence (Figure 17). They had more inflorescences (8.33 per pot), longer inflorescences (13.92 cm) and more flowers than in growing substrate. The number of flowers average per inflorescence was 18.11 flowers (Table 13). Real flowers has 3-5 flowers. Moreover, the inflorescence is curved down similar in nature. In other hand, there was incomplete bulbils and no regeneration into new plantlets from bulbils in this experiment.

4.2.2 Physiological responses of *G. schomburgkii*

There was no significant difference in the physiological responses except for stomatal conductivity between growing substrate and hydroponic cultures (Table 14). Plants grown in the hydroponic condition had higher photosynthetic rate (9.48 µmol/(m^2.s)), transpiration rate (3.16 mmol H_2O/(m^2.s)), and stomatal conductivity (0.22 µmol CO_2/mol).

Table 12 Growth indices of *G. schomburgkii* using SUT's solution and Hoagland's solution.

Parameters	Treatments	DAT			
		15	**30**	**45**	**60**
No. of shoots ± SE	T1	4.60±0.20^{a}	6.93±0.32^{a}	12.77±0.42^{a}	16.00±0.31^{a}
	T2	3.47±0.35^{b}	7.03±0.41^{a}	9.63±0.87^{b}	13.07±0.60^{b}
	T3	1.43±0.15^{c}	3.97±0.18^{b}	8.77±0.34^{bc}	11.07±0.82^{c}
	T4	1.27±0.15^{c}	4.07±0.32^{b}	7.37±0.15^{c}	12.27±0.43^{bc}
F-test		**	**	**	**
Shoot length ± SE	T1	6.77±0.29^{c}	8.88±0.20^{c}	11.10±0.35^{c}	11.17±0.50^{c}
	T2	8.57±0.35^{b}	12.79±0.26^{b}	15.88±0.35^{b}	19.21±0.05^{b}
	T3	11.89±0.16^{a}	14.04±0.56^{a}	17.93±0.68^{a}	20.42±0.27^{a}
	T4	11.18±0.17^{a}	14.78±0.38^{a}	17.99±0.23^{a}	21.16±0.15^{a}
F-test		**	**	**	**
No. of leaves ± SE	T1	3.66±0.13	3.86±0.08^{a}	3.87±0.08^{bc}	4.01±0.03^{c}
	T2	3.72±0.07	3.94±0.06^{a}	4.33±0.03^{a}	5.02±0.08^{a}
	T3	3.40±0.09	3.52±0.04^{b}	3.68±0.12^{c}	3.80±0.04^{d}
	T4	3.65±0.06	3.80±0.01^{a}	4.00±0.04^{b}	4.22±0.04^{b}
F-test		ns	**	**	**
Leaf area ± SE	T1	2.48±0.23	3.54±0.12	4.57±0.13^{b}	4.83±0.08^{d}
	T2	2.95±0.02	3.91±0.06	5.43±0.13^{a}	6.26±0.08^{b}
	T3	2.39±0.05	4.16±0.33	5.45±0.09^{a}	5.91±0.10^{c}
	T4	2.70±0.12	4.35±0.10	5.71±0.08^{a}	7.44±0.13^{a}
F-test		ns	ns	**	**

Table 12 (Continued).

Parameters	Treatments	DAT			
		15	30	45	60
Stem diameter ± SE	T1	0.26±0.01[b]	0.38±0.01[c]	0.38±0.01[d]	0.39±0.00[d]
	T2	0.32±0.01[a]	0.43±0.01[b]	0.50±0.01[b]	0.57±0.02[b]
	T3	0.30±0.00[a]	0.45±0.02[ab]	0.45±0.00[c]	0.46±0.00[c]
	T4	0.32±0.00[a]	0.49±0.02[a]	0.53±0.00[a]	0.64±0.01[a]
F-test		**	**	**	**

Means in the same column followed by different letters a-d are significantly different according to the Duncan's multiple range test (DMRT) at $P \leq 0.05$. T1: *G. schomburgkii* grown in growing substrate using SUT's solution, T2: *G. schomburgkii* grown in growing substrate using Hoagland's solution, T3: *G. schomburgkii* grown in hydroponic condition using SUT's solution, T4: *G. schomburgkii* grown in hydroponic condition using Hoagland's solution. (** indicates significant *P*-value at 0.01 level; ns =not significant)

Table 13 Reproductive growth indices of *G. schomburgkii* at 60 DAT using SUT's solution and Hoagland's solution.

Treatments	Parameters		
	No. of inflorescence±SE	**Inflorescence length±SE**	**No. of flowers±SE**
T1	4.63±0.07^{c}	4.89±0.05^{c}	4.05±0.11^{b}
T2	7.93±0.55^{a}	11.85±0.40^{b}	14.85±0.65^{a}
T3	5.90±0.17^{b}	5.41±0.27^{c}	4.74±0.13^{b}
T4	8.33±0.49^{a}	13.92±0.33^{a}	18.11±1.88^{a}
F-test	**	**	**

Means in the same column followed by different letters a-d are significantly different according to the Duncan's multiple range test (DMRT) at $P \leq 0.05$. a, b, c, and d denote difference between groups soil and hydroponic. T1: *G. schomburgkii* grown in growing substrate using SUT's solution, T2: *G. schomburgkii* grown in growing substrate using Hoagland's solution, T3: *G. schomburgkii* grown in hydroponic condition using SUT's solution, T4: *G. schomburgkii* grown in hydroponic condition using Hoagland's solution. (** indicates significant *P*-value at 0.01 level)

Table 14 Physiological responses of *G. schomburgkii* grown in growing substrate and hydroponic system at 60 DAT using SUT's solution and Hoagland's solution.

Treatments	Conditions	Photosynthetic rate (A) µmol/(m^2.s)	Transpiration rate (E) mmol H_2O/(m^2.s)	Stomatal conductivity (Gs) µmol CO_2/mol	Leaf temperature (Tci) (°C)
SUT	Hydroponic	8.38±0.69	3.08±0.21	0.22±0.01[a]	33.7±0.85
	Growing substrate	7.83±0.38	2.96±0.16	0.13±0.01[c]	36.7±0.71
Hoagland	Hydroponic	9.48±0.07	3.16±0.18	0.22±0.01[a]	33.9±0.11
	Growing substrate	7.74±0.87	2.84±0.16	0.16±0.00[b]	35.9±0.65
F-test		ns	ns	**	ns

** $P < 0.01$ statistically significant difference from growing substrate

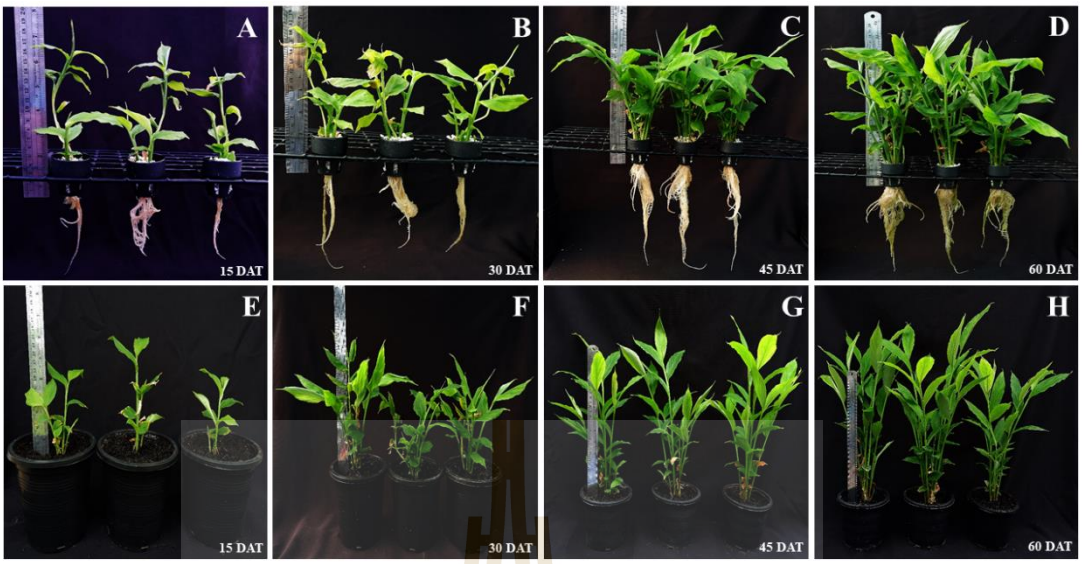

Figure 14 The development of *G. schomburgkii* during different dates between growing substrate and hydroponic system using Hoagland's solution; A-D plants grown in hydroponic condition, E-H plants grown in growing substrate.

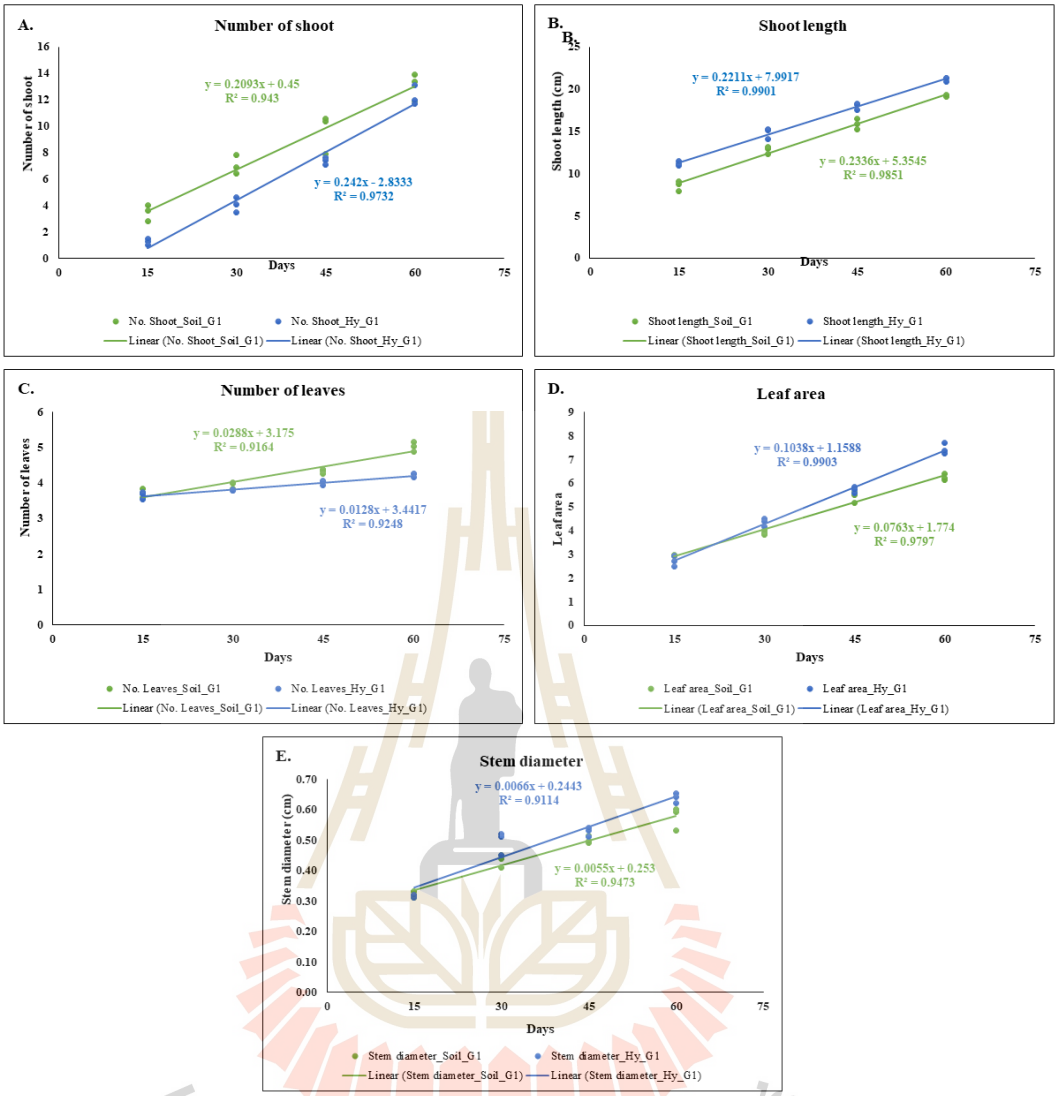

Figure 15 The relationship of *G. schomburgkii* grown between growing substrate and hydroponic system using Hoagland' s solutions; (A.) days and number of shoots, (B.) days and shoot length, (C.) days and number of leaves, (D.) days and leaf area and (E.) days and stem diameter. Linear regression fits and associated R^2 values are displayed in each figure.

Figure 16 Characteristics of roots of *G. schomburgkii* grown in growing substrate and hydroponic condition using Hoagland's solution at 60 DAT; (Left) Roots of *G. schomburgkii* grown in growing substrate and (Right) Roots of *G. schomburgkii* grown in hydroponic condition.

Figure 17 Characteristics of inflorescence of *G. schomburgkii* grown in growing substrate and hydroponic condition using SUT's solution and Hoagland's solution; (A.) The inflorescence of *G. schomburgkii* grown in growing substrate using SUT's solution at 41 DAT, (B.) The inflorescence of *G. schomburgkii* grown in hydroponic condition using SUT's solution at 38 DAT, (C.) The inflorescence of *G. schomburgkii* grown in growing substrate using Hoagland's solution at 50 DAT and (D.) The inflorescence of *G. schomburgkii* grown in hydroponic condition using Hoagland's solution at 45 DAT.

4.3 Comparison of growth and physiology responses of *G.schomburgkii* in growing substrate and hydroponic system using SUT's solution and Hoagland's solution

For comparison of growth and physiology responses of *G. schomburgkii* between growing substrate and hydroponic system among two nutrient solutions, the mean values showed that all parameters were significantly different between hydroponic and growing substrate (Table 12).

4.3.1 Growth responses

After 2 weeks, plantlets of *G. schomburgkii* transplanted to growing substrate produced new leaves, indicating that they could adapt well to the condition outside the tissue culture room. While, leaves of plants grown in the hydroponic condition started to turn yellow in the beginning, and produced new leaves after one week after transplantation. Plants grown in both conditions had growth rate increases with increasing number of days. The maximum number of shoots value was recorded in *G. schomburgkii* grown in growing substrate using SUT's solution (16.00 ± 0.31, $P < 0.05$; Table 12, Figure 18A) while the minimum value was in hydroponic condition using SUT's solution (11.07 ± 0.82, $P < 0.05$; Table 12, Figure 18A). The shoot length in both conditions was significantly different between growing substrate and hydroponic condition. When compared between two nutrient solutions, the higher mean value of shoot length was found in plants grown in hydroponic culture using Hoagland's solution with the maximum shoot length about 21.16 cm. The minimum shoot length was about 11.17 cm was recorded in plants grown in growing substrate using SUT's solution as presented in Table 12 and Figure 18B. Figure 18C shows

number of leaves in *G. schomburgkii* grown in growing substrate and hydroponic condition. When compared between SUT's solution and Hoagland's solution, the result showed that number of leaves increased with increasing number of days. The maximum number of leaf value was recorded in plants growth in hydroponic system using Hoagland's solution about 5.02 leaves per shoot while the minimum value was in hydroponic system using SUT's solution about 3.80 leaves per shoot as shown in Table 12. Leaf area was significantly different in both conditions. The leaf area maximum value was found in *G. schomburgkii* grown in hydroponic condition using Hoagland's solution (7.44±0.13, $P < 0.05$; Table 12, Figure 18D) and the minimum value was in growing substrate using SUT's solution (4.83±0.08, $P < 0.05$; Table 12, Figure 18D). In addition, it was observed that plants grown in hydroponic condition had darker green leaves compared with growing substrate. Figure 18E shows stem diameter of *G. schomburgkii* when the plants were transplanted to growing substrate and hydroponic condition. The data of stem diameter were significantly different in both conditions. The maximum of stem diameter value was recorded in *G. schomburgkii* grown in hydroponic condition using Hoagland's solution (0.64±0.01, $P < 0.05$; Table 12) while the minimum value was in growing substrate using SUT's solution (0.39±0.00, $P < 0.05$; Table 12).

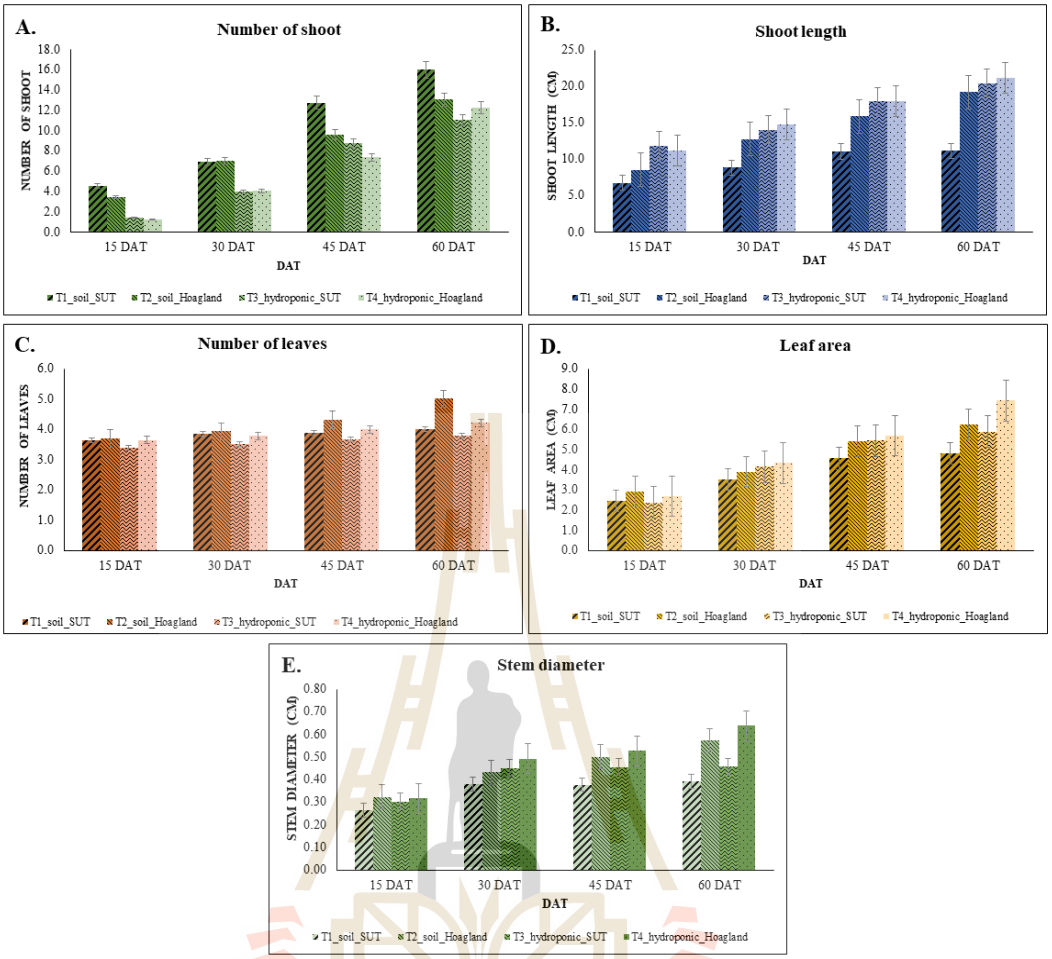

Figure 18 Comparison of growth characteristics of *G. schomburgkii* between growing substrate and hydroponic system using SUT's solution and Hoagland's solution. A. Number of shoot, B. Shoot length, C. Number of leaves, D. Leaf area and E. Stem diameter. (T1: Plants grown in growing substrate using SUT's solution, T2: Plants grown in growing substrate using Hoagland's solution, T3: Plants grown in hydroponic condition using SUT's solution, T4: Plants grown in hydroponic condition using Hoagland's solution).

For reproductive growth parameters of plants between two different nutrient solution, it was also observed that plants were grown in hydroponic condition using SUT's solution had earlier inflorescent emergence than those grown in hydroponic condition using Hoagland's solution (32 DAT in comparison to 35 DAT). However, plants grown in hydroponic condition using Hoagland's solution had more inflorescences than those SUT's solution (8.33 per pot in comparison to 5.90 per pot), longer inflorescences (13.92 cm in comparison to 5.41 cm) and more flowers (18.11 flowers in comparison to 4.74 flowers) as presented in Table 13. Real flowers has 3-5 flowers. Moreover, flowers and the inflorescences are curved down similar to nature. In other hand, plants grown in both conditions using Hoagland's solution had incomplete bulbils and did not have new plantlets regenerated from bulbils when compared with plants grown in SUT's solution.

4.3.2 Physiological responses

When compared between two nutrient solutions there was no significant differences in the physiological responses except for stomatal conductivity in both conditions as shown in Table 14. The result showed that plants grown in the hydroponic condition using Hoagland's solution had higher in all parameters than those grown in the same condition using SUT's solution including photosynthetic rate (9.48 µmol/(m^2.s) in comparison to 8.38 µmol/(m^2.s)), transpiration rate (3.16 mmol H_2O/(m^2.s) in comparison to 3.08 mmol H_2O/(m^2.s)) and stomatal conductivity (0.22 µmol CO_2/mol in comparison to 0.22 µmol CO_2/mol) (Figure 19).

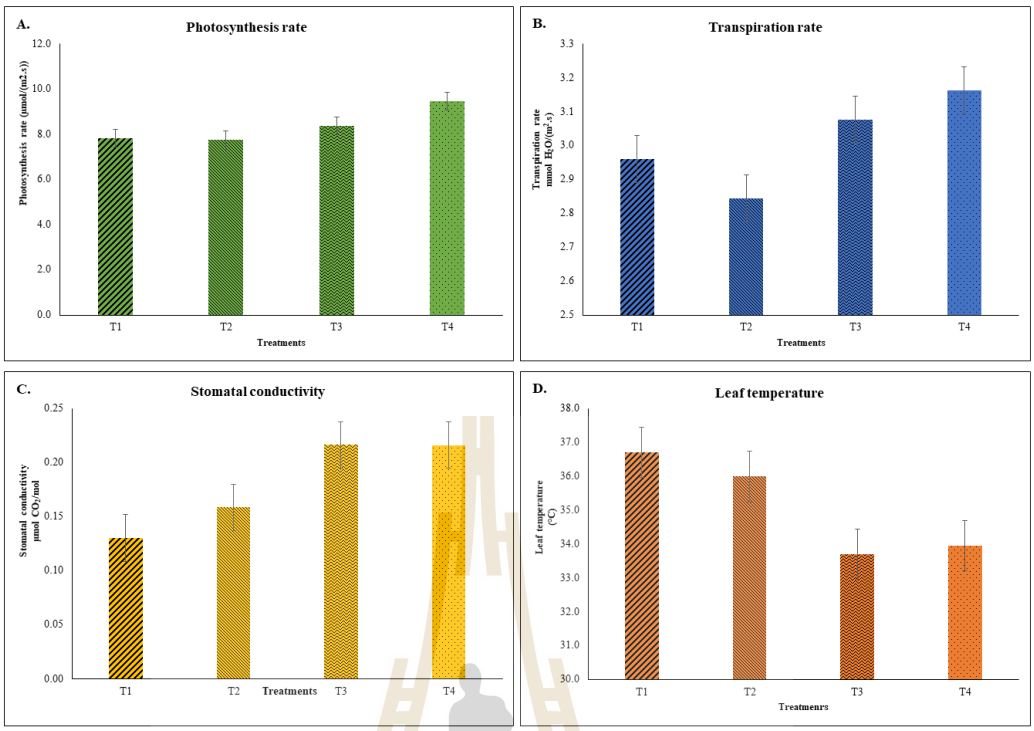

Figure 19 Physiological responses of *G. schomburgkii* between growing substrate and hydroponic system using SUT's solution and Hoagland's solution. A. Photosynthetic rate, B. Transpiration rate, C. Stomatal conductivity and D. Leaf temperature. (T1: Plants grown in growing substrate using SUT's solution, T2: Plants grown in growing substrate using Hoagland's solution, T3: Plants grown in hydroponic condition using SUT's solution, T4: Plants grown in hydroponic condition using Hoagland's solution.).

4.4 DISCUSSIONS

4.4.1 Growth responses in hydroponic system and growing substrate

This is the first report on ornamental plants of ginger family plants grown in hydroponic conditions. Currently, hydroponic devices have been developed on a larger scale used worldwide for a commercial means of growing both food and ornamental plants. In recent years, a wide range of hydroponic techniques have been developed and commercially introduced for production of horticultural crops, particularly in greenhouses. Reasons for replacing soils as growing media arise from problems with after years of cultivation, deterioration in soil fertility and increase in soil salinity and pesticides, in addition to the incurrence of soil-borne diseases (Ghehsareh et al., 2011). Two months after transplanting from *in vitro* culture into hydroponic condition, plantlets of *G. marantina* and *G. schomburgkii* could adapt to the *ex vitro* conditions with well developed root structure supporting the hypothesis that both species can be successfully reared in hydroponic systems. This finding was similar to other authors who successfully produced several ornamental plants to increase productivity by this method such as: *Anthurium andreanum* (Dufour and Guerin, 2005), *Althaea rosea*, *Calendula officinalis* and *Impatiens balsamina* (Liu et al., 2008), Gerbera (Khalaj et al., 2011; Karras et al., 2007), *Gladiolus* (Milandri et al., 2008; Nosir, 2011), *Iris* (Chang et al., 2010), *Eustoma grandiflorum* (Mondal et al., 2015), Rose (Yeo et al., 2016) and Chrysanthemum (Viyachai et al., 2015). Modern growing media provide aeration and water absorption, oxygen and other nutrients that affect growth and development (Verdonck et al., 1982; El-Sayed et al., 2015). Different nutrients may impact the plants directly. Therefore, suitable nutrients selection is vital in determining productivity increments (Olympious, 1992). Our results were similar to observations

from other authors. For example, Chanchula (2012) studied another species of genus *Globba* (*Globba williamsiana*) and reported that the highest 94.44% survival rate was in sand: burned rice husk: peat moss (1:1:1 by volume), while in this study both species had 100% survival rate. In addition, I also found that the roots of plants grown in growing substrate were short and large, tuberous roots. In contrast, the plant roots grown in hydroponics were longer and had more branching roots than those grown in growing substrate, indicating that plants grown in growing substrate had stress effect that could be due to less moisture. Therefore, plants adjusted by increasing size of roots to accumulate food for the plant growth. This study gave similar result to a study of Janagrad et al. (2009) who reported that water stress delayed the growth rate, resulting potato have smaller leaf and limited soil moisture availability effect on yield and the number and size of tubers. Gajanayake and Reddy (2013) reported that soil moisture levels affected rate of storage root of sweet potato. They found that number of storage root decreased in soil moisture content of 0.256 $m \cdot m^{-3}$ when compared with 0.216 $m \cdot m^{-3}$.

Both *G. marantina* and *G. schomburgkii* were reported to have annual inflorescences between June and September (Saensouk et al., 2017). However, this study showed inflorescences of both species from October to November for the experiment I and showed inflorescences of *G. schomburgkii* from July to August for experiment II, indicating that they can bloom out of season. Therefore extending the inflorescence period from nature may have been induced with the hydroponics or continuous watering. Thus hydroponic technique has an advantage to increase flower production as found by Asker (2015) who studied Asiatic hybrid lily cv. "Blackout", Norsir (2011) who studied gladiolus and Dufour and Guerin (2005) who studied

Anthurium andreanum. Moreover, my research found that plants grown in SUT's solution had more bulbils when compared with plants grown in Hoagland's solution. If considering the concentration of mineral nutrients in both solutions, the concentrations of macroelements and microelements were different such as P, K, S, Fe, Cu, Zn, Mo and Ni. Phosphorus is responsible for promoting the flowering and fruit setting of plants. Therefore, the high concentration of phosphorus in SUT's solution may cause more bulbils production than Hoagland's solution.

The proportion of macroelements and microelements is important for the development of plant growth. In this work, I used two different nutrient solutions (SUT's solution and Hoagland's solution) as shown in the Table 7 and Table 8. Plants used the available N and K in solution to meet their high requirements for building their vegetative growth and high yield (El-Sayed et al., 2015). Our result showed that plants growth in hydroponic condition using Hoagland's solution had higher reproductive growth, indicating that Hoagland's solution is a suitable nutrient of choices to produce this plant into cut flower. Because this solution gave more inflorescences and more flowers when compared with SUT's solution. This study agrees with a previous report by El- Sayed et al. (2015) who studied sweet pepper. It was similar to the results of Ayemi et al. (2017) who studied about effect of NPK on plant growth, flower quality and yield of gerbera (*Gerbera jamesonii* L.). They reported that high level of potassium and low nitrogen promoted flowering resulting in maximum flower. Maheta et al. (2016) studied about effect of nitrogen and phosphorus on growth, flowering and flower yield of China aster (*Callistephus chinensis* L. Nees). They found that high level of phosphorus increased flower yield. Therefore each plant species needs different nutrient levels. SUT's solution may be

available for vegetative propagation while Hoagland's solution may be used for flower production because more inflorescence and more flower were obtained.

4.4.2 Physiological responses in hydroponic system and growing substrate

There was no significant differences in the photosynthetic rate, the transpiration rate and leaf temperature, except stomatal conductance between the growing substrate and hydroponic cultures. The result of study was similar to Zhang et al. (2013) who reported that the net photosynthetic rate and the transpiration rate of lotus were not significantly different between hydroponic and soil culture. In contrast, in this study the photosynthetic rate and transpiration rate of both species in hydroponics were higher than in growing substrate. Thus the results indicate that hydroponic plants accumulate CO_2 with higher stomatal conductance and are well adapted to increase photosynthetic rate. Hydroponic culture increases leaf area index so as to improve the photosynthetic rate (Qiuying et al., 2005; Gajewska et al., 2006; He and Tan, 2011), which was consistent with that of stomatal conductivity and these results indicate that there were differences between the two conditions in term of leaf physiological indices. Hence, the result indicates that *G. marantina* and *G. schomburgkii* are capable of adapting to a water-culture environment well.

CHAPTER V

CONCLUSIONS

Hydroponic culture is one of techniques for propagating *Globba* and can be an alternative way for production of *Globba* into cut flower or pot plants in the future. In this thesis study, two *Globba* species could adapt well to the conditions under greenhouse and plantlets had 100% survival rate after transplanting. Summary of conclusions as follows:

1. *G. marantina* and *G. schomburgkii* showed better growth performance in hydroponic condition than in growing substrate.

2. The roots of *Globba* grown in growing substrate were short and large, tuberous roots, while the plant roots grown in hydroponics were longer and had more branching roots.

3. For physiological study of two *Globba* species, plants grown in the hydroponic culture had higher photosynthetic rate, transpiration rate and stomatal conductivity when compared with growing substrate.

4. *G. schomburgkii* grown in hydroponic condition using Hoagland's solution had better growth with longer inflorescences, more inflorescence and more flowers with incomplete bulbils when compared with plants grown in SUT's solution.

5. In both species, all growth measurements indicate a consistently higher growth pattern in hydroponic condition compared to growing substrate and plants

grown in hydroponic condition had earlier inflorescences than those in growing substrate.

6. Hoagland's solution promoted better growth performance of *Globba* species under hydroponic culture and could be considered as an alternative choice for production of *Globba* and other Zingiberaceae into cut flower or potted plants in future.

Thus it was concluded that, based on growth and physiological responses of two *Globba* species, the hydroponic system using Hoagland's solution was best for production of *Globba* into cut flower due to it can produce more inflorescence and more flower.

Future directions

In my study on hydroponics, SUT's and Hoagland's nutrient solutions were afforded out of season flowering potential for *G. marantina* and *G. schomburgkii* of ginger family but fever in number of flowers. Therefore further researches should be study in other nutrient solution such as half of Hoagland's solution, modifies of Hoagland's solution and on different nutrient combinations based on SUT's and Hoagland's solution would be required to find better nutrient combinations that led to produce more inflorescences and flowers.

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APPENDICES

APPENDIX A

MURASHIGE AND SKOOG MEDIA

A.1 Murashige and Skoog medium (MS) (Murashige and Skoog, 1962)

Chemical	Concentration (mg/l)	Concentration in Stock solution (mg/l)	Fold	Value used (ml/L)
Stock solution 1				50
NH_4NO_3	1,650	33,000	20	
KNO_3	1,900	38,000		
$CaCl_2.2H_2O$	440	8,800		
$MgSO_4.7H_2O$	370	7,400		
KH_2PO_4	170	3,400		
Stock solution 2				5
KI	0.83	1.66	200	
H_3BO_3	6.2	1,240		
$MnSO_4.4H_2O$	22.3	4,460		
$ZnSO_4.7H_2O$	8.6	1,720		
$Na_2MoO_4.2H_2O$	0.25	50		
$CuSO_4.5H_2O$	0.025	5		
$CoCl_2.6H_2O$	0.025	5		
Stock solution 3				5
$FeSO_4.7H_2O$	27.85	5,560	200	
$Na_2.EDTA.5H_2O$	37.3	7,460		
Stock solution 4				5
Myo-inosital	100.50	20,000	200	
Nicotinic acid	0.5	100		
Pyridoxine HCl	0.5	100		
Thiamine HCl	0.5	100		
Glycine	2	400		

Remark: Sugar 30 gram per liter, Agar 7 gram per liter, Adjusted pH at 5.7-5.8

A.2 Plant hormones 100 mg/l of Benzyladenine (BA)

Preparation of stock: the BA is weighted at 100 mg and then dissolved in 1-2 ml. of ethanol, mixed thoroughly until dissolved and brought volume up to 100 ml. The solution is kept in a plastic container in the dark and stored at room temperature.

APPENDIX B

NUTRIENTS SOLUTION

B.1 Nutrients of SUT's solution

Solution	Fertilizer
Nutrient solution A	$Ca(NO_3)_2 \cdot 4H_2O$
	Fe-EDTA (12% Fe)
	KNO_3
Nutrient solution B	$MgSO_4$
	KH_2PO_4
	Nicsprey

Remark: ratio of 1: 100 fold

B.2 Nutrients of Hoagland's solution

Solution	Fertilizer
Nutrient solution A	KH_2PO_4
	$MgSO_4 \cdot 7H_2O$
	$ZnSO_4 \cdot 7H_2O$
	$CuSO_4 \cdot 5H_2O$
	$MnSO_4 \cdot H_2O$
	H_3BO_3
	$Na_2MoO_4 \cdot 2H_2O$
Nutrient solution B	KNO_3
	$Ca(NO_3)_2 \cdot 4H_2O$
	HNO_3
	Fe-EDTA

Remark: ratio of 1: 100 fold

B.3 Comparison of macro elements and micro elements between SUT's solution and Hoagland's solution

Elements	SUT's solution	Hoagland and Arnon's solution
	ppm	ppm
N	213.53	210
P	60.31	31
K	304.32	234
Mg	59.81	48
Ca	188.56	200
S	76.49	64
Fe	5.87	2.5
Mn	0.48	0.5
B	0.54	0.5
Cu	0.52	0.02
Zn	0.47	0.05
Mo	0.006	0.01
Ni	0.0125	0

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Publications

Phantong, P., Machikowa, T., Saensouk, P., and Muangsan, N. (2018). Comparing growth and physiological responses of *Globba schomburgkii* Hook. f. and *Globba marantina* L. under hydroponic and soil conditions. **Emirates Journal of Food and Agriculture**. 30(2): 157-164.

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Awards	-
Grants and Fellowships	Suranaree University of Technology
Position and Place of Work	-