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GROWTH AND PHENOLOGY OF JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS* L.)

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Abstract

A standardized, accurate, and easy system is needed to describe Jerusalem artichoke (*Helianthus tuberosus* L.) plant development. Therefore, this study was designed to define stages of development descriptions for Jerusalem artichoke. Field experiments were conducted during early rainy season and the post rainy season of 2011 and 2012. Data were collected and uniform growth stage descriptions, based on visually observable events, were developed for the vegetative (V), reproductive (R) and tuberization (T) stages. The V stage was determined by counting the number of developed nodes on the main axis of the Jerusalem artichoke, beginning with emergence of the sprout seedling and ending with the initial visual appearance of the inflorescence. The proposed R stages include R1 (Floral bud formation), R2 (beginning bloom), R3 (flowering), R4 (beginning of anthesis), R5 (seed set) and R6 (seed maturity). The T stage include T1 (stolonization), T2 (tuber initiation), T3 (tuber formation), T4 (tuber bulking), T5 (skin set) and T6 (tuber maturity). The V, R and T stages can be measured separately and concurrently and apply to populations or single plants. The present study revealed that reproductive and tuberization development occurred more rapidly in the post-rainy season than in the early-rainy season. The proposed standard descriptions of Jerusalem artichoke development will help research and extension personnel better communicate results and recommendations related to this crop.

Key words: Sunchoke, Vegetative stage, Reproductive stage, Tuberization stage.

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is crop native to North America which stores the carbohydrate inulin (instead of starch) in its tubers. It was originally grown in temperate climates and has been introduced to most parts of the world including in the semi-arid tropics in Thailand. It is cultivated widely in many countries for different purposes such as food industry, medical applications and also for the production of ethanol (Muir *et al*., 2007; Kiru & Nasenko, 2010). Jerusalem artichoke tubers contain 20% carbohydrates, 70 % to 90% of which is inulin (Abou-Arab *et al*., 2011; Puttha *et al*., 2012). Inulin is considered as functional food that is beneficial to human health and can reduce the risk of many diseases (Roberfroid, 2002).

Uniform growth stage descriptions have been developed most crops, and these descriptions have aided communication among producers, researchers, and educators. They are especially useful to producers in the scheduling of cultural practices, irrigation, fertilizer and harvest (Carneiro, 2007). In addition, the precise knowledge of plant growth stages is important for researchers to use as model on the effects of pest and disease infestations, to devise and implement action thresholds for pest management and to develop a plant breeding program (Leather, 2010).

Jerusalem artichoke (*Helianthus tuberosus)* has no relationship to Jerusalem or artichoke (*Cynara cardunculus var. scolymus*) it belongs to the genus *Helianthus* which is often cultivated for its tuber. Jerusalem artichoke is a close relative of the sunflower (above ground) and potato (underground). Growth stages have been defined for both sunflower (*Helianthus annuus* L.) (Schneiter & Miller, 1981) and potato (*Solanum tuberosum*) (Jefferies & Lawson, 1991). However, staging of Jerusalem artichoke development has been proposed by at least one researcher.

There are a few published reports on the growth stages of Jerusalem artichoke. Most previous research on growth stage has been limited to temperate regions, hence there was a little information of growth and phenology in the tropical climate. Denoroy (1996) reviewed and concluded there were five developmental stages of Jerusalem artichoke. However, they have not described the morphology and phenology stage of Jerusalem artichoke. Kays & Nottingham (2007) have described vegetative and reproduction stages, but not tuberization stage. Both Jerusalem artichoke staging reports provided definition of needed crop development stages, yet additional definition is needed of subterranean development (stolonisation and tuberization). We also found that some of the criteria used in tuberization stages were not reliable, nor were they clearly defined. Thus, the description of tuberization stage is needed to increase communication among agricultural sciences and phenological observation networks. Therefore, the objective of this study was to design stages of development descriptions for Jerusalem artichoke.

Materials and Methods

Plant materials and experimental design: Field experiments were conducted during early rainy season (June to September) in 2011 and 2012, and during the post rainy season (September to December) in 2011 and 2012 at the Field Crop Research Station of Khon Kaen University. A randomized complete block design (RCBD) with five replications was used in this study. Two

Jerusalem artichoke genotypes (HEL 65 (late maturity) and CN 52867 (early maturity) were used. Plot size was 6 × 6 m with a spacing of 50 cm between rows and 50 cm between hills with in a row.

Pre-sprouted seed tubers were used as planting materials. To prepare the sprouted seed tubers, the tubers were cut into small pieces each having 2-3 buds/piece. The tuber pieces were then pre-sprouted in charred rice husk with mixed trichoderma at in the ratio of 3:1 under ambient conditions for 7 days. The tuber pieces with active buds and roots were then transferred to plastic plug trays containing a 3:1:1 mixture of soil and burnt rice husk and trichoderma for 7 days. Those tuber pieces with two leaf-sprouted seedlings were then transplanted, at a density of one seedling per hill into the plots. Fertilizer (15-15-15 of N- P_2O_5-K_2O) was applied at 30 days after transplanting (DAT) at a rate of 156 kg per ha^{-1}. A Terraclor (quintozene 24 % W/V EC) was applied monthly for 3 months after transplanting at the rate of 25 mL/ 20 L of water for control of stem rot. This diseases incited by *Sclerotium rolfsii* is more prevalent under the high temperature and high humidity conditions (Sennoi *et al*., 2013). The plots were sprinkler irrigated every 2 days.

Data collection: Data were collected for vegetative (V) and reproductive (R) stages on three-plants sampled at 2-day intervals. The tuberization (T) stage data was made from observations of on three plants sampled at 5-day intervals in each replication.

Vegetative stages: Determination of the vegetative (V) stages was based on the number of developed nodes on the main axis, beginning with emergence of the sprout seedling and ending with the initial visual appearance of the inflorescence. Nodes, rather than leaves, are used for stage determination because they are permanent, whereas early leaves may be lost. When a Jerusalem artichoke leaf drops, the node can easily be identified by either the stipules, the petiole scar or by presence of a branch in the former axils of the leaf. The individual stages after emergence are determined by true leaf number.

Reproductive stages: Determination of the reproductive stages was based on visually observable events related to flower initiation, beginning of flower bloom, flowering and seed set. The number of days between reproductive stages is variable and dependent upon genotypic and environmental factors.

Tuberization stages: Determination of the tuberization stages was based on visually observable events related to stolon, tuber initiation, tuber expanded, tuber skin set and maturity. The number of days between tuberization stages is variable and dependent upon genotypic and environmental factors.

Daily maximum and minimum temperatures and solar radiation during the two seasons were recorded daily from transplanting until harvest by a meteorological station located near the experimental site.

Growing degree days (GDD) for each growth stage for each genotype was calculated as the summation of daily mean temperatures above the 0°C base-temperature from day of transplanting to harvest. GDD for reproductive stage was calculated from the day of transplanting to floral bud formation (R1), beginning bloom (R2), flowering (R3), beginning of anthesis (R4), seed set (R5) and seed maturity (R6). GDD for tuberization stage was calculated from the day of transplanting to stolonization (T1), tuber initiation (T2), tuber formation (T3), tuber bulking (T4), skin set (T5) and tuber maturity (T6).

Statistical analysis: Comparisons were made for growing degree days of each growth stage for each genotype between seasons. Mean differences between seasons were tested by t-test in each genotype. Calculation procedures were done using STATISTIX8 software program (Statistix8, 2003).

Results and Discussion

Soil properties and weather conditions: The soil in tropics is sandy with low organic matter (0.53%), low nitrogen (0.029%), medium phosphorus (49 mg kg^{-1}) and medium potassium (46 mg kg^{-1}) (Table 1). In contrary, the soil in temperate regions is usually with medium organic matter (1.76%), high phosphorus (126 mg kg^{-1}), and rich potassium (121 mg kg^{-1}) (Danilcenko *et al*., 2013). However, Jerusalem artichoke can grow in dry regions with poor soil (Kays & Nottingham, 2007). The differences of soil properties between growing environments would cause significant differences in plant growth and yield.

Table 1. Physical and chemical properties of the soil from the experimental field

Soil properties / depth	0-30 cm
Physical properties	
Sand (%)	88.3
Silt (%)	7.3
Clay (%)	4.4
Texture class	Sand
Chemical properties	
pH (1:2.5 H_2O)	5.52
Organic Matter (%)	0.53
Total N (%)	0.029
Available P (mg kg^{-1})	48.8
Exchangeable K (mg kg^{-1})	45.7

Seasonal mean maximum temperature in the early-rainy seasons were 32.0ºC and 30.4ºC in the post-rainy seasons in 2011 and minimum temperature in the rainy-seasons were 23.0°C and 20.2°C in the post-rainy season in 2011 (Fig. 1). Maximum temperature in the early-rainy seasons were 32.4ºC and 31.0ºC in the post-rainy seasons in 2012 and minimum temperature in the early-rainy seasons were 23.0°C and 21.7°C in the post-rainy seasons in 2012 (Fig. 2).

The growing conditions were different between tropical and temperate regions where the crop was originated. The difference between regions could be due to difference in temperatures. As Jerusalem artichoke was grown in tropics, the growing temperatures were much higher than temperate regions (Puttha *et al*., 2012). In temperate regions, the average temperatures during the growing season are between of 6ºC to 26ºC and the crop required at least 4 to 5 months for tuber maturity (Kays & Nottingham, 2007). Therefore, temperature is directly related to the rate of tuber growth. Maturity in tropical area (approximately 4 months) is generally shorter than in the temperate regions (Ruttanaprasert *et al*., 2013).

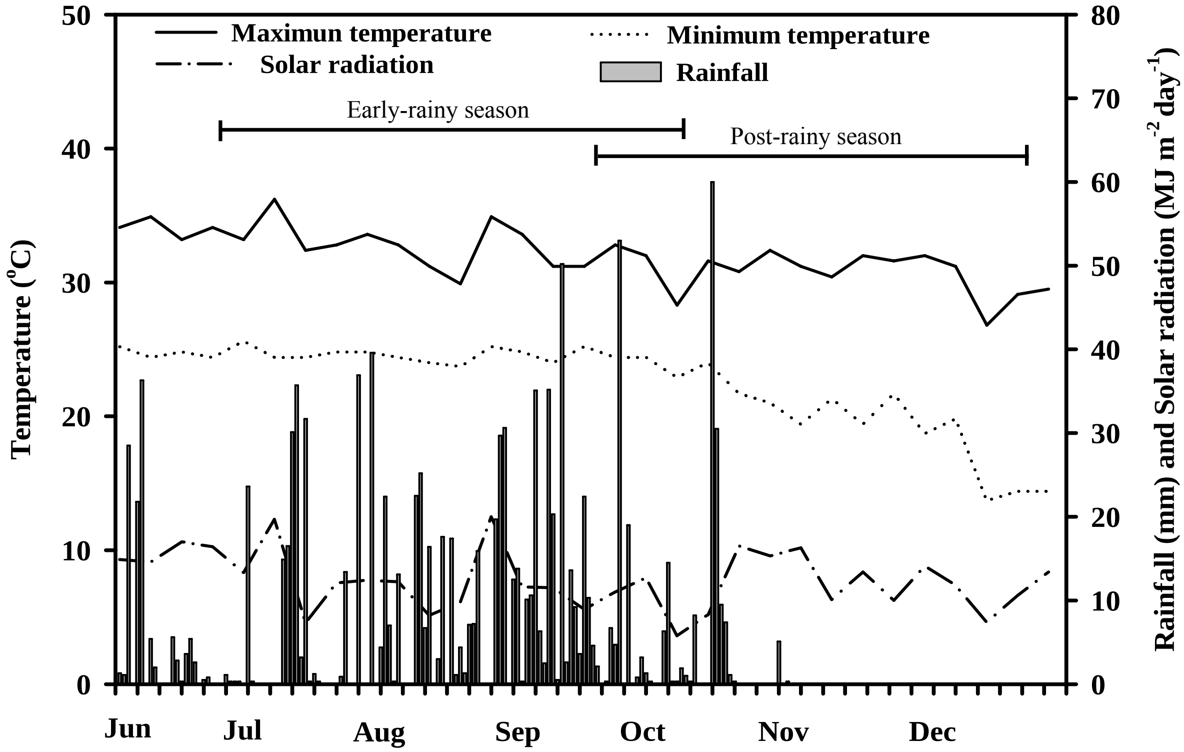

Fig. 1. Daily maximum temperature, minimum temperature, solar radiation and rainfall during the early-rainy and post-rainy seasons in 2011.

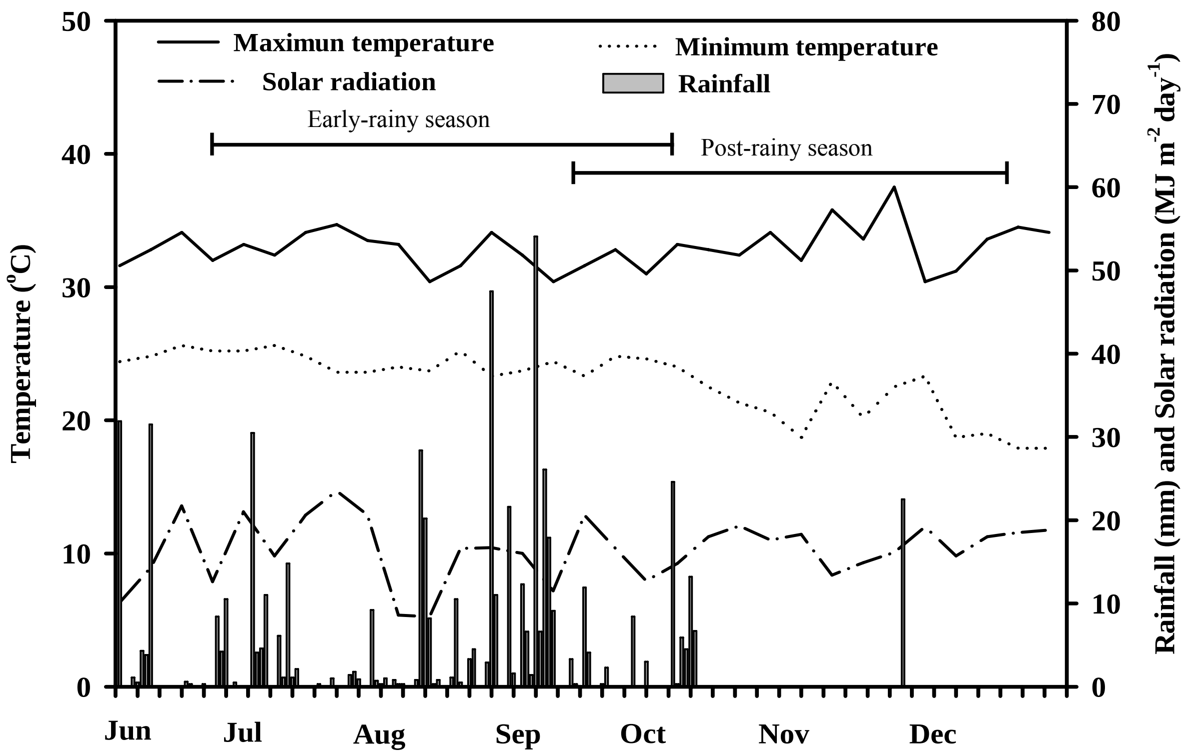

Fig. 2. Daily maximum temperature, minimum temperature, solar radiation and rainfall during the early-rainy and post-rainy seasons in 2012.

Seasonal biome dynamics are controlled by recurrent variations of environmental conditions, especially temperature changes driven by weather. Although temperature is the main factor affecting plant development, other environmental factors also play a role.

The means of solar radiation in the early-rainy seasons were 12.3 MJ m^{-2} d^{-1} and 12.5 MJ m^{-2} d^{-1} in the post-rainy seasons in 2011 (Fig. 1). In 2012, the means of solar radiation in the early-rainy seasons were 16.2 MJ m^{-2} d^{-1} and 17.2 MJ m^{-2} d^{-1} in the post-rainy seasons (Fig. 2). Rainfalls in the early-rainy seasons were 815 mm and 276 mm in the post-rainy seasons in 2011 (Fig. 1) and in rainfall in the early-rainy seasons were 480 mm and 108 mm in the post-rainy seasons in 2012 (Fig. 2).

The solar radiation in temperate regions for growing season was 17 MJ m^{-2} d^{-1}, indicating that there is not a significant different between tropical conditions and temperate regions. Solar radiation was not expected to significantly affect the growth and development of Jerusalem artichoke grown in tropics. However, solar radiation is the one factor which effect on photosynthesis and yield of Jerusalem artichoke grown in shade conditions (Kays and Nottingham, 2007). Rainfall well distributed throughout the crop cycle in the early-rainy seasons in both years. However, no water stress was observed during the growing seasons for post-rainy seasons in both years.

Vegetative development: The sprout development "VE" is when the sprouts develop from buds on the tuber (Table 2, Fig. 3). As did Kays & Nottingham (2007) and others, we noted the length of time to this stage which was dependent on temperature, available soil water, tuber dormancy and cultivar. In temperate regions, Jerusalem artichoke requires at least 6.7ºC of soil temperature for sprout development (Kays & Nottingham, 2007), while in this experiment high temperature (approximately 28 ºC) for sprout development was required. However, cold temperatures are needed to break dormancy (5°C or less) (Denoroy, 1996).

The vegetative stage V1 is when the first leaf develops from an aboveground node along the emergence sprout (Fig. 3). Vegetative stage V2 is defined as one developed node with two true leaves that are flat. Subsequent V stages up to V_N are based on N developed nodes on the main axis of the plant, counting the uppermost last node having true leaves that are flat. Leaf attachment in Jerusalem artichoke appears to begin in an opposite arrangement and gradually develops a spiral phyllotaxy of alternate phyllotaxy leaves. Our results were similar to those of Kays & Nottingham (2007), where the first leaves are arranged opposite on the stem, but by the 19th node the plant has switched to alternate. Both ours and those of Kays & Nottingham (2007) also noted that the location of the shift from opposite to alternate appears to vary with cultivar. In our study CN 52867 changed its leaf orientation from opposite to alternate around the node 23 while HEL 65, changed orientation at node 25.

Reproductive development: Growing degree days (GDD) from transplanting (V4) to specific R stages are given in Table 3 for CN 52867 and HEL 65 in both seasons. Growth stages are given in Table 2, while Fig. 4 shows the identifying traits associated with the reproductive stages R1-R6. Although these photographs are of CN 52867, the visual traits for these stages in HEL 65 are very similar except for HEL 65's larger flower size.

Reproductive stage R1, Floral bud formation, is when the plants have one floral bud at any node on the plant (Fig. 4). The GDD was calculated from transplanting (V4) to R1 for both genotypes. GDD to reach R1 was 997°C and 1248°C for CN 52867 and HEL 65 in the early-rainy season (Table 3). In the post-rainy seasons, CN 52867 and HEL 65 required 909 and 1121°C GDD to reach R1.

Table 2. Growth stage descriptions for Jerusalem artichoke (*Helianthus tuberosus* L.).

Stage no.	Abbreviated stage title	Description
	Vegetative Stages	
VE	Sprout development	Sprouts develop from bud on tuber (Fig 3, VE).
V1	Vegetative stage	The first leaf develops from an above ground node along emergence sprout (Fig 3, V1).
V2-Vn	The second true leaf to N leave	Two to N leaves have developed on nodes on main stem, a node is counted when its true leaf are flat (Fig 3, V2-Vn).
	Reproductive Stages	
R1	Floral bud formation	One floral bud at any node on plant (Fig 4, R1).
R2	Beginning bloom	One flower begins to unroll or ligules yellow-green (ray flower corollas) beginning to elongate (Fig 4, R2).
R3	Flowering	First open flower with petals that are completely horizontal (Fig 4, R3).
R4	Beginning of anthesis	50% of the plants have one open flower flowering and the anthers and first stigma have emerged on the outer whorl (Fig 4, R4).
R5	Seed set	50% of the ray flowers are wilting, disk flower petals are intact and the seed is starting to set (Fig 4, R5).
R6	Seed maturity	The first flowers have shed their ligules and the disk flower corollas are wilting (Fig 4, R6)
	Tuberization Stages	
T1	Stolon	Stolons develop at below ground node. The plants have one stolon (2-5 cm in length) (Fig 5, T1)
T2	Tuber initiation	The trip of stolon being to swell to at least twice the width of T1 stage (Fig 5, T2).
T3	Tuber formation	Tuber diameter enlarged to greater than 1 cm or twice the T2 stage (Fig 5, T3).
T4	Tuber bulking	Tuber diameter is at least 2.5 cm or four times of T2 stage (Fig 5, T4).
T5	Skin set	Tuber skin becomes yellow and brown (Fig 5, T5).
T6	Tuber maturity	Stems turn yellow or brown and lose leaves, tuber skin becomes dark (Fig 5, T6).

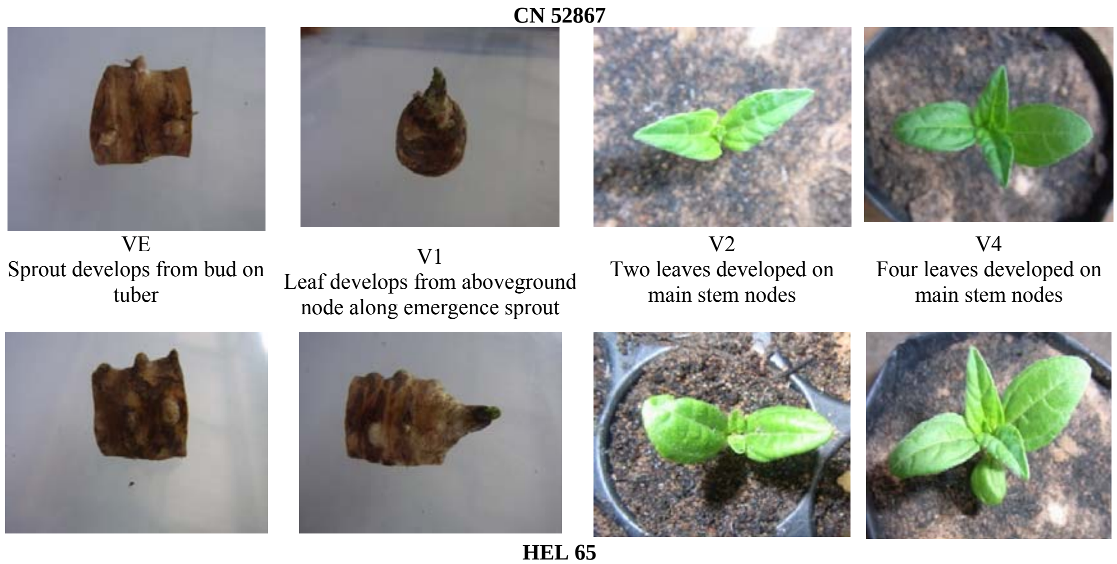

Fig. 3. Vegetative stages for CN 52867 and HEL 65 of Jerusalem artichoke (*Helianthus tuberosus* L.).

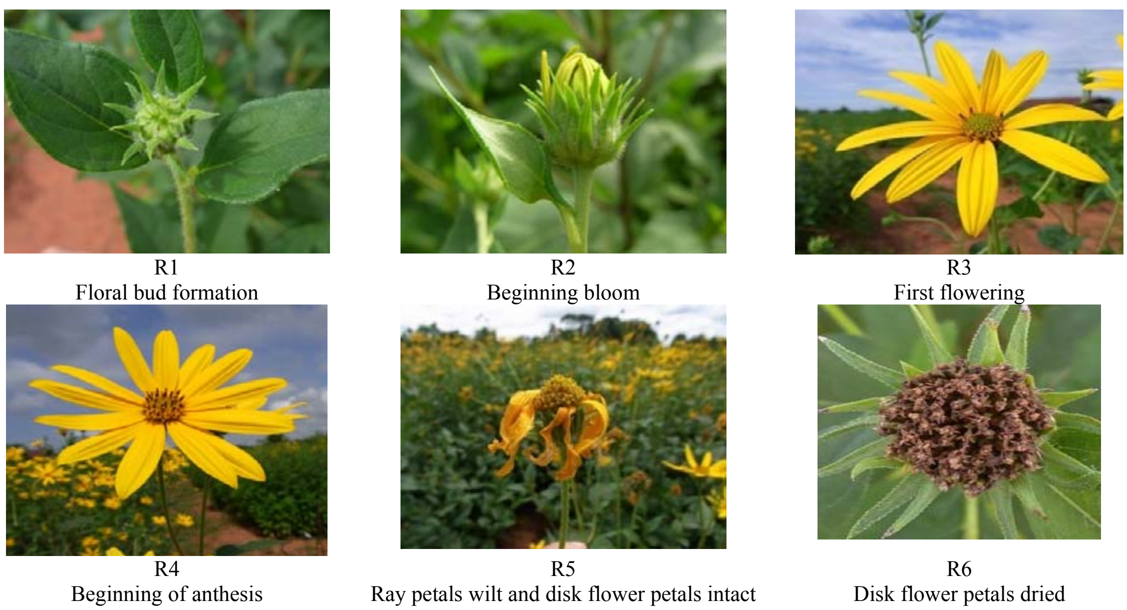

Fig. 4. Reproductive stages of Jerusalem artichoke (*Helianthus tuberosus* L.).

The results indicated that the GDD to reach floral bud formation (R1) in the early-rainy season was higher than in the post-rainy-seasons. Thus, floral bud formation in the post-rainy seasons (short day) occurred earlier than in the early-rainy season (long day) because long day favored development of aerial growth rather than reproductive and tuber growth, similar to other reports by Ruttanaprasert *et al*. (2013); Kays & Kultur (2005). Similar to Fenner (1998) reported that seasonal changes in photoperiod may be a major determinant of flowering time in individual species.

Kays & Nottingham (2007) noted that Jerusalem artichoke is a photoperiod-sensitive short-day plant that requires long light periods followed by shorter light periods to trigger the shift to reproductive stage of development. In tropical and temperate regions GDD during the growing season is a main factor affecting growth and yield of Jerusalem artichoke (Kocsis *et al*., 2007; Puangbut *et al*., 2012; Rattanaprasert *et al*., 2014).

In addition, temperature is also important factor affecting floral buds and inflorescence formation (Fenner, 1998; Hassan *et al*., 2005; Dasumiati *et al*., 2015). Several reports indicated that low temperature delayed floral bud formation in many plant (Konvalinková, 2003; Kaleem *et al*., 2010). Therefore, floral bud formation needs sufficiently high temperatures. A cooler temperature can result in a return to vegetative growth. Thus, short day reduced the number of days to flowering.

Table 3. Growing degree days (GDD) for each growth stages of CN 52867 and HEL 65 Jerusalem artichoke genotypes in the early-rainy season (ERS) and post-rainy season (PRS) in year 2011 and 2012.

Growth stage	Growing degree days (°C)					
	CN 52867		T-test	HEL 65		T-test
	ERS	PRS		ERS	PRS	
Reproductive stages						
R1	997	909	*	1248	1121	*
R2	1222	1094	**	1416	1309	*
R3	1276	1229	ns	1527	1413	*
R4	1416	1360	ns	1725	1548	**
R5	1583	1495	ns	1856	1731	*
R6	2088	2023	ns	2596	2254	**
Tuberization stages						
T1	546	692	**	633	747	*
T2	945	987	*	997	1041	*
T3	1670	1335	**	1753	1413	**
T4	1978	1628	**	2061	1549	**
T5	2257	1996	**	2398	1996	**
T6	2760	2350	**	3217	2493	**

T-test is the differences between seasons in each growth stage

R2, Beginning bloom, is when plants have one flower beginning to unroll or ligules yellow-green (ray flower corollas) beginning to elongate (Fig. 4). Seasons were significant difference for GDD to reach R2 in both genotypes (Table 3). GDD to reach R2 in the early-rainy season were 1222 and 1416°C for CN 52867 and HEL65, respectively while GDD to reach R2 was 1094 and 1309°C for CN 52867 and HEL65 in the post-rainy seasons (Table 3).

R3, Flowering, is when plants have their first open flower with petals completely horizontal, and the first disk flowers on the outer whorl have their anthers emerging from corollas (Fig. 4). Seasons were significant difference for GDD to reach R3 in HEL 65 only. In the early-rainy seasons, CN 52867 and HEL 65 required 1276 and 1527°C GDD to reach R3, respectively while GDD to reach R3 was 1229 and 1413°C for CN 52867 and HEL 65 in the post-rainy seasons (Table 3).

Previously reports indicate that the onset and duration of flowering vary widely among genotypes and planting date, location production and conditions (Kays & Nottingham, 2007; Kays & Kultur, 2005). In this (tropics) condition, the onset of flowering started at 45 days after transplanting and then earlier than plants grown in temperate zone (Kays & Kultur, 2005). Recent studies indicated that photoperiod and temperature is an important factor influence on plant phenology including the timing of flowering (Rejŝková *et al*., 2010; Song *et al*., 2013). However, understanding the mechanisms by which plants integrate both photoperiod and temperature cues to control flowering is not well understood.

R4, Beginning of anthesis, is when 50% of the plants have one completely open flower and the anthers and first stigma have emerged on the outer whorl (Fig. 4). In the early-rainy seasons, CN 52867 and HEL 65 required 1416 and 1725°C GDD to reach R4, respectively while GDD to reach R4 was 1360 and 1548°C for CN 52867 and HEL 65 in the post-rainy seasons (Table 3). The results revealed that HEL 65 showed significant differences between seasons for GDD to reach R4.

R5, Seed set, is when 50% of the ray flowers are wilting, disk flower petals are intact and the seed is starting to set (Fig. 4). Generally there are a few seed per flower. In the early-rainy seasons, CN 52867 and HEL 65 required 1583 and 1856°C GDD to reach R5 while GDD to reach R4 was 1495 and 1731°C for CN 52867 and HEL 65 in the post-rainy seasons (Table 3). The results indicated that GDD to reach R5 were different between seasons in HEL 65 only.

R6, Seed maturity, is when the first flowers have shed their ligules and the disk flower corollas are wilting (Fig. 4). Mature seeds are flattened, wedge shaped and smooth (Kays & Nottingham, 2007). Their external color or pericarp is mottled black or brown with black spots. Seed size ranges from 5-7 mm in length and 1-2 mm in width and vary among genotypes. In the early-rainy seasons, GDD to reach R6 of CN 52867 and HEL 65 were 2088 and 2596°C, respectively while GDD to reach R6 was 2023 and 2254°C for CN 52867 and HEL 35 in the post-rainy seasons (Table 3). However, only HEL 65 showed significant difference between seasons for GDD to reach R6.

Seed production varies with clone (Konvalinková, 2003) and usually wild clones produce more seed per flower (5) than cultivated clones (1 or 2) (Kays & Nottingham, 2007). Several factors contribute to this low seed production including self-incompatibility, late flowering and cool temperatures during seed development. These challenges have slowed progress in Jerusalem artichoke breeding programs.

Tuberization development: Tuberization stage T1, Stolonization, is when the plants have one stolon (2-5 cm in length) (Fig. 5). To assist readers in visualizing tuberization stages defined in Table 2. Seasons were significantly different for GDD to reach T1 in both genotypes (Table 3). In the early-rainy seasons, CN 52867 and HEL 65 required 546 and 633 °C GDD to reach T1, respectively (Table 3). In the post-rainy season, GDD to reach T1 was 692 and 747 °C for CN 52867 and HEL 65. The results indicated that the GDD accumulation for tuber initiation in the post-rainy seasons (October) occurred later than in the early-rainy seasons (July) because of the longer day length, which will delay the stolonization stage and induce aerial growth (Denoroy, 1996; Kays & Kultur, 2005).

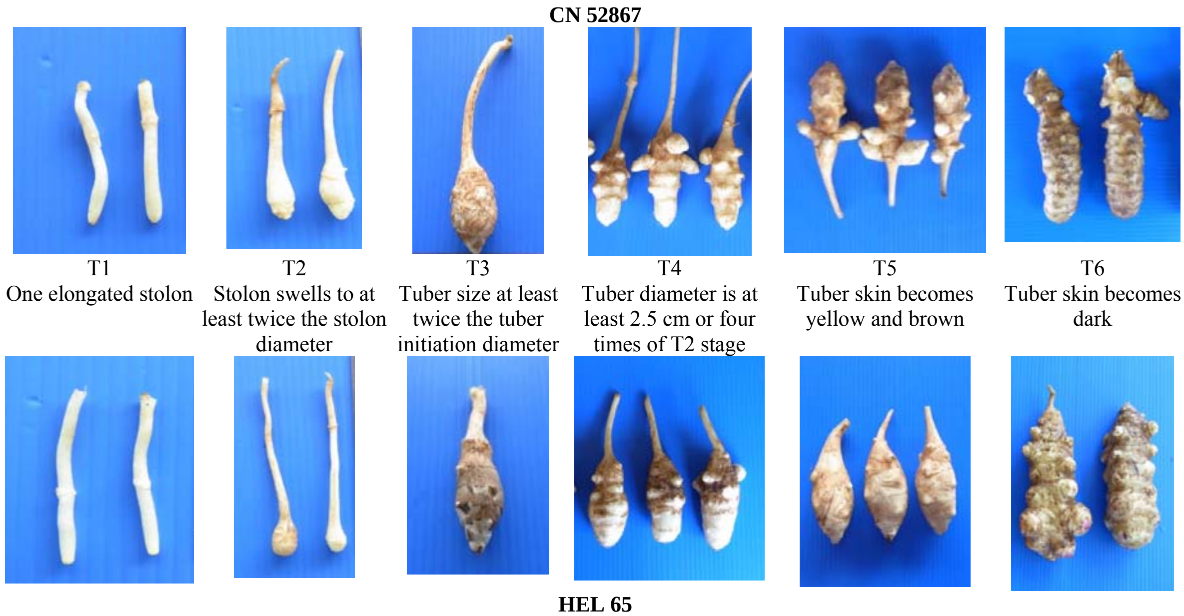

Fig. 5. Tuberization stages for CN 52867 and HEL 65 Jerusalem artichoke genotypes.

T2, Tuber initiation, is when 50% of the plants have stolon tips being to swell to at least twice the width of those in the T1 stage, indicating the initiation of tubers (Fig. 5). Two genotypes showed significant differences between seasons for GDD to reach T2 (Table 3). In the early-rainy season, GDD to reach T2 was 945 and 997°C for CN 52867 and HEL 65. In the post-rainy seasons, CN 52867 and HEL 65 required 987 and 1041°C GDD to reach T2 (Table 3).

T3, Tuber formation, is when 50% of the plants have a tuber diameter greater than 1 cm or twice the T2 stage (Fig. 5). Seasons were significantly different for GDD to reach T3 in both genotypes (Table 3). In the early-rainy seasons, GDD to reach T3 for CN 52867 and HEL 65 were 1670 and 1753°C, respectively while CN 52867 and HEL 65 required 1335 and 1413°C GDD to reach T3 in the post-rainy seasons (Table 3).

T4, Tuber bulking, is when 50% of the plants have tuber diameter is at least 2.5 cm or four times of T2 stage (Fig. 5). Seasons were significantly different for GDD to reach T4 in both genotypes (Table 3). In the early-rainy seasons, GDD to reach T4 for CN 52867 and HEL 65 were 1978 and 2016°C, respectively while GDD to reach T4 was 1628 and 1549°C for CN 52867 and HEL 65 in the post-rainy seasons (Table 3).

T5, Skin set, is when 50% of the plants have a yellow and brown tuber skin (Fig. 5). Seasons were significantly different for GDD to reach T5 in both genotypes (Table 3). In the early-rainy seasons, GDD to reach T5 of CN 52867 and HEL 65 were 2257 and 2398°C, respectively while CN 52867 and HEL 65 required 1996 and 1996°C GDD to reach T5 in the post-rainy seasons (Table 3).

T6, Tuber maturity, is when 50% of the plants have a stem which has turned yellow or brown, is losing leaves and has a dark tuber skin (Fig. 5). Seasons were significantly different for GDD to reach T6 in both genotypes (Table 3). In the early-rainy seasons, GDD to reach T6 of CN 52867 and HEL 65 were 2760 and 3217°C, respectively while CN 52867 and HEL 65 required 2350 and 2493 °C GDD to reach T6 in the post-rainy seasons (Table 3).

The results indicated that GDD to tuber maturity had higher in the early-rainy season than in the post-rainy seasons. However, tuber maturity occurred more rapidly in post-rainy season than in the early-rainy seasons. Recent report, GDD was associated with temperature and photoperiod (Rattanaprasert *et al*., 2014). The result revealed that low GDD or low temperature favored development of tuber growth. Similar to Puangbut *et al*. (2012) and Rattanaprasert *et al*. (2014) reported that tuber yield increased with low GDD (temperature sum) and short photoperiod. In our studies, as Denoroy's (1996) and others, tuber was influenced by daylength, temperature and genotype. Tuberization occurred more rapidly in the post-rainy seasons than in the early-rainy seasons. Short day length has been documented to favor tuber formation over flowers (Denoroy, 1996), although this mechanism is not well understood. While temperature is known to affect tuber yield, it is also known to influence inulin content (Hassan *et al*., 2005; Puangbut *et al*., 2011; Ruttanaprasert *et al*., 2013, 2014). The present study indicated that Jerusalem artichoke grown under tropical climate had early maturity (100-120 days) than did the crop grown in temperate regions (125-150 days) and this could be due to speed up of growth rate in regions near the equator (Kays & Nottingham, 2007).

Our results revealed that GDD could be used to determine growth stage of Jerusalem artichoke in different environment conditions. The current study supports earlier findings that GDD was used to estimate plant development suggesting that it gave better estimates for determining various physiological stages in response to environmental conditions (Noreen *et al*., 2013). The accumulation of GDD determines the maturity of crop as well as performance and quality of produce.

Conclusions

The present study demonstrated that seasonal variation was influenced on phenological development and growth stages. The crop maturity in the post-rainy season required low GDD than that in the early-rainy season which resulted in more rapid of tuber maturity in the post-rainy season. The scope of this study provided the opportunity to describe the developmental stages for Jerusalem artichoke with emphasis on details important for researchers. Certain stages, such as tuberization stage, were described in detail because of their importance to producers, researchers and educators. We have outlined a number of visually identifiable events in the vegetative, reproductive and tuberization stages of Jerusalem artichoke. These stages will be useful in describing research results and provide a more precise basis for scheduling cultural practices rather than use of general descriptors.

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