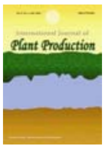

International Journal of Plant Production 7 (3), July 2013
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

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Photoperiod and growing degree days effect on dry matter partitioning in Jerusalem artichoke

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Received 27 February 2012; Accepted after revision 25 December 2012; Published online 1 April 2013

Abstract

The effect of photoperiod and growing degree days (GDD) on dry matter and dry matter partitioning in Jerusalem artichoke was investigated during 2008-09 and 2009-10. Three Jerusalem artichoke genotypes (CN-52867, JA-89 and HEL-65) were planted in 15 day-intervals between with thirteen different dates (September 20 to March 20) at Khon Kaen University, Thailand. Jerusalem artichoke genotypes responded differently to varying planting dates for harvest index, shoot dry weight, leaf area, number of tubers and tuber size. Two genotypes, CN-52867 and JA-89, were significantly more productive on the planting date of 20 September and they also performed well on planting dates of 5 October to 20 March. Plant grown in long photoperiod with a higher number of GDD produced shoot dry weight rather than greater number of harvestable tubers, while short photoperiod induced high partitioning of assimilates to harvestable tubers. Jerusalem artichoke plants grown during short photoperiod were smaller and produced larger tubers than those grown during long photoperiod. Tuber yield was relatively unchanged across planting dates. Since Jerusalem artichoke during short photoperiod had smaller plants, growing Jerusalem artichoke at higher plant population with optimum density is highly recommended to increase tuber yield. The information obtained in this study is extremely important for Jerusalem artichoke production and breeding in the tropical agro-climatic conditions such as Thailand.

Keywords: Planting date; Harvest index; Shoot dry weight; *Helianthus tuberosus* L.

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is an under-utilized crop native to North America. It had been used as food by the American Indian and the new settlers and was known as potato for poor people (Kay and Nottingham, 2008). Currently, agronomists and plant breeders pay more attention to Jerusalem artichoke as an important source of inulin (Ge and Zhang, 2005). Inulin is a form of carbohydrate stored in Jerusalem artichoke tubers instead of starch which is stored in most tuber and root crops (Kay and Nottingham, 2008). Inulin is beneficial to human health as it is not digested in digestives system and, therefore, functions as a soluble fiber. Inulin contains high fructose and it is used as raw material for production of high fructose syrup (Chekroun et al., 1996). Jerusalem artichoke can be used as a raw material to produce many value-added products such as health food (Kaur and Gupta, 2002), animal feed additive (Seiler and Campbell, 2004) and bio-ethanol (Denoroy, 1996).

Jerusalem artichoke is the best candidate for inulin production in the tropics, where artichoke and chicory (the other inulin containing crops) cannot be grown commercially, even though Jerusalem artichoke is not as productive in this environment as when it is grown in temperate regions. Plants are much smaller and mature earlier, yielding smaller and fewer tubers than in temperate regions (Kay and Nottingham, 2008).

Because of fast growth and early maturity in regions near the Equator, production of Jerusalem artichoke for two or more crops per year is possible (Kay and Nottingham, 2008). Therefore, Jerusalem artichoke production can be extended to the dry period of the year with limited irrigation and can meet the annual demand for fresh tuber products and reduce post harvest cost from cool storage facilities. The environmental conditions that affect off-season production of Jerusalem artichoke in the tropics are not well understood. Observations in yield trials indicated that low temperature associated with short photoperiod during the dry season greatly reduced growth and tuber yield of Jerusalem artichoke (Pimsaen et al., 2010) and brix values (Puangbut et al., 2011).

In temperate regions, the sum of temperature (equivalent to GDD) during the growing season is a main factor affecting growth and yield of Jerusalem artichoke (Kocsis et al., 2007; Kocsis et al., 2008). Photoperiod can affect the above and below ground growth of Jerusalem artichoke (Soja and Dersch, 1993; Kocsis et al., 2007). The effects of growing environment during the dry season on Jerusalem artichoke growth and tuber yield at must be investigated to achieve appropriate production management in the tropics.

The response of different Jerusalem artichoke genotypes to planting date has not been clearly investigated of this under-utilized crop and is very scarce. This information is very important for appropriate planting date management and improving productivity of this crop under tropical growing conditions. The objective of this study was to determine the effects of GDD and photoperiod on dry matter and dry matter partitioning of different Jerusalem artichoke genotypes. Difference in temperature and photoperiod for growth, development and maturity was created by planting Jerusalem artichoke at different dates during low temperature and short photoperiod thus giving a wide range of temperature from transplanting through maturity.

Materials and Methods

Three Jerusalem artichoke elite lines (CN-52867, JA-89 and HEL-65) with difference in maturity and yield performance were planted in containers in an open environment with natural sunlight. The CN-52867 is an early maturity (107 days) genotype of Jerusalem artichoke under seasonal growing conditions in Thailand and it was kindly donated to Thailand by the Plant Gene Resource of Canada (PGRC). The JA-89 with 110-day maturity was also introduced to Thailand by PGRC. Another genotype, HEL-65 was introduced by the Leibniz Institute of Plant Genetics and Crop Plant Research of Germany (IPK) and it takes 114 days to maturity.

A field experiment was conducted at Khon Kaen University agronomy farm (latitude 16° 28′ N, longtitude102° 48′ E, 200 masl). The plants were grown in plastic containers with 31 cm in diameter and 28 cm in height. There were one plant in each container and two containers for each experimental unit. The three Jerusalem artichoke varieties were arranged in a completely randomized design with four replications 13 planting dates. Field experiments were conducted for two years in 2008-09 and 2009-10. The planting dates in both years were exactly the same with 15-day intervals during the growing period of September 20 to March 20.

Prior to planting, each container was filled with 23 kg of soil mix consisting of burnt rice husk and soil at the ratio of 1:1 by volume. Soil analysis is presented in Table 1 and the weather conditions for each year are given in Figure1.

Table 1. Soil texture and chemical properties of pot experiment in 2008-09 and 2009-10.

Soil texture	2008-09	2009-10
Sand	69%	80%
Silt	19%	16%
Clay	12%	4%
Soil chemical properties		
pH	6.60	6.80
EC (dS/m)	0.04	0.03
OM (%)	1.20	1.12
Total N (%)	0.05	0.03
P (ppm)	152.00	201.00
K (ppm)	95.00	86.00

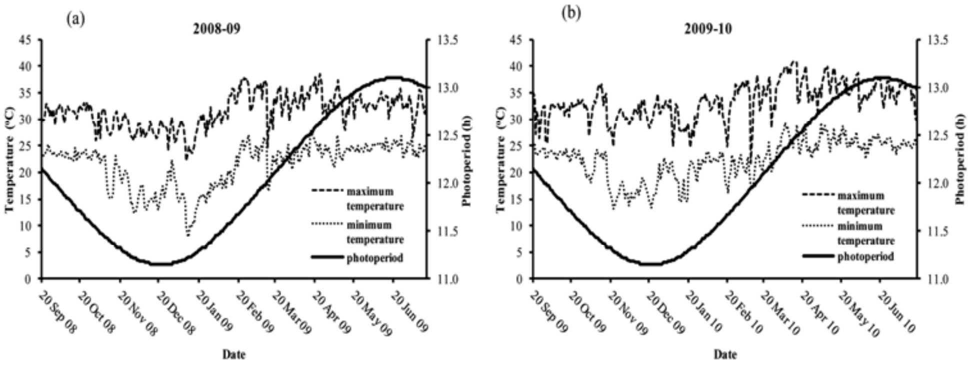

Figure 1. Climatological data at the Field Crop Research Station of Khon Kean University from (a) 20 September 2008 to 15 July 2009 and (b) 20 September 2009 to 18 July 2010 (latitude 16° 28′, longitude 102° 48′ E, 200 m above mean sea level).

Uniform seed tubers were used as planting materials. The tubers were cut into small pieces each of which had two to three buds. These tuber pieces were then pre-sprouted in coconut peat medium under ambient conditions for 4 to 7 days and transferred to germinating plug trays with mixed medium containing burnt rice husk and soil for 7 days for complete sprouting. Well-sprouted and uniform tuber seedlings were selected for transplanting.

Weeds were manually controlled throughout the experiment and the combination of N-P_2O_5-K_2O fertilizers (15-15-15) @ 2 g per container was applied to each container 30 days after transplanting giving an application rate of 150 kg-N/ha. Water was supplied daily to the experiment to avoid moisture stress. Terraclor (quintozene 24% W/V EC) was applied at 15-day intervals after transplanting at the rate 25 mL/water 20 L to control stem rot caused by *Sclerotiumrolfsii*.

Leaf area (cm^2) was measured at 90 days after transplanting using leaf area meter (LI-3100 area meter, LI-COR, Inc., USA). The plants were harvested at maturity, which was determined by leaf senescence of 50% and stem browning. Plants were cut at soil surface and separated into shoots, tubers and roots. Roots and tubers were washed in tap water to remove the potting medium. The number of tubers per plant were counted and recorded. The samples were then oven-dried at 80 °C for at least 72 hours or until the weight of roots and tubers became constant and no further loss of weight was observed. Shoots dry weight, roots dry weight, tubers dry weight, total biomass, tuber size (dry weight of individual tuber) and harvest index were recorded. Biomass included shoots, tubers and roots. Tuber size was recorded as tuber dry weight divided by number of tubers per plant. Harvest index (HI) was calculated as tuber dry weight divided by the total biomass of the plant. Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

Photoperiod was calculated as shown in equation;

$$\frac{\sum \mathrm{Pi}}{\mathrm{DAT}}$$

Where, P_i (i=1-n, n is photoperiod from day of transplanting to harvest time) is photoperiod for each genotype for each planting date and DAT is day after transplanting.

Data analysis

Analysis of variance was performed for individual planting dates according to a completely randomized design, error variances were tested for homogeneity and combined analysis of variance for each characteristic was performed across years and planting dates (Hoshmand, 2006). There were significant G×E interactions for all characteristics and data of individual seasons were reported. Least significant difference (LSD) was used to compare mean differences. All data analyses were accomplished using Statistic 8 software package (Statistic 8, 2003) and graphical presentation was done in Microsoft Excel.

Results

Soils and weather conditions

The soils used in this experiment were sandy with high sand particles (69 to 80%) and low clay particles (4 to 12%) (Table 1). The soils were low in organic matter (1.12 to 1.20%) and total nitrogen contents (0.03 to 0.05%), whereas phosphorus (152 to 201 ppm) and potassium (86 to 95 ppm) contents in the soils were more than the requirements of plants (Lebot, 2009).

Large variations were imposed for photoperiod, which were shorter during November to February (Figure 1). Temperature followed the similar pattern of the photoperiod although it fluctuated more than the photoperiod and air temperatures in 2008-09 were lower than those in 2009-10. The crop growth conditions were better in 2009-10 that Jerusalem artichoke grew better, produced more yields than in 2008-09.

The correlation coefficients between GDD and photoperiod were positive and significant in 2008-09 (r=0.95, P≤0.01) and 2009-10 (r=0.84, P≤0.01) (Figure 2a,b). These results indicated that environmental factors were highly co-related and may have synergistic and significant effects on growth and yield of Jerusalem artichoke.

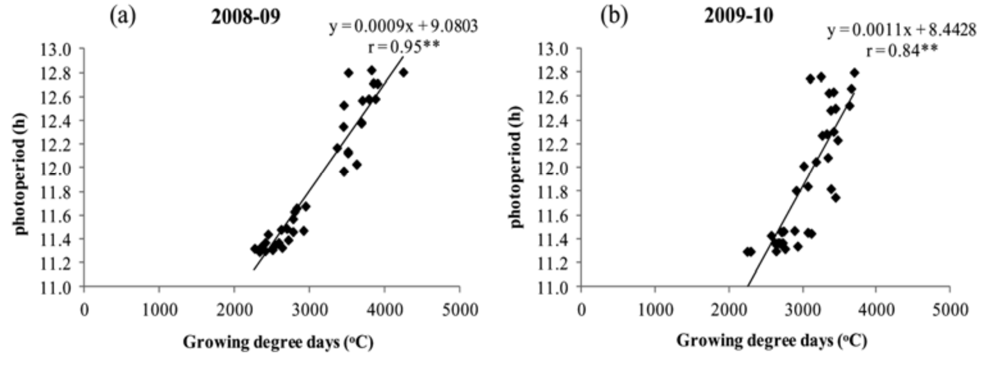

Figure 2. Relationship between photoperiod and growing degree days (GDD[a]) in 2008-09 and 2009-10.

[a] Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

Combined analysis of variance

Significant differences in GDD, photoperiod, total biomass, shoot dry weight, leaf area, harvest index, tuber dry weight, number of tubers per plant and weight of individual tubers were observed among planting dates (PD) and Jerusalem artichoke genotypes (G) (Table 2). Differences between years were also significant for most traits except for leaf area. The differences were mainly due to higher temperature in the second year that caused greater total biomass production and shoot dry weight.

The interactions between year and planting date (Y×PD) and between year and genotype (Y×G) were also significant for all traits. The interactions between planting date and genotype (PD×G) were significant for all traits and the secondary levels of interactions (Y×PD×G) were also significant.

Genotype×year (G×Y) interactions were significant for all plant factors studied in this experiment. The interactions were generally smaller than genotype×planting date (G×PD) interactions for most traits except for tuber dry weight and weight of individual of tuber (Table 2). Although both variables were significant, the magnitude of variations for characteristics was different as indicated by the range of the characteristics for each variable. For example, shoot dry weight is evident that year had closer range (25.3 to 41.6 g/plant) and planting date had wider range (7.2 to 122.8 g/plant in 2008-09 and 11.1 to 160.2 g/plant in 2009-10).

Effects of GDD and its relationships to total biomass and biomass components

The correlation coefficients between GDD and total biomass for three Jerusalem artichoke genotypes were not significant in 2008-09, but the correlation coefficients ($r=0.60$ to 0.72, $P \leq 0.01$ and $P \leq 0.05$) were positive and significant in 2009-10 (data not shown). The correlation coefficients between GDD and shoot dry weight were positive for all genotypes for both years (Table 3). Most correlation coefficients were significant ($P \leq 0.01$ and $P \leq 0.05$), ranging from $r=0.58$ to $r=0.68$. However, positive but not significant correlations ($r=0.40$ and $r=0.47$) were also observed in the experiment in 2008-09 for the genotypes CN-52867 and JA-89.

The correlations between GDD and leaf area at 90 days after transplanting were also positive and significant for most genotypes for both years of study (r=0.57 to 0.82, P≤0.01 and 0.05) except for r=0.50 (P>0.05) of HEL-65 in 2008-09 (Table 3). The correlations between GDD and leaf area were stronger than those between GDD and shoot dry weight.

The correlation coefficients between GDD and harvest index of three Jerusalem artichoke genotypes were negative and significant, ranging from r= -0.56 to r= -0.81 (P≤0.01 and 0.05) (Table 3). The negative and strong correlations between GDD and harvest index indicated that high GDD promoted the accumulation of above ground plant biomass rather than the partitioning of assimilates to harvestable tubers.

Most correlation coefficients between GDD and number of tuber of three Jerusalem artichoke genotypes in two years were positive and significant, ranging from r=0.56 to r=0.86 (P≤0.01 and 0.05) except for the correlation coefficient of JA-89 (r=0.52, P>0.05) in 2008-09 (Table 3). GDD promoted high number of tubers especially in the genotype HEL-65 as it had the highest correlation coefficient (r=0.86, P≤0.01).

In contrast, most correlation coefficients between GDD and tuber size (weight of individual tubers) were negative and significant, ranging from r= -0.60 to r= -0.89 (P≤0.01 and 0.05) except for the correlation coefficient of CN-52867 (r= -0.53, P>0.05) in 2009-10 (Table 3). These results indicated that greater GDD reduced tuber size of Jerusalem artichoke. This finding is very important and should be considered for promoting the production practices of Jerusalem artichoke in Thailand and in other tropical regions of the world.

Effects of photoperiod and its relationships to total biomass and biomass components

The correlation coefficients between photoperiod and total biomass for three Jerusalem artichoke genotypes were not significant in 2008-09, but the correlation coefficients (r=0.72 to 0.85, P≤0.01) were positive and significant in 2009-10 (data not shown) indicating the strong effect of yearly variations in climatic conditions. The correlation coefficients between photoperiod and shoot dry weight were positive for all genotypes in both years (Table 4). Most correlation coefficients were significant (P≤0.01 and ≤0.05), ranging r=0.55 to r=0.83. However, positive but not significant correlation (r=0.48) was also found in 2008-09 for CN-52867.

Table 2. Mean square from the combine analysis of variance for growing degree days (GDD), biomass, shoot dry weight, leaf area, harvest index, number of tuber and weight of individual tuber of three genotypes in two years (2008-09 to 2009-10) and thirteen planting dates spaced at 15 day-intervals from September, 20 to March, 20.

Source of variation	df	Growing Degree day (°C)[b]	Photoperiod (h)	Biomass (g/plant)	Shoot dry weight (g/plant)	Leaf area (cm^2)	Harvest index[c]	Tuber dry weight (g/plant)	Number of tuber	Individual of tuber (g)
Year (Y)	1	330070^{**a}	1.88**	49610**	19591**	166306^{ns}	0.051**	2940**	2326**	98**
Planting date (PD)	12	5015395**	81.90**	14211**	9790**	2915296**	0.541**	3544**	1426**	93**
Y*PD	12	715161**	1.65**	13740**	2677**	2211533**	0.019**	2734**	347**	21**
Genotype(G)	2	1214568**	0.04**	22159**	14110**	4784774**	0.658**	3825**	2116**	97**
Y*G	2	18741.6**	0.06**	788**	272**	384355**	0.028**	1474**	61*	36**
PD*G	24	78010.6**	0.59**	2545**	1319**	543327**	0.033**	1107**	100**	17**
Y*PD*G	24	30061.1**	0.53**	988**	331**	377490**	0.016**	651**	173**	8**
Pooled error	228	1E-26	4E-29	125	23	29766	0.002	58	18	2
Total	311									

[a] ns, *, ** Non significant, significant at $P \leq 0.05$ and 0.01 respectively.

[b] Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

[c] Harvest index (HI) was calculated as tuber dry weight divided by the total biomass of the plant.

Table 3. Simple correlation coefficients between growing degree days (GDD[b]) and agronomic traits of three genotypes in two years at thirteen planting dates.

Genotypes	Shoot dry weight (g/plant)		Leaf area (cm^2)		Harvest index[c]		Number of tuber per plant		Weight of individual tuber (g)	
	2008-09[a]	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
CN-52867	0.40^{ns}	0.61^{*}	0.62^{*}	0.82^{**}	-0.60^{*}	-0.57^{*}	0.56^{*}	0.57^{*}	-0.77^{**}	-0.53^{ns}
JA-89	0.47^{ns}	0.58^{*}	0.57^{*}	0.79^{**}	-0.81^{**}	-0.56^{*}	0.52^{ns}	0.63^{**}	-0.89^{**}	-0.60^{*}
HEL-65	0.59^{*}	0.71^{**}	0.50^{ns}	0.60^{*}	-0.78^{**}	-0.77^{**}	0.86^{**}	0.72^{**}	-0.74^{**}	-0.70^{**}

[a] ns, *, ** Non significant and significant at $P \leq 0.05$ and 0.01 probability levels, respectively.

[b] Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

[c] Harvest index (HI) was calculated as tuber dry weight divided by the total biomass of the plant.

Table 4. Simple correlation coefficients between photoperiod and agronomic traits of three genotypes in two years at thirteen planting.

Genotypes	Shoot dry weight (g/plant)		Leaf area (cm^2)		Harvest index[b]		Number of tuber per plant		Weight of individual tuber (g)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
CN-52867	0.48^{nsa}	0.82^{**}	0.57^{*}	0.84^{**}	-0.70^{**}	-0.77^{**}	0.61^{*}	0.75^{*}	-0.78^{**}	-0.59^{*}
JA-89	0.55^{*}	0.83^{**}	0.14^{ns}	0.83^{**}	-0.90^{**}	-0.90^{**}	0.61^{*}	0.67^{**}	-0.89^{**}	-0.72^{**}
HEL-65	0.66^{**}	0.77^{**}	0.27^{ns}	0.65^{**}	-0.85^{**}	-0.85^{**}	0.75^{**}	0.77^{**}	-0.65^{**}	-0.81^{**}

[a] ns, *, ** Non significant and significant at $P \leq 0.05$ and 0.01 probability levels, respectively.

[b] Harvest index (HI) was calculated as tuber dry weight divided by the total biomass of the plant.

The correlations between photoperiod and leaf area at 90 days after transplanting were also positive and significant for most genotypes in two years (r=0.57 to 0.84, P≤0.01 and 0.05) except for JA-89 (r=0.14; P>0.05) and HEL-65 (r=0.27; P>0.05) in 2008-09 (Table 4). The correlation coefficients between photoperiod and harvest index were negative and significant, ranging from r= -0.70 to r= -0.90 (P≤0.01) for the three Jerusalem artichoke genotypes and two years (Table 4). All correlations coefficients between photoperiod and number of tubers were positive and significant, ranging from r=0.61 to r=0.77 (P≤0.01 and ≤0.05) (Table 4). In contrast to the relationship between photoperiod and number of tubers, all correlation coefficients between photoperiod and tuber size (weight of individual tubers) were negative and significant, ranging from r= -0.59 to r= -0.89 (P≤0.01 and ≤0.05) (Table 4).

Figure 3 showed patterns of shoot dry weight of three Jerusalem artichoke genotypes across planting dates for two years. The CN-52867 and HEL-65 genotypes were rather insensitive to GDD, whereas JA-89 was highly sensitive. High shoot dry weights were observed in JA-89 at the start of the experiment and the end of the experiment when GDD were rather highly on 20 September and 20 March, whereas GDD at the mid-period of the experiment (5 November and 20 December) were rather low.

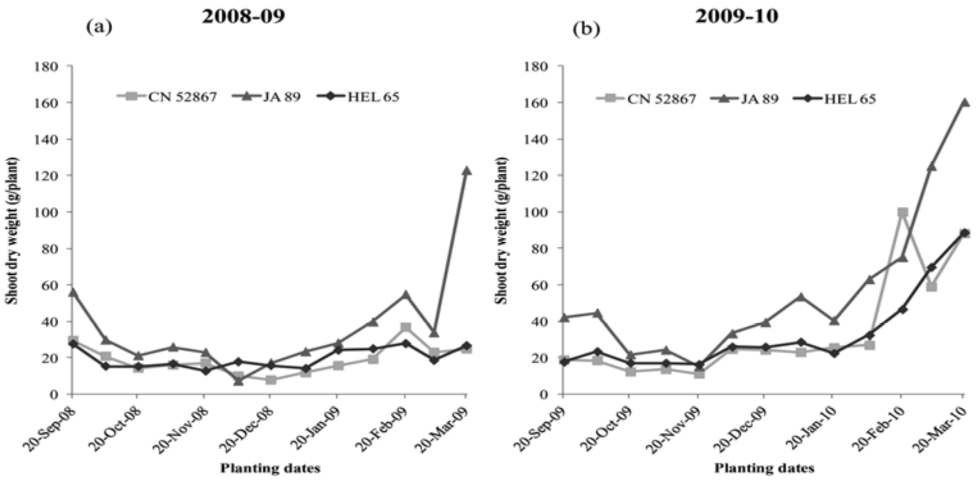

Figure 3. Patterns of shoot dry weight of three Jerusalem artichoke genotypes across planting dates (representing different growing degree days).

Positive and significant correlation coefficients (r=0.36 to 0.54, P≤0.01 and ≤0.05) between GDD and shoot dry weight were observed across Jerusalem artichoke genotypes and planting dates for two years and correlation coefficients (r=0.41 to 0.73, P≤0.01) between photoperiod and shoots dry weight were also positive and significant (Figure 4a-d). The correlation coefficients between GDD and leaf area at 90 days after transplanting were significant, ranging from r=0.48 to r=0.67 (P≤0.01), the correlation coefficients between photoperiod and leaf area were also positive and significant and, ranging from r=0.43 to r=0.71 (P≤0.01) (Figure 5a-d). This finding is again a very significant finding of this study and must be highlighted. This finding shows that GDD has direct impact on the growth of Jerusalem artichoke and this relationship must be considered when deciding production practices.

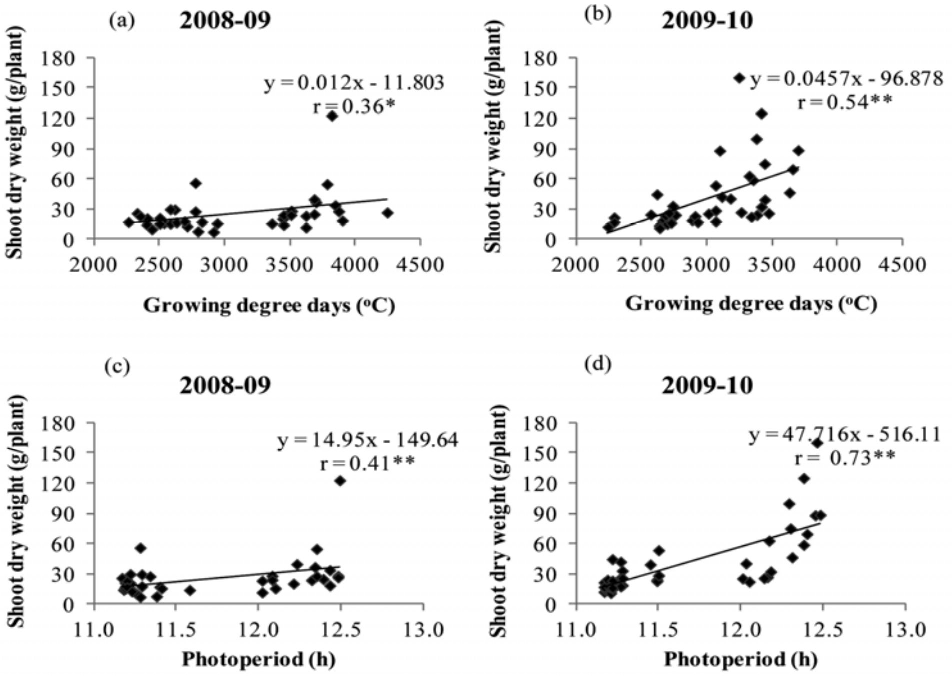

Figure 4. Relationship between shoot dry weight (g/plant) on (a) photoperiod (2008-09), (b) photoperiod (2009-10), (c) growing degree days (2008-09) and (d) growing degree days (2009-10) of three Jerusalem artichoke genotypes at harvest in two years (2008-09 to 2009-10). r=correlation coefficients (n=39), *, ** Significant at P≤0.05 and ≤0.01, respectively. Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

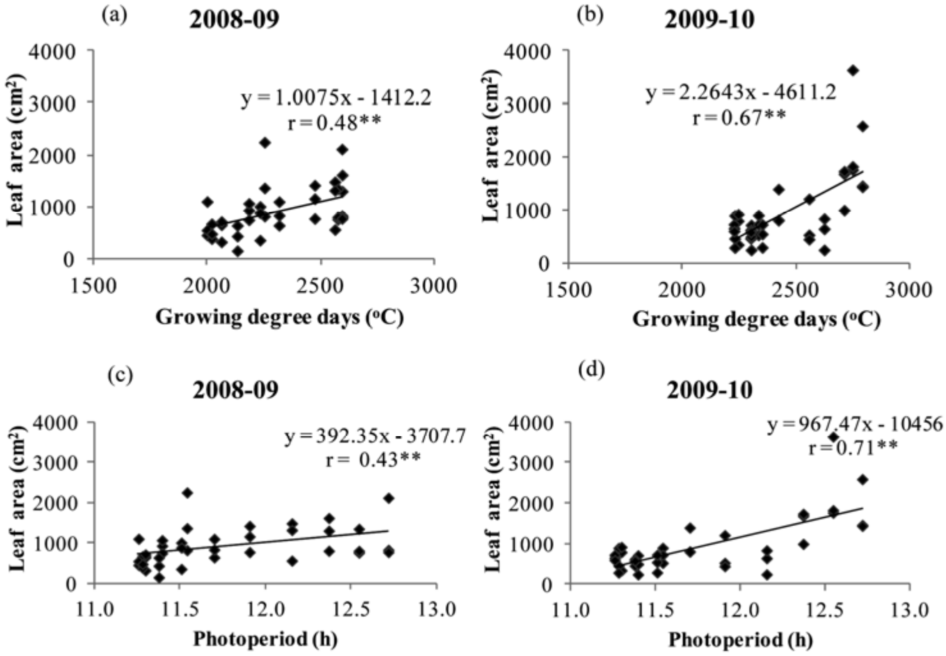

Figure 5. Relationship between leaf area (cm^2) on (a) photoperiod (2008-09), (b) photoperiod (2009-10), (c) growing degree days (2008-09) and (d) growing degree days (2009-10) of three Jerusalem artichoke genotypes at harvest in two years (2008-09 to 2009-10).
r=correlation coefficients (n=39), *, ** Significant at P≤0.05 and ≤0.01, respectively.
Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

Correlation coefficients (r = -0.58 to -0.73, P≤0.01) between GDD and harvest index were negative and significant across Jerusalem artichoke genotypes and planting dates in 2008-09 and 2009-10 and correlation coefficients (r= -0.75 to -0.77, P≤0.01) between photoperiod and harvest index were also negative and significant (Figure 6a-d). Correlation coefficients (r=0.45 to r=0.48, P≤0.01) between GDD and number of tubers were significant and correlation coefficients (r=0.55 to r=0.66, P≤0.01) between photoperiod and number of tuber were also positive and significant (Figure 7a-d). Correlation coefficients (r= -0.59 to -0.60, P≤0.01) between GDD and harvest index were negative and significant across Jerusalem artichoke genotypes and planting dates in 2008-09 and 2009-10 and correlation coefficients (r= -0.64 to -0.73, P≤0.01) between photoperiod and weight of individual tubers were also negative and significant (Figure 8a-d). High GDD and long photoperiod reduced harvest index and weight of individual tubers, whereas they increased number of tuber. Growing Jerusalem during short photoperiod in November to January gave larger tubers than growing Jerusalem artichoke during long photoperiod in February to October because of high harvest index.

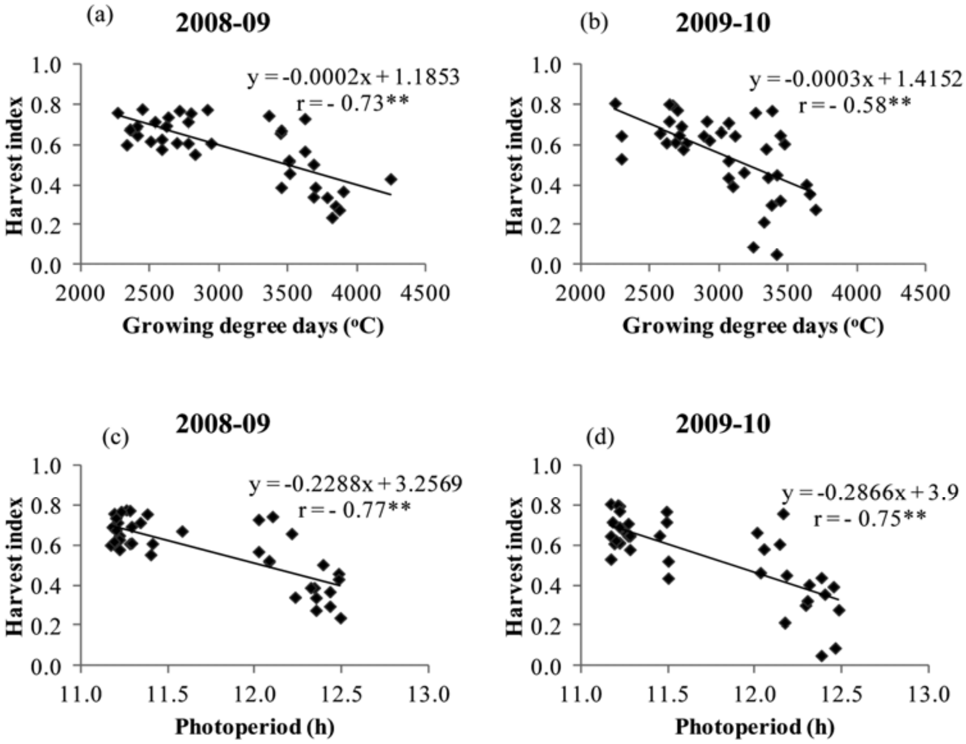

Figure 6. Relationship between harvest index on (a) photoperiod (2008-09), (b) photoperiod (2009-10), (c) growing degree days (2008-09) and (d) growing degree days (2009-10) of three Jerusalem artichoke genotypes at harvest in two years (2008-09 to 2009-10).
r=correlation coefficients (n=39), *, ** Significant at P≤0.05 and ≤0.01, respectively.
Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.
Harvest index (HI) was calculated as tuber dry weight divided by the total biomass of the plant.

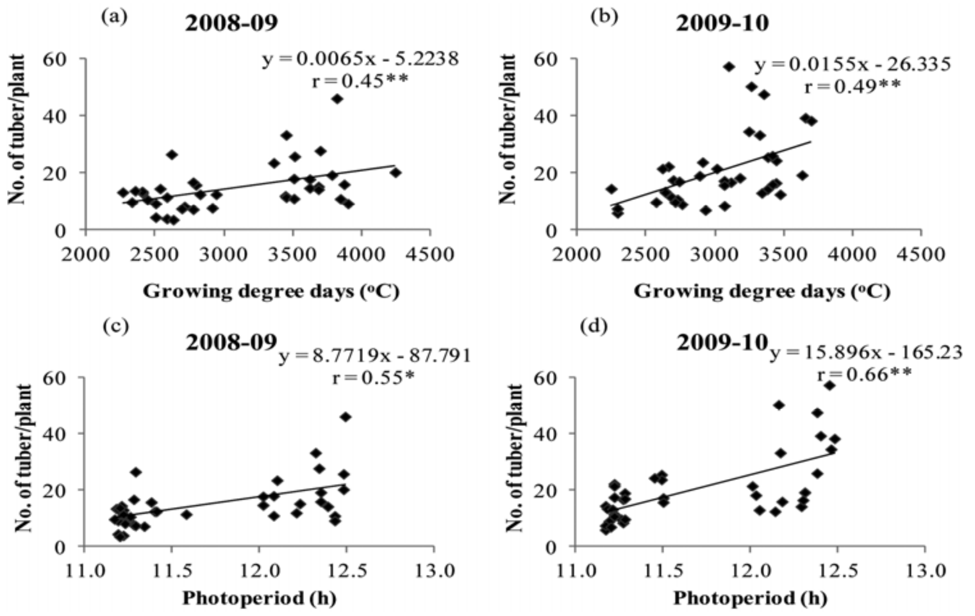

Figure 7. Relationship between number of tuber per plant on (a) photoperiod (2008-09), (b) photoperiod (2009-10), (c) growing degree days (2008-09) and (d) growing degree days (2009-10) of three Jerusalem artichoke genotypes at harvest in two years (2008-09 to 2009-10). r=correlation coefficients (n=39), *, ** Significant at $P \leq 0.05$ and ≤ 0.01, respectively.
Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 °C base-temperature from day of transplanting to harvest time.

Discussion

Jerusalem artichoke tubers are highly perishable under ambient temperature conditions. The tubers need storage facilities of 4 °C to keep the tubers fresh for less than 7 weeks (Chekroun et al., 1997). Off-season production of Jerusalem artichoke during the dry period of the year can meet the market demand at a reduced storage cost when fresh tubers are in short supply. The typical features of the dry period in the tropics are the differences in temperature and photoperiod compared to those in the rainy season when temperature and photoperiod are rather stable and, therefore, the possibility of growing Jerusalem artichoke in this period is a good option for farmers as well as consumers. Therefore, a study was conducted to answer some of the fundamental questions on how Jerusalem artichoke genotypes will respond to the changes in temperature and photoperiod during the dry period and affect growth and yield of Jerusalem artichoke.

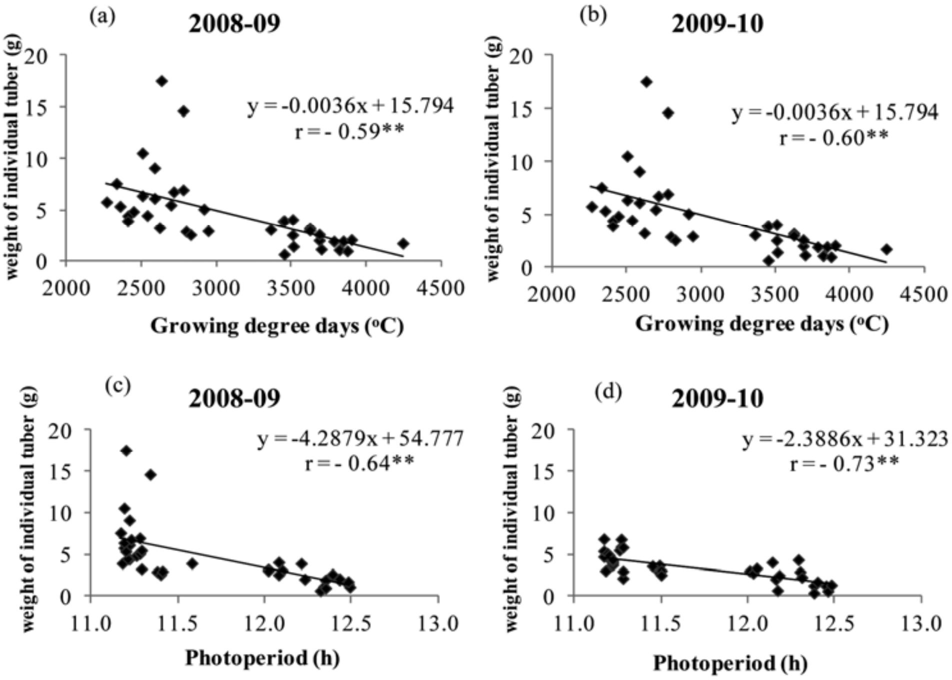

Figure 8. Relationship between weight of individual tuber (g) on (a) photoperiod (2008-09), (b) photoperiod (2009-10), (c) growing degree days (2008-09) and (d) growing degree days (2009-10) of three Jerusalem artichoke genotypes at harvest in two years (2008-09 to 2009-10). r=correlation coefficients (n=39), *, ** Significant at P≤0.05 and ≤0.01, respectively.
Growing degree days (GDD) for each genotype for each planting date was calculated as the summation of daily mean temperatures above the 0 ^{o}C base-temperature from day of transplanting to harvest time.

The photoperiod ranged from 11.20 hours to 13.20 hours and this range was consistent both years. GDD varied from 2,245 to 4,242 and were more variable within years in comparison to photoperiod (varied from 11.17 to 12.48 h) although the patterns of variability were rather similar. The strong correlation between photoperiod and GDD indicated that these factors had synergistic and significant effects on the growth and yield of Jerusalem artichoke.

The results of this study are in agreement with previous findings made on other crops. Warm day/night temperature of 32/22 ^{o}C during day and photoperiod of 16 hours increased plant height and leaf numbers while translocation of photosynthate to the tubers of potato was low under these conditions (Wolf et al., 1990). Similarly, warm day/night temperature of 30/24

^{o}C and photoperiod of 18 hours delayed the onset of tuber growth and the onset of tuber bulking (Van Dam et al., 1996). Higher temperature and longer photoperiod gave lower relative rates of partitioning of dry matter to the tubers.

The effects of GDD and photoperiod on partitioning of assimilates were in the same direction because these factors were closely associated to plant growth. These findings were rather similar to those made for other tuber crops such as potato. In potato, high temperatures reduces the allocation of photosynthates to the tubers in detriment of biomass and long photoperiod delays maturity at high temperatures because plants will be so poorly induced to tuberize that tuber will form much later than normal and new leaves will continue to form over a longer period of time. Potato plants that were exposed to short photoperiod showed reductions in leaf area, branching and root growth. However, assimilate allocated to root growth was increased (Ewing and Sandlan, 1995). In cassava, short days increased root growth and reduced vegetative growth and the development of roots. Long photoperiod increased shoot growth and reduced carbohydrates available for root growth (Lebot, 2009).

In this experiment when the crop was planted at 15-day intervals from September 20 to March 20, GDD and photoperiod were higher at the beginning of the experiment and at the end of the experiment. Higher GDD and long photoperiod were associated with high temperature (33.5 ^{o}C), whereas low GDD and short photoperiod were associated with low temperature (17.5 ^{o}C). Planting dates from September to March greatly affected growth and tuber development of Jerusalem artichoke and the information is important for production planning. The growing conditions were rather different from those in the temperate regions where Jerusalem artichoke was domesticated.

In temperate regions, the average temperatures during the growing season between March and November are 6 to 26 ^{o}C and the crop requires at least 125 frost-free days (Kay and Nottingham 2008) and photoperiod of more than 13 hours. Cooler temperatures prolong the accumulation of heat units required for maturity and thus extend days to harvest. Maturity in the temperate regions (approximately 8 months) is generally longer than in the tropics (approximately 4 months) because crop growth rates near the Equator are faster (Kay and Nottingham, 2008). As Jerusalem artichoke is often grown under long photoperiod of nearly 14 hours in temperate regions, short photoperiod is not expected to significantly affect the growth of Jerusalem artichoke. However, short photoperiod does severely affect growth and yield of Jerusalem artichoke grown in the tropics.

Jerusalem artichoke is a photoperiod-sensitive short-day plant (13 and 13.5 hrs). In temperate regions, some late maturing genotypes do not flower because the stems are killed by early frost (Denoroy, 1996). In contrast, some early maturing genotypes included in our experiment did not flower during the shortest photoperiod. The crop stops vegetative growth earlier and tuber initiation starts sooner than in more northerly latitudes, resulting in shorter plant and smaller tubers (Kay and Nottingham, 2008).

As the soil texture and nutrients in two years were rather similar, difference in soils was not expected to cause large difference in Jerusalem artichoke growth performance. Furthermore, chemical fertilizers were also applied to avoid nutrient deficiency and reduce nutrient differences between the years.

Compared to yearly effect, genotype effect and planting date effect, the interactions for primary and secondary levels of treatments were rather small for all traits especially for those associated with genotype effect. These results indicated that good genotypes could be readily identified for a particular set of environmental conditions. However, identification of good planting dates was rather confounding because of high interaction effects. This could be due to high variations in environmental conditions especially temperature between years and within years. In multi-location trials, Pimsaen et al. (2010) found that the contribution of location and seasonal effects was significant on tuber yield, tuber number and tuber size.

Differences in planting dates significantly affected GDD, photoperiod, total biomass, shoot dry weight, leaf area, tuber dry weight, harvest index, number of tubers per plant and weight of individual tubers, indicating that GDD and photoperiod played an important role on the growth performance of these traits. The results from this study suggested a strong correlation between GDD and total biomass production although the correlation coefficients were only significant in 2009-10. Results also indicated a close relationship between photoperiod and total biomass.

In general, GDD plays an important role in determining the maturity of crops and yield. The present study showed that GDD was positively associated with shoot dry weight. Kocsis et al. (2007) and Kocsis et al. (2008) found that shoot dry weight was increased with high temperature sums (equivalent to GDD) in temperate regions. Accumulation of above ground biomass requires high heat unit, however, Tsialtas and Maslaris (2008) reported that high temperatures (35-37 ^{o}C) degraded leaf chlorophyll and repress photosynthesis of sugar beet in the temperate climate. The strong relationship was rather unexpected as Jerusalem artichoke generally transfers assimilates to tubers at maturity, leaving small portion of assimilates in shoots. The strong relationship in this study was due mainly to the positive response of the cultivar JA-89 to high temperature for shoot dry weight (Figure 3). This genotype had prolific branching at high temperature and low harvest index.

Jerusalem artichoke genotypes were also different in days to harvest, total biomass, shoot dry weight, leaf area, tuber dry weight, harvest index, tubers per plant and weight of individual tubers and selection for these traits could be possible. The genotypes CN-52867 and JA-89 showed consistently high tuber yield across planting dates and years. These genotypes showed good general adaptation and might be recommended to farmers for growing in the dry period. Genotype specific to any planting date could not be identified largely due to high variation in temperature.

The number of tubers was generally increased with GDD, whereas weight of individual tuber was reduced. The plants showed highly prolific stolons under high GDD and long photoperiod, resulting in smaller tubers and low harvest index. The plants grown under short photoperiod, in contrast, had low number of tuber and high harvest index. This was possibly due to the effect of short photoperiod that promotes partitioning of assimilates to harvestable tubers (Soja and Dersch, 1993).

In temperate regions, short photoperiod of 13 hours generally increases harvest index of Jerusalem artichoke (Denoroy, 1996). Short photoperiod is also a favorable condition for the initiation of flowers and rapid tuber growth (Meijer and Mathijssen, 1991). Short photoperiod (11 hours) reduced stem length, stem dry matter and leaf growth, induced stolon and tuber growth and enhanced senescence, whereas long photoperiod (14 hours) promoted leaf and stem growth, but it delayed stolon and tuber induction (Soja and Dersch, 1993).

GDD and photoperiod were well associated with shoot dry weight, but their correlations with tuber dry weight were not statistically significant. The negative correlations of GDD and photoperiod with harvest index indicated that these factors gave more contribution to shoot dry weight rather than tuber yield as harvest index is the proportion of tuber dry weight and biomass. Since short photoperiod can severely reduce growth but increase harvest index and tuber size, Jerusalem artichoke could be planted at higher plant population density in the winter season when temperature is low and photoperiod is short. In winter wheat, Sun et al. (2013) reported that sowing time and rate affected biomass accumulation. The optimized sowing time and sowing rate has the potential to improve yield of winter wheat. Manipulation of planting density under different planting dates is thus a way to increase tuber yield and improve tuber quality. The tubers were generally larger under short day conditions in the dry period and these planting dates had lower stem rot disease caused by *Sclerotium rolfsii*. This idea to manipulate plant population density needs to be proven in the field.

Growing Jerusalem artichoke in the tropics is rather a different agricultural practice from that in the temperate regions. The crop in the tropics requires shorter growing period of about four months to complete crop cycle, while the crop cycle in the temperate can be as long as eight months during the frost free period. Therefore, growing Jerusalem artichoke in the tropics for three crops per year is possible and crop response to different planting dates should be further investigated for better crop management for different planting dates and crop modeling efforts should be further investigated to optimize crop production practices for soil and water sustainability and farmer profitability.

Conclusion

Jerusalem artichoke varieties responded differently to varying GDD and photoperiod for harvest index, shoot dry weight, leaf area, number of tubers and tuber size due largely to high variation in planting dates within years and between years. Therefore, the most productive planting dates were difficult to determine. However, CN-52867 and JA-89 were most productive at the planting date of 20 September and performed well at other planting dates. High GDD was positively associated with high shoot dry weight, high leaf area and high number of tubers, but it had negative correlations with harvest index and tuber size. However, the experiment was limited to growing Jerusalem artichoke in containers and further studies in the fields are necessary.

Acknowledgements

This work was funded by the Thai Royal Golden Jubilee Ph.D. Program (Grant no. PHD/0026/2551), the Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group and the Thailand Research Fund (TRF), The Commission of Higher Education (CHE) and Khon Kaen University for providing fund through the Distinguish Research Professor Grant of Professor Dr. Aran Patanothai. We also acknowledge supported by the Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Thailand.

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