RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
49 (1) 58-68, 2017

EVALUATION OF STEM ROT RESISTANCE IN JERUSALEM ARTICHOKE HYBRID CLONES UNDER FIELD CONDITIONS

D. PUANGBUT[1,2], S. JOGLOY[1,3*] and R. PUTTHA[1]

[1]Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand
[2]Plant Production Technology, Faculty of Technology, Udon Thani Rajabhat University, Udon Thani, Thailand
[3]Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group, Khon Kaen University, Khon Kaen, Thailand
*Corresponding author's email: sjogloy@gmail.com
Email addresses of co-authors: daruneepom@gmail.com

SUMMARY

Stem rot disease caused by *Sclerotium rolfsii* is an important problem for Jerusalem artichoke production. Development of Jerusalem artichoke varieties for resistance to stem rot disease is an effective and sustainable strategy to solve stem rot disease problem. The objective of this study was to evaluate Jerusalem artichoke breeding clones for stem rot resistance and high tuber yield. Forty-seven breeding clones and four commercial genotypes were evaluated in a RCBD with four replications. Field experiment was conducted during the early-rainy season from June to September and late-rainy seasons from September to December in 2014 at the Field Crop Research Station of Khon Kaen University, Thailand. This experiment was not inoculated but allowed to natural infection. The data were recorded for disease score at 60 and 80 days after transplanting and tuber yield at harvest. The results indicated that season contributed to a large portion of total variation for disease score, tuber number and fresh tuber yield while genotype and genotype × season contributed to small portions of variations for all characters. Breeding clones and varieties of Jerusalem artichoke were significantly different for disease score, number of tubers per plant and tuber yield in both seasons. In the early-rainy season, the breeding clones [JA 6×HEL 65]-2 and [JA 37×JA 6]-10 were resistant to stem rot disease, whereas the breeding clone [JA 6×CN 52867]-4 had the highest tuber yield and high resistance to stem rot disease. In the late-rainy season, the differences among breeding clones and varieties of Jerusalem artichoke for stem rot resistance were low due to low disease incidence, and the breeding clones [CN 52867×HEL 65]-17and [JA 37×HEL 65]-16 had the highest tuber yield. Over all seasons, [JA 6×CN 52867]-4 and [JA 37×HEL 65]-16 could be identified as high tuber yield and moderate resistance to stem rot disease. Thus, selecting for high tuber yield combined with resistance to stem rot disease is possible in Jerusalem artichoke hybrid clones.

Key words: Jerusalem artichoke, breeding clones, tuber rot, *Sclerotium rolfsii*

Key findings: Breeding clones of Jerusalem artichoke were significantly different for disease score and tuber yield. Selection of Jerusalem artichoke hybrid clones for high yield coupled with resistance to stem rot disease was successful in this study.

Manuscript received: November 16, 2016; Decision on manuscript: November 29, 2016; Manuscript accepted: January 3, 2017.

Communicating Editor: Naqib Ullah Khan

INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.) is a tuber crop containing inulin about 55-75% on dry weight basis (Puttha *et al*., 2012). Inulin has complex molecules consisting of chains of fructose (Niness, 1999). The Jerusalem artichoke is, therefore, a crop that is useful for health as inulin is not digested in digastric system. Inulin reduces obesity as it is a diet that is low in calories and does not increase blood sugar, thus reducing the risk of diabetes, fat cholesterol, triglycerides and low-density lipoprotein (LDL) and cardiovascular (Rumessen *et al*., 1990; Davidson and Maki, 1999; Gaafar *et al*., 2010). Inulin is digested by healthful microorganisms, including Bifidobacteria and Lactobacillus in the colon and induces immune system, infection of diseases and the risk of colon cancer (Farnworth, 1993; Roberfroid, 2005).

Therefore, Inulin is considered as a prebiotic substance with health benefits (Roberfroid, 2007). Inulin can help prevent colon cancer, reduce blood cholesterol and the risk of coronary heart disease (Davidson and Maki, 1999). In addition, inulin is also used as a sweetener for people with diabetes type 2 and as food for people who want to lose weight (Hellwege *et al*., 2000). Jerusalem artichoke has high potential for development as a new agronomic crop.

A stem rot disease caused by *Sclerotium rolfsii* is an important problem of Jerusalem artichoke production in Thailand (Sennoi *et al*., 2013a). Stem rot disease is also a serious problem in Jerusalem artichoke in the temperate regions, but the causal fungi are different (Sennoi *et al.*, 2010). This diseases incited by *S. rolfsii* is more prevalent under the high temperature and high humidity conditions of the rainy seasons (Sennoi *et al*., 2013b). Stem rot substantially reduces tuber yield of Jerusalem artichoke. A considerable decrease of 60% had been reported in yield (McCarter and Kays, 1984).

Seed tuber is also a source of the disease outbreak in the next crops. Various methods of management for *S. rolfsii* have been investigated in Jerusalem artichoke including fungicide and biological control (Sennoi *et al*., 2013a), except resistant hybrid clones. However, effective methods for control of *S. rolfsii* in Jerusalem artichoke have not been available. This could be due to those methods will not be potential effective and sustainable to combat stem rot in Jerusalem artichoke. The development of resistant varieties is important for Jerusalem artichoke production. If resistant varieties are available, the production potential of this crop in commercial scale should be increased, and the raw material can be used for functional food, feed additive and bioethanol. The objective of this study was to evaluate Jerusalem artichoke hybrid clones for resistance to stem rot disease and tuber yield under field conditions.

MATERIALS AND METHODS

Plant materials and experimental design

Forty-seven Jerusalem artichoke breeding clones were generated from the hybridization of three stem rot resistant genotypes and high yield (CN 52867, HEL 65 and JA 37) (Pimsean *et al*., 2010; Sennoi *et al*., 2012; Sennoi *et al.*, 2013c) with two stem rot susceptible genotypes JA 6 and JA 89 (Pimsean *et al*., 2010; Puttha *et al*., 2012; Sennoi *et al*., 2013c) (Table 1). Genotypes JA 6 and JA 89 were selected because of its high tuber yield. Four Jerusalem artichoke genotypes (KT1, KT 2, KT 3 and KT 50-4) are commercial cultivar in Thailand which used as check genotypes.

Forty-seven hybrid clones were selected for good agronomic traits in field experiments during the early-rainy season from June to September and late-rainy seasons from September to December in 2014 at the Field Crop Research Station of Khon Kaen University, Thailand (latitude 16º28́ N, longitude 102º48́ E, 200 m above mean sea level). A randomized complete block design with four replications was used. Plot size was 1.6 × 5 m with a spacing of 50 cm between rows and 40 cm between hills in a row.

Table 1. Characteristics of parental clones used for hybridization.

Genotypes	Characteristics	References
CN 52867	Resistant, high yield	Sennoi *et al*. (2012); Pimsean *et al*. (2010)
HEL 65	Resistant, high yield	Sennoi *et al*. (2013c); Pimsean et al (2010)
JA 37	Resistant, high yield	Sennoi *et al*. (2012); Pimsean et al (2010)
JA 6	susceptible, medium yield	Sennoi *et al*. (2013c); Puttha et al (2012)
JA 89	susceptible, high yield	Sennoi *et al*. (2013c); Pimsean et al (2010)

Crop management

Soil was ploughed once using a 3-disc tractor and twice using a 7-disc tractor and ridged at a distance of 2 m. Then, the ridges were leveled to make soil beds.

Seed tubers were cut into small pieces each of which had 2 or 3 buds. The tuber pieces were incubated in plastic bags containing moist coconut peat at the bottom and the top of the bags for 7 days under ambient conditions. The plastic bags were kept open for good aeration. The tuber pieces with active buds and roots were further transferred to germinate plug trays with mixed medium containing burnt rice husk and soil for 7 days for complete sprouting. The fourth leaf-sprouted (V4) seedlings were then suitable for transplanting in the plot (Puangbut *et al*., 2015a). One seedling was transplanted per hill. Fertilizer formula 15-15-15 was applied at 30 days after transplanting (DAT) at a rate of 156 kg ha^{-1}. Supplementary irrigation was applied to the crop with an overhead sprinkler system at two-day intervals. The carboxamide and *Trichoderma* were used to prevent the stem rot diseases before incubation. This experiment was non-inoculated but allowed to natural infection. However, the non-inoculated natural infection method could identify the differences among Jerusalem artichoke varieties (Junsopa *et al*., 2016).

Data collection

Weather parameters

Rainfall, solar radiation, maximum and minimum temperatures were recorded daily from transplanting until harvest by a weather station located 100 m away from the experimental field.

Disease score

At 60 and 80 days after transplanting, 10 plants in each plot were sampled randomly and used for determination of disease score. A disease severity rating scale, adapted from a scale used to rate *S. rolfsii* severity in Jerusalem artichoke (Sennoi *et al.*, 2013c), was used to score individual plants on a 1–5 scale as follows: 1 = healthy; 2 = lesions present, but leaves not wilting; 3 = lesions present and leaves wilting; 4 = lesions present and leaves wilting > 50%; 5 = plant dead.

Fresh tuber yield and number of tuber per plant

At harvest, plants each end of the rows were discarded, and all plants in an area of 3.5 m^2 were harvested discarding the border rows. The plants were cut at the soil surface and separated into shoots and tubers. Tubers were washed in tap water to remove the soil and then tuber fresh weight was determined. Two plants in each plot were sampled randomly and used for determination of number of tubers per plant.

Statistical analysis

Analysis of variance was performed for individual seasons and error variances were tested for homogeneity by Bartlett's test (Hoshmand, 2006). Due to genotype × seasons interactions were significant for all characters (Table 2), data were reported for individual seasons. Duncan's multiple range tests (DMRT) was used to compare means among genotypes. Calculation procedures were done by using MSTAT-C package (Bricker, 1989).

Table 2. Soil texture and chemical properties for the early-rainy season (ERS) and late-rainy season (LRS).

Soil properties	ERS	LRS
Physical properties		
Sand (%)	89.93	89.86
Silt (%)	6.07	8.00
Clay (%)	4.00	2.14
Texture class	Sand	Sand
Chemical properties		
pH (1:2.5 H_2O)	6.76	6.61
CEC (c mol kg^{-1})	1.49	1.51
Organic matter (%)	0.44	0.51
Total N (%)	0.02	0.03
Available P (mg kg^{-1})	28.29	25.78
Exchangeable K (mg kg^{-1})	52.46	36.21

RESULTS

Soil properties and weather data

The chemical and physical properties were slightly different between seasons (Table 2). The soils used in both seasons were sandy soil with pH 6.61-6.76 and cation exchange capacity (CEC) was 1.49-1.51 c mol kg^{-1}. The proportions of sand, silt and clay in the soil were 89-90%, 6-8% and 2-4%, respectively. The soils in both seasons were low in organic matter (0.44-0.51%), low nitrogen (0.02-0.03%), low phosphorus (25.8-28.3 mg kg^{-1}) and medium potassium (36.2-52.5 mg kg^{-1}).

Seasonal mean of maximum temperature in the early-rainy season was 37.8ºC and minimum temperature was 12.5°C (Figure 1). Maximum temperature in late-rainy season was 36.7ºC and minimum temperature was 12.6°C (Figure 2). The means of solar radiation in the early-rainy season were 18.0 MJ m^{-2} d^{-1} (Figure 1) and it was 17.9 MJ m^{-2} d^{-1} in the late-rainy season (Figure 2). Rainfalls in the early-rainy seasons were 717.3 mm (Figure 1) and it was 211.7 mm in the late-rainy season (Figure 2).

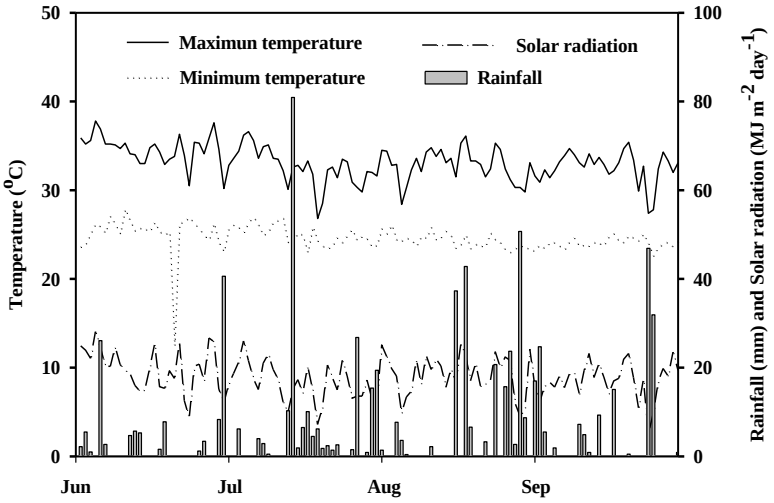

Figure 1. Daily maximum temperature, minimum temperature, solar radiation and rainfall in the early-rainy season 2014.

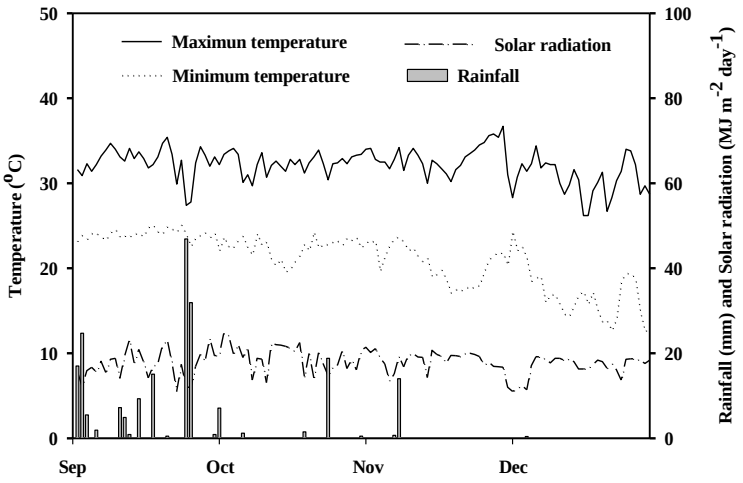

Figure 2. Daily maximum temperature, minimum temperature, solar radiation and rainfall in the late-rainy season 2014.

Genotypic variability and genotype × environment interactions

Significant differences ($P \leq 0.01$) between seasons (S) were observed for disease score, tuber number and fresh tuber yield and significant differences ($P \leq 0.01$) among Jerusalem artichoke genotypes (G) were observed for all traits (Table 3). Season contributed to a large portion of total variation for disease score (75.8%), tuber number (81.2%) and fresh tuber yield (68.8%). Because the season effect was high for most characters, the data for each season was reported separately.

Genotype contributed rather small portions of variation for disease score (9.0%), tuber number (8.1%) and fresh tuber yield (12.4%). Similarly, the interactions between genotype and the season contributed to small portions of variations for disease score, tuber number and fresh tuber yield.

Genotypic variation of disease score

Significant differences between seasons were observed for disease score (Table 3), the data for each season are shown separately (Tables 4 and 5). Disease score differed significantly among 47 Jerusalem artichoke hybrid clones in both seasons. In the early-rainy season, [CN 52867 × JA 6]-1,[JA 6 × HEL 65]-2,[JA 37 × JA 6]-10and [JA 6 × CN 52867]-27 were identified as having high resistance to stem rot (healthy plant) while [JA 6 × CN 52867]-24, [HEL 65 × JA 89]-1, [CN 52867 × JA 6]-9 had the highest disease score (4.2-4.9) and susceptible to stem rot disease (Table 4).

In the late-rainy season, the genotype with high or low resistance to stem rot could not be clearly identified into groups. This could be due to the temperature and humidity in late-rainy season is unsuitable for disease infection lead to low disease severity. There were 19 hybrid clones (e.g., [CN 52867 × JA 6]-1, [CN 52867 × JA 6]-17, [CN 52867 × JA 6]-23, [CN 52867 × HEL 65]-22, [CN 52867 × HEL 65]-33, [JA 6 × CN 52867]-27, [JA 6 × CN 52867]-32, [JA 37 × JA 6]-10and [JA 6 × HEL 65]-4 had the lowest disease score, whereas 3 hybrid clones and 1 commercial cultivar (CN 52867 × JA 6]-1, [JA 37 × JA 6]-4, [CN 52867 × HEL 65]-25 and KT 3) had the highest disease score (1.6-1.8) (Table 5).

Genotypic variation of tuber yield and tuber number

Jerusalem artichoke breeding clones were significantly different for tuber number per plant and fresh tuber yield in both seasons (Table 3).

Table 3. Mean squares from combined analysis of variance for disease score, number of tuber per plant and tuber yield of 47 Jerusalem artichoke hybrid lines and 4 recommended genotypes observed in the early-rainy season and late-rainy season.

Source of variation	Df	Disease score	Tuber number (tuber plant^{-1})	Fresh tuber yield
Season (S)	1	65,016.9** (75.8)	4.109E+08** (81.2)	7.519E+07** (68.8)
Rep. within S	4	26.0 (0.1)	14,3955 (0.1)	21,793.8 (0.1)
Clone/genotype (G)	50	153.6** (9.0)	81,8153** (8.1)	27,0739** (12.4)
S × G	50	151.3** (8.8)	82,8405** (8.2)	27,2072** (12.5)
Pooled error	200	27.2 (6.3)	61,243.9 (2.4)	34,112.1 (6.2)

** Significant at $P < 0.01$.
Numbers within the parentheses are percentages of sum squares to total sum of squares.

In the early-rainy season, the hybrid clones [JA 6 × CN 52867]-32 had the highest tubers (61 tubers) followed by [JA 37 × JA 6]-3 (56 tubers), [JA 6 × HEL 65]-6 (53 tubers) and [CN 52867 × JA 6]-1 (52 tubers) (Table 4). The high fresh tuber yield was observed in [JA 6 × CN 52867]-4 (16,563 kg ha^{-1}) followed by [JA 37 × HEL 65]-16 (11,581 kg ha^{-1}).

In the late-rainy season, the hybrid clones [JA 6 × CN 52867]-38 had the highest tubers (60 tubers) followed by [CN 52867 × JA 6]-6 (53 tubers), [JA 37 × JA 6]-3 (51 tubers) and [JA 37 × JA 6]-4 (50 tubers) (Table 5). The hybrid clones with high fresh tuber yield were [CN 52867 × HEL 65]-17 (26,675 kg ha^{-1}) followed by [JA 37 × HEL 65]-16 (24,781 kg ha^{1}) and [HEL 65 × JA 89]-6 (21,200 kg ha^{-1}).

DISCUSSION

A stem rot disease caused by *S. rolfsii* is a serious problem of Jerusalem artichoke production in the tropics. Breeding for improving stem rot resistance would be the best strategy and sustainable to cope with stem rot disease. Screening of Jerusalem artichoke genotypes for stem rot resistance has been reported (Sennoi *et al*., 2013c; Cassells and Walsh, 1995). The research on stem rot disease resistance in Jerusalem artichoke is rare and considered in hybrid clones. Furthermore, there is limited information of genotype evaluation for stem rot resistance in different environments under field conditions. Variation in environment and genotype × environment interaction can affect stem rot resistant traits.

The results revealed that the effect of genotype by environment interaction was rather low for disease score. A recent report has been demonstrated that the interaction between genotype and environment for disease severity was low compared to the genotype effect (Sennoi *et al.*, 2013c). The authors also suggested that day to permanent wilting could be a useful selection criterion for stem rot resistance because the genotype main effect for days to permanent wilting contributed to a large portion of the variation compared to other traits. This study indicated that disease score may be used to identify the resistant and susceptible genotypes in Jerusalem artichoke.

Planting Jerusalem artichoke in the early-rainy season had the highest disease incidence than did planting in the late-rainy season as the early rainy season had higher temperature and higher relative humidity. The temperature of 30°C is the most suitable for the outbreak of the disease (Kwon *et al.*, 2008; Sennoi *et al.*, 2012). Evaluation of disease resistance in the early-rainy season could better identify the resistant and susceptible varieties than did the evaluation in the late-rainy season.

Inconsistency of the results is an important problem in identifying resistance to *S. rolfsii* (Shokes *et al*., 1996; Sennoi *et al*., 2013c). Inconsistent results of genotype evaluations for stem rot resistance have been reported in other crops (Fery and Dukes, 2002; Bradley *et al*., 2006; Garg *et al*., 2008). However, the resistant breeding clones could be identified across two seasons and this suggests more consistent variation among hybrid clones for disease score between seasons. Similar to Sennoi *et al* (2013c) reported the genotype with

Table 4. Disease score, number of tuber per plant and fresh tuber yield of 47 Jerusalem artichoke hybrid clones and 4 commercial cultivars in the early-rainy season.

Line/variety	Disease score[1/]		Tuber number (tuber plant^{-1})		Fresh tuber yield (kg ha^{-1})	
[CN 52867 × JA 6]-1	1.0	p[2/]	52	a-e	5,294	h-m
[CN 52867 × JA 6]-6	2.5	e-n	35	f-n	3,444	mn
[CN 52867 × JA 6]-8	3.1	e-g	38	f-m	7,506	c-j
[CN 52867 × JA 6]-9	4.9	a	28	g-p	1,800	n
[CN 52867 × JA 6]-15	1.9	f-p	27	i-p	5,588	g-m
[CN52867 × JA6]-17	1.4	i-p	24	k-p	3,925	lmn
[CN52867 × JA6]-19	1.4	i-p	27	i-p	4,875	j-n
[CN52867 × JA6]-23	2.3	e-p	40	c-j	3,556	mn
[CN52867 × JA6]-25	2.3	e-p	32	g-p	7,050	d-k
[CN 52867 × HEL 65]-7	1.6	h-p	28	h-p	7,438	c-j
[CN 52867 × HEL 65]-11	1.2	k-p	32	g-p	9,231	b-f
[CN 52867 × HEL 65]-17	3.0	c-g	30	g-p	4,650	j-m
[CN 52867 × HEL 65]-22	4.1	a-d	23	l-p	6,050	g-m
[CN 52867 × HEL 65]-25	2.7	e-j	25	j-p	5,738	g-m
[CN 52867 × HEL 65]-33	3.4	b-e	27	i-p	3,744	lmn
[CN 52867 × HEL 65]-34	3.5	b-e	19	op	5,513	h-m
[CN 52867 × HEL 65]-36	1.9	f-p	26	i-p	8,506	c-g
[CN 52867 × HEL 65]-37	2.3	e-p	18	op	4,256	k-n
[CN 52867 × HEL 65]-44	1.3	k-p	23	l-p	5,944	g-m
[CN 52867 × HEL 65]-45	2.8	e-i	17	p	8,038	c-h
[JA 6 × CN 52867]-4	1.5	h-p	53	abc	16,563	a
[JA 6 × CN 52867]-5	1.9	f-p	42	b-h	7,013	d-k
[JA 6 × CN 52867]-15	1.1	nop	47	b-f	6,381	f-m
[JA 6 × CN 52867]-21	1.2	f-p	39	c-k	3,919	lmn
[JA 6 × CN 52867]-24	4.2	abc	30	g-p	4,594	j-n
[JA 6 × CN 52867]-27	1.1	nop	33	g-p	9,081	b-f
[JA 6 × CN 52867]-32	1.9	f-p	61	a	7,731	h-m
[JA 6 × CN 52867]-33	1.4	j-p	27	h-p	5,175	d-k
[JA6 × CN 52867]-36	2.4	e-o	39	c-k	7,144	d-k
[JA6 × CN 52867]-38	3.0	c-g	30	g-p	5,913	g-m
[JA 6 × HEL 65]-2	1.0	p	31	g-p	6,000	g-m
[JA 6 × HEL 65]-4	1.5	i-p	19	op	4,444	k-m
[JA 6 × HEL 65]-6	1.3	k-p	53	a-d	5,075	h-m
[JA 6 × HEL 65]-8	1.2	l-p	26	i-p	4,731	j-m
[JA 6 × HEL 65]-15	1.0	p	31	g-p	5,163	h-m
[JA 37 × JA 6]-3	2.5	e-m	56	ab	5,294	h-m
[JA 37 × JA 6]-4	2.6	e-k	38	e-m	6,550	e-l
[JA 37 × JA 6]-10	1.0	p	41	c-i	3,450	mn
[JA 37 × JA 6]-11	1.5	i-p	28	g-p	9,344	b-e
[JA 37 × HEL 65]-12	1.1	nop	38	d-l	4,969	i-m
[JA 37 × HEL 65]-15	2.9	d-h	36	f-m	10,094	bc
[JA 37 × HEL 65]-16	3.2	b-f	26	i-p	11,581	b
[HEL 65 × JA 89]-1	4.4	ab	23	m-p	5,581	g-m
[HEL 65 × JA 89]-4	2.4	e-o	30	g-p	3,875	lmn
[HEL 65 × JA 89]-5	3.4	b-e	25	j-p	9,481	bcd
[HEL 65 × JA 89]-6	2.5	e-l	21	nop	6,081	g-m
[HEL 65 × JA 89]-7	2.0	f-p	35	f-n	7,700	c-i
KT 1	1.7	j-p	43	b-g	8,463	c-g
KT 2	1.6	h-p	19	op	7,738	c-i
KT 3	1.5	h-p	39	c-k	7,063	d-k
KT 50-4	1.3	k-p	23	m-p	10,194	bc
Mean	2.2		32		6,443	

Disease score: 1 = healthy; 2 = lesions present but leaves not wilting; 3 = lesions present and 1-50% of leaves wilting; 4 = lesions present and > 50% of leaves wilting; 5 = plant dead

Means in the same column with the same letter (s) are not significantly different by DMRT at $P < 0.05$.

Table 5. Disease score, number of tuber per plant and fresh tuber yield of 47 Jerusalem artichoke hybrid clones and 4 commercial cultivars in the late-rainy season.

Line/variety	Disease score[1/]		Tuber number (tuber plant^{-1})		Fresh tuber yield (kg ha^{-1})	
[CN 52867 × JA 6]-1	1.0	b[2/]	43	b-f	9,663	o-t
[CN 52867 × JA 6]-6	1.2	ab	53	ab	19,000	b-e
[CN 52867 × JA 6]-8	1.1	ab	41	b-g	20,975	bc
[CN 52867 × JA 6]-9	1.2	ab	25	j-o	19,150	b-e
[CN 52867 × JA 6]-15	1.3	ab	31	e-n	14,963	e-m
[CN52867 × JA6]-17	1.0	b	34	d-l	20,750	bcd
[CN52867 × JA6]-19	1.4	ab	32	e-n	17,544	b-h
[CN52867 × JA6]-23	1.0	b	32	e-n	16,181	e-j
[CN52867 × JA6]-25	1.2	ab	47	a-d	13,206	h-o
[CN 52867 × HEL 65]-7	1.2	ab	35	d-k	15,875	e-j
[CN 52867 ×HEL 65]-11	1.1	ab	24	k-o	8,675	q-u
[CN 52867× HEL 65]-17	1.1	ab	44	b-e	26,675	a
[CN 52867 ×HEL 65]-22	1.0	b	23	k-o	14,025	g-n
[CN 52867 ×HEL 65]-25	1.6	ab	25	j-o	8,294	r-u
[CN 52867 ×HEL 65]-33	1.0	b	26	h-o	15,669	e-l
[CN 52867 ×HEL 65]-34	1.1	ab	23	k-o	18,738	b-e
[CN 52867 ×HEL 65]-36	1.0	b	32	e-m	13,275	h-o
[CN 52867 ×HEL 65]-37	1.0	b	20	l-o	16,938	c-i
[CN 52867 ×HEL 65]-44	1.0	b	26	i-o	18,325	b-g
[CN 52867 ×HEL 65]-45	1.0	b	22	k-o	14,906	e-m
[JA 6 × CN 52867]-4	1.0	b	23	k-o	16,613	d-i
[JA 6 × CN 52867]-5	1.0	b	35	d-k	13,938	g-n
[JA 6 × CN 52867]-15	1.2	ab	25	j-o	6,525	tu
[JA 6 × CN 52867]-21	1.2	ab	43	b-f	8,844	p-u
[JA 6 × CN 52867]-24	1.5	ab	41	b-h	12,975	i-j
[JA 6 × CN 52867]-27	1.0	b	22	k-o	11,125	m-s
[JA 6 × CN 52867]-32	1.0	b	34	d-m	15,600	e-l
[JA 6 × CN 52867]-33	1.0	b	29	f-o	16,325	e-i
[JA6 × CN 52867]-36	1.1	ab	29	f-o	12,988	i-p
[JA6 × CN 52867]-38	1.2	ab	60	a	11,356	l-r
[JA 6 × HEL 65]-2	1.0	b	38	c-j	8,481	r-u
[JA 6 × HEL 65]-4	1.1	ab	29	f-o	19,013	b-e
[JA 6 × HEL 65]-6	1.3	ab	28	g-o	9,963	n-t
[JA 6 × HEL 65]-8	1.1	ab	22	k-o	6,250	tu
[JA 6 × HEL 65]-15	1.0	b	17	no	7,019	stu
[JA 37 × JA 6]-3	1.0	b	51	abc	14,381	f-m
[JA 37 × JA 6]-4	1.8	a	50	abc	13,944	g-n
[JA 37 × JA 6]-10	1.0	b	40	b-i	12,806	i-q
[JA 37 × JA 6]-11	1.1	ab	23	k-o	11,438	k-r
[JA 37 × HEL 65]-12	1.0	b	28	f-o	11,900	j-r
[JA 37 × HEL 65]-15	1.3	ab	26	h-o	16,894	c-i
[JA 37 × HEL 65]-16	1.2	ab	35	d-k	24,781	a
[HEL 65 × JA 89]-1	1.0	b	20	k-o	5,413	u
[HEL 65 × JA 89]-4	1.3	ab	19	mno	21,013	bc
[HEL 65 × JA 89]-5	1.2	ab	25	j-o	14,238	g-n
[HEL 65 × JA 89]-6	1.0	b	22	k-o	21,200	b
[HEL 65 × JA 89]-7	1.3	ab	34	d-l	17,181	b-i
KT 1	1.1	ab	35	d-k	15,956	e-j
KT 2	1.0	b	15	o	15,438	e-m
KT 3	1.8	a	30	e-n	15,781	e-k
KT 50-4	1.2	ab	23	k-o	16,644	d-i
Mean	1.2		31		14,681	

Disease score: 1 = healthy; 2 = lesions present but leaves not wilting; 3 = lesions present and 1-50% of leaves wilting; 4 = lesions present and > 50% of leaves wilting; 5 = plant dead

Means in the same column with the same letter (s) are not significantly different by DMRT at $P < 0.05$.

Figure 3. Stem rot susceptible clones (above) and stem rot resistant clones (below) at 80 days after transplanting.

resistant to stem rot disease could be identified across experiments.

Disease scores indicated that Jerusalem artichoke hybrid clones showed difference in disease resistance. The Jerusalem artichoke hybrid clone with high or low stem rot resistant could be identified. [JA 6 × HEL 65]-2, [JA 37 × JA 6]-10, [CN 52867 × JA 6]-1 and [JA 6 × HEL 65]-15 had consistently high stem rot resistance in both seasons, whereas [CN 52867 × JA 6]-9, [CN 52867 × HEL 65]-22, [JA 6 × CN 52867]-24 and [HEL 65 × JA 89]-1 were susceptible to stem rot disease (Figure 3).

This study indicated that fresh tuber yield for all hybrid clones was higher in the late-rainy seasons than in the early-rainy seasons while tuber number was higher in the early-rainy season than in the late-rainy seasons. This was in agreement with Puangbut *et al*. (2015b) who reported that tuber yield was higher in the late-rainy season compared to the early-rainy season. They also indicated that tuber size in the late-rainy seasons was larger than in the early-rainy season.

Higher yield in the late-rainy season would be possibly due to larger tubers and higher tuber weight (Ruttanaprasert *et al*., 2013; Puangbut *et al*., 2015b). Over all seasons, Jerusalem artichoke hybrid clones showed significant differences for fresh tuber yield, indicating that hybrid clone with high tuber yield could be identified in this study. [JA 6 × CN 52867]-4 and [JA 37 × HEL 65]-16 had high fresh tuber yield and large tuber across seasons (Table 4, Figure 4).

Recent study indicated that stem rot resistant genotype could be identified but they were poor for yield and agronomic traits (Sennoi *et al*., 2013c). Therefore, consistent result of genotype evaluations for stem rot resistance and good tuber yield under field conditions are required.

These breeding clones had one resistant parent as a resistant donor (Sennoi *et al*., 2012, 2013c). As the traits segregated independently, this study was able to select some Jerusalem artichoke breeding clones with high fresh tuber yield and resistance to *S. rolfsii.* The results indicated that resistance to *S. rolfsii* in hybrid clones was not related to fresh tuber yield (data not presented). However, some breeding clones showed high fresh tuber yield and high

[JA 6 x CN 52867]-4
a

[JA 37 x HEL 65]-16
b

[CN 52867 x HEL 65]-17
c

Figure 4. Tuber characteristics of hybrid clones which are high yield grown under late-rainy season.

resistance to *S. rolfsii*. These breeding clones included [CN 52867 × HEL 65]-11, [JA 6 × CN 52867]-4 and [JA 6 × CN 52867]-27 in the early-rainy season. In the late-rainy season, [CN 52867 × HEL 65]-17, [JA 37 × HEL 65]-16, and [HEL 65 × JA89]-6 had high fresh tuber yield and high resistance to *S. rolfsii*. These breeding clones will be further evaluated in regional trials and other advanced trials for high fresh tuber yield and resistance to *S. rolfsii*. At the end of evaluation process, one or more advanced breeding clones are expected to be released for cultivation.

CONCLUSION

Jerusalem artichoke breeding clones evaluated in the early-rainy season had higher variation in disease incidence of stem rot caused by S. *rolfsii* than did Jerusalem artichoke evaluated in the late-rainy season. Early-rainy season is, therefore, suitable for evaluation of Jerusalem artichoke for stem rot disease resistance. Over all seasons, the genotype with resistance to stem rot disease and high tuber yield could be identified. [JA 6 × CN 52867]-4, [JA 37× HEL 65]-16 and [CN 52867 × HEL 65]-17 had high tuber yield and high level of stem rot resistance. Selection of Jerusalem artichoke genotypes for high yield coupled with resistance to stem rot disease was successful in this study.

ACKNOWLEDGEMENTS

This work was supported by the Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group and the research funding support of Khon Kaen University. Grateful acknowledgement is also made to Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission, through the Food and Functional Food Research Cluster of Khon Kaen University, Thailand and to the Thailand Research Fund for providing financial supports to this research through the Senior Research Scholar Project of Professor Dr. Sanun Jogloy (Project No. RTA 5880003). Acknowledgement is extended to the Thailand Research Fund (IRG 5780003), Khon Kaen University and Faculty of Agriculture, KKU for providing financial support for manuscript preparation activities.

REFERENCES

Bradley CA, Henson RA, Porter PM, LeGare DG, Río del LE, Khot SD (2006). Response of canola cultivars to *Sclerotinia sclerotiorum* in controlled and field environments. *Plant Dis.* 90: 215-219.

Cassells AC, Walsh M (1995). Screening for *Sclerotinia* resistance in *Helianthus tuberosus* L. (Jerusalem artichoke) varieties, lines and somaclones, in the field and in vitro. *Plant Pathol*. 44:428–437.

Davidson MH, Maki KC (1999). Effects of dietary inulin on serum lipids. *J. Nutr*. 129: 1474S−1477S.

Farnworth ER. 1993. Fructans in human and animal diets. In: M. Suzuki and N.J. Chatterton, eds., *Science and Technology of fructans*. CRC Press, London. pp 257-272.

Fery RL, Dukes Sr PD (2002). Southern blight (*Sclerotium rolfsii* Sacc.) of cowpea: yield-

loss estimates and sources of resistance. *Crop Prot*. 21: 403-408.

Gaafar AM, Serag El-Din MF, BoudyEA, El-Gazar HH (2010). Extraction conditions of inulin from Jerusalem artichoke tubers and its effects on blood glucose and lipid profile in diabetic rats. *J. Am. Sci*. 6: 36-43.

Garg H, Sivasithamparam K, Banga SS, Barbetti MJ (2008). Cotyledon assay as a rapid and reliable method of screeningfor resistance against *Sclerotinia sclerotiorum* in *Brassica napus* genotypes. *Australas Plant Pathol*. 37:106-111.

Hellwege EM, Czapla S, Jahnke A, Willmitzer L, Heyer AG (2000). Transgenic potato (*Solanum tuberosum*) tubers synthesize the full spectrum of inulin molecules naturally occurring in globe artichoke (*Cynaras colymus*) roots. *PNAS*. 97: 8699–8704.

Hoshmand AR (2006). Design of experiments for agriculture and the natural sciences. Chapman & Hall, Florida.

Junsopa C, Jogloy S, Saksirirat W, Songsri P, Kesmala T, Shew BB, Patanothai A (2016). Inoculation with *Sclerotium rolfsii*, cause of stem rot in Jerusalem artichoke, under field conditions. *Eur. J. Plant Pathol*. 146: 47-58.

Kwon JH, Jee HJ, Park CS (2008). Occurrence of bulbrot of *Allium victorialis* var. *platyphyllum* caused by *Sclerotium rolfsii* in Korea. *Plant Pathol. J.* 24(1): 90-92.

McCarter SM, Kays SJ (1984). Disease limiting production of Jerusalem artichokes in Georgia. *Plant Dis*. 68: 299-302.

Niness KR (1999). Inulin and Oligofructose: What Are They? *J. Nutr*. 129: 1402S-1406S.

Pimsaen W, Jogloy S, Suriharn B, Kesmala T, Pensuk V, Patanothai A (2010). Genotype by environment interaction for yield components of Jerusalem artichoke. *Asian J. Plant Sci*. 9: 11-19.

Puangbut D, Jogyloy S,Vorasoot N, Patanothai A (2015a). Growth and phenology of Jerusalem artichoke (*Helianthus tuberosus* L.). *Pak. J. Bot*. 47: 2207-2214.

Paungbut D, Jogloy S, Vorasoot N, Patanothai A (2015b). Responses of growth, physiological traits and tuber yield in *Helianthus tuberosus* to seasonal variations under tropical area. *Sci. Hortic*. 195: 108-115.

Puttha R, Jogloy S, Wangsomnuk PP, Srijaranai S, Kesmala T, Patanothai A. (2012). Genotypic variability and genotype by environment interactions for inulin content of Jerusalem artichoke germplasm. *Euphytica* 183: 119-131.

Roberfroid MB (2005). Introducing inulin-type fructans. *Brit. J. Nutr*. 93: 13S-25S.

Roberfroid MB (2007). Prebiotics: the concept revisited. *J. Nutr*. 137: 830S–837S.

Rumessen JJ, Bodé S, Hamberg O, Gudmand-Høyer E (1990). Fructans of Jerusalem artichokes: intestinal transport, absorption, fermentation, and influence on blood glucose, insulin, and C-peptide responses in healthy subjects. *Am. J. Clin. Nutr*. 52: 675-681.

Ruttanaprasert R, Jogloy S, Vorasoot N, Kesmala T, Kanwar RS, Holbrook CC, Patanothai A (2013). Photoperiod and growing degree days effect on dry matter partitioning in Jerusalem artichoke. *Int. J. Plant Prod*. 7(3): 393-419.

Sennoi R, Jogloy S, Saksirirat W, Patanothai A (2010). Pathogenicity test of *Sclerotium rolfsii*, a causal agent of Jerusalem artichoke (*Helianthus tuberosus* L.) stem rot. *Asian J. Plant Sci*. 95:281–284.

Sennoi R, Jogloy S, Saksirirat W, Kesmala T, Singkham W, Patanothai A (2012). Levels of *Sclerotium rolfsii* inoculum influence identification of resistant genotypes in Jerusalem artichoke. *Afr. J. Microbiol. Res*. 6(38): 6755-6760.

Sennoi R, Singkham N, Jogloy S, Boonlue S, Saksirirat W, Kesmala T, Patanothai A (2013a). Biological control of southern stem rot caused by *Sclerotium rolfsii* using *Trichoderma harzianum* and *Arbuscular mycorrhizal* fungi on Jerusalem artichoke. (*Helianthus tuberosus* L.). *Crop Prot*. 54: 148-153.

Sennoi R, Jogloy S, Saksirirat W, Banterng P, Kesmala T, Patanothai A (2013b). Evaluation of seedling and adult plant stages resistance to *Sclerotium rolfsii* Sacc. In Jerusalem artichoke (*Helianthus tuberosus* L.). *SABRAO J. Breed. Genet.* 45(2): 324-331.

Sennoi R, Jogloy S, Saksirirat W, Kesmala T, Patanothai A (2013c). Genotypic variation of resistance to southern stem rot of Jerusalem artichoke caused by *Sclerotium rolfsii. Euphytica* 190: 415-424.

Shokes FM, Rozalski K, Gorbet DW, Brenneman TB, Berger DA (1996). Techniques for inoculation of peanut with *Sclerotium rolfsii* in the greenhouse and field. *Peanut Sci*. 23: 124-128.