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GENOTYPIC VARIABILITY OF YIELD COMPONENTS AND CROP MATURITY IN JERUSALEM ARTICHOKE GERMPLASM

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SUMMARY

The study of genetic diversity of germplasm is the first priority for genetic improvement of crop species, but the information on genetic diversity for traits related to yield is limited in Jerusalem artichoke. The objectives of this study were to determine genetic variations in tuber number per plant, tuber size, tuber width, tuber length and days to maturity in Jerusalem artichoke genotypes and to identify superior genotypes for these characters under different water regimes. A strip-plot design with 4 replications for 2 years was used in this study. Three water treatments were assigned as factor A (W1 = 100%, W2 = 75% and W3 = 45% of the crop water requirement) and forty Jerusalem artichoke genotypes were assigned as factor B. Data were recorded for tuber number per plant tuber size, tuber width, tuber length, days to maturity and plant height. The differences among water regimes and Jerusalem artichoke genotypes were significant for all characters. Genotypes contributed to the largest portions of total variations in most characters except for tuber length. The genotypes with high tuber number per plant in all drought levels and years were JA92, HEL246 and JA15, whereas HEL65, HEL231, HEL53 and JA89 had a high tuber width across water regimes and years. JA70, JA 36, JA 46, HEL 65 and JA 97 had high performance for the tuber length across water regimes and years, whereas HEL65, JA76, HEL253, HEL53, HEL62, HEL231 and HEL335 had high performance for tuber size across water regimes and years. These genotypes should be useful in future breeding programs for drought tolerance.

Key words: *Helianthus tuberusus* L., tuber size, water stress**,** drought tolerant**,** diversity

Key findings: Genotypic variability of yield components in Jerusalem artichoke germplasm under different water levels.

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INTRODUCTION

Non-communicable diseases such as obesity, diabetes, cardiovascular disease, immune system, blood cholesterol and cancer have been recognized as important global issue (Kays and Nottingham, 2008). Functional food with health beneficial phytochemicals can reduce risk of these health problems. Jerusalem artichoke (*Helianthus tuberosus* L.) is an inulin containing crop (55.0-85.5%) that can serve this purpose to reduce the risk of non-communicable diseases (Puangbut *et al*., 2015; Aduldecha *et al*., 2016) as it can be used for supplementing various value-added, health and functional foods. (Baldini *et al*., 2011; Roberfroid, 2000; Kay and Nottingham, 2008). In addition, Jerusalem artichoke can substitute for some antibiotics in animal feed, and also used in bio-fermentation for ethanol production.

Large size of tubers is favorable for the newly released cultivars and large tubers gain higher price than small tuber. Hence, larger tubers may be desirable even if total yield is lower (Pimsaen *et al*., 2010). Drought stress is an important limiting factor in crop growth and yield (Efeoglu *et al*., 2009). Production of Jerusalem artichoke in many parts of the world is under rain-fed conditions where drought is a common problem because of low rainfall and uneven rain distribution. In temperate regions, drought stress could cause tuber loss of 20-22% (Conde *et al*., 1991; Losavio *et al*., 1997; Schittenhelm, 1999).

In tropical regions, drought stress reduced Jerusalem artichoke tubers by 29.0-98.2% under moderate and severe drought conditions (Ruttanaprasert *et al.*, 2014; Ruttanaprasert *et al*., 2016). Water stress also reduced leaf area, specific leaf area, tuber dry matter, total biomass and tuber size of Jerusalem artichoke (Conde *et al*., 1991; Losavio *et al*., 1997; Schittenhelm, 1999; Rattanaprasert *et al*., 2014; Rattanaprasert *et al.*, 2016). Irrigation is a means to solve the drought problem, but water resources are scarce and high investment is necessary. Development of tolerant genotypes would be the better alternative to combat drought problem and sustain crop productivity under water limited conditions. This breeding goal can be achieved through screening of large germplasm collections and identification of superior genotypes.

Tuber yield and yield components are important traits in determining productivity. Water stress affects tuberization, stolonnization and plant maturity in tuber crops. During the period of tuber and stolon formation, the plants are very sensitive to water stress, and number of tubers, quality and economic yield are greatly reduced (Losavio *et al*., 1997; Schittenhelm, 1999; Ruttanaprasert *et al.*, 2016). Drought at early growth stages prolongs the maturation process and the delay of maturity plays an important role in the drought resistance mechanism. Drought at later growth stages accelerates the maturation process and rapid maturity to complete life cycle is a mechanism of drought escape.

Previous studies on days to maturity, tuber size and yield components under well watered and drought conditions so far have been limited to few Jerusalem artichoke genotypes (Conde *et al*., 1991; Losavio *et al*., 1997; Schittenhelm, 1999). Large germplasm collections have not been screened for drought resistant genotypes. The knowledge of the response of Jerusalem artichoke gemplasm to water stress is important for selection of Jerusalem artichoke with good performance under water stress conditions. Therefore, our objective in this experiment were to evaluate a large number of Jerusalem artichjoke germplasm under drought stress, for maturity and yield components and to identify superior genotypes for these characters under different water regimes.

MATERIALS AND METHODS

Plant materials and field preparation

Forty Jerusalem artichoke genotypes with differences in yield and agronomic traits and from diverse sources of origin were selected for this study (Table 1**)**. To prepare the sprouted seed tubers, the tubers were cut into small pieces to 2-3 buds each and tuber price were immersed in water containing fungicide (Carboximide) at the ratio of 1 g per 2L of water. The tuber pieces were then incubated for 4-7 days to stimulate

Table 1. Forty genotypes of Jerusalem artichoke used in the experiment, their characteristics and sources of origin.

Genotypes	Characteristics	Sources of origin
JA 1 , JA 4, JA 6, JA 36, JA 70, JA 92, JA 114	early, short plant and low biomass	PGRC[1], Canada
JA3, JA 16, JA 21, JA 37, JA 38, JA 97, JA 132	early, short plant and high biomass	PGRC, Canada
JA 5, JA 122	early, tall plant and low biomass	PGRC, Canada
HEL 324	early, tall plant and low biomass	IPK[2], Germany
HEL 53, HEL 61, HEL 231, HEL 335	early, tall plant and high biomass	IPK, Germany
CN 52867	early, tall plant and high biomass	PGRC, Canada
KKUAc001	early, tall plant and high biomass	
JA 61	early, tall plant and high biomass	PGRC, Canada
JA 46, JA 60, JA 109	late, short plant and low biomass	PGRC, Canada
JA 76, JA 77	late, short plant and high biomass	PGRC, Canada
HEL 62	late, short plant and high biomass	IPK, Germany
HEL 246, HEL 257	late, tall plant and low biomass	IPK, Germany
JA 15, JA 67, JA 125	late, tall plant and high biomass	PGRC, Canada
JA 89	late, tall plant and high biomass	PGRC, Canada
HEL 65, HEL 253, HEL 256	late, tall plant and high biomass	IPK, Germany
JA102×JA89(8)	late, tall plant and high biomass	Jerusalem Artichoke Research Project[3]

[1]The Plant Gene Resource of Canada (PGRC).
[2]The Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) of Germany.
[3]Jerusalem artichoke Research Project, Thailand.

germination in charred rice husks with *Trichoderma* spp. (1:1 v/v) and transferred into plug trays containing a mixture of soil, burn rice husk and *Trichoderma* spp. at the ratio of 3:2:2 v/v. Trichoderma was inoculated into the soil to control stem rot disease caused by *Sclerotium rolfsii*. Water was supplied uniformly to the seedlings for 7-10 days or until the seedlings had 2-3 leaves, and then the pre-spouted seedlings was used in the experiment.

The soil hard pan was broken using a sub-soiler to a depth of 60 cm and then the field was tilled twice. A line source sprinkler system was installed to supply three water gradients, which were assigned as W1, W2 and W3, respectively. W1 was the full crop water requirement and water gradients supplied to the plot at W2 and W3 were 75% and 45% of crop water requirement, respectively. The amounts of water applied to the crop at all water treatments were measured by catch cans (24 cans for each water regime). An aluminum access tube was installed in the middle of each water treatment of the plot border to measure changes in soil moisture.

Experimental procedures and crop management

The experimental field site was at the Field Crop Research Station of Khon Kaen University, Khon Kaen Province, Thailand (latitude 16˚28´ N, longitude 102˚48´ E, 200 m above sea level) in the dry season for 2 years. The soil type is Yasothon Series (loamy sand in 2010/11 and sand in 2011/12) as shown in Table 2. The experimental design was a strip-plot, with the strips consisting of three irrigation levels created by line source sprinkler irrigation system (Hank *et al*., 1976). The 40 Jerusalem artichoke genotypes were assigned randomly within the strips.

Plot size was 2 x 4 m in both years with a spacing of 50 cm between rows and 10 cm between hills within the row. From transplanting to 10 days after planting (DAT), water was supplied by drip irrigation at field capacity (FC) level at the depth 10 cm for good and uniform establishment of the crop. Replanting was done within a week after transplanting, using spouted seed tubers of the same age. Manual weeding was done as needed, and mixed fertilizer of N-P_2O_5-K_2O (15-15-15) at the rate of 156.25 kg ha^{-1}

Table 2. Soil physical and chemical properties in the experimental fields at the depth 0-30 cm.

Chemical and physical properties	2010/11	2011/12
Chemical properties (USDA system)[1/]		
Sand (%)	85.08	90.29
Silt (%)	7.30	8.05
Clay (%)	7.62	1.66
Physical properties		
pH (1:1 H_2O)	6.08	6.12
Organic matter (%)	0.44	0.42
Total N (%)	0.02	0.01
Available phosphorus (mg kg^{-1})	23.95	37.83
Exchangeable potassium (mg kg^{-1})	33.09	37.83
Electrical conductivity (EC., dS/m) (1:5 H_2O)	0.03	0.02
Cation exchange capacity (CEC) (c mol kg^{-1})	5.22	5.93
Exchangeable Ca (mg kg^{-1})	418.33	448.75
Texture class	Loamy sand	Sand

was applied over the trial at 30 DAT. No pesticide and insecticide was applied throughout the trial.

After 14 DAT, water gradients were supplied to the crop using line source sprinkler system until harvest. The amount of crop water requirement (ETcrop) for W1 was calculated as described by Doorenbos and Pruitt (1992):

$$ETcrop = ETo \times Kc$$

Where ETcrop is a crop water requirement (mm/day), ETo is evapotranspiration of a reference plant under specified conditions calculated by pan evaporation method and Kc is the crop water requirement coefficient which varies on growth stage. The crop water requirement coefficient of Jerusalem artichoke was not available in literature, so the crop water requirement coefficient for sunflower was used for calculation (Janket *et al*., 2013; Ruttanaprasert *et al*., 2016).

Data collection

Meteorological data

Data were recorded daily for evaporation (E_0), maximum and minimum temperatures, rainfall and relative humidity (RH) from transplanting to harvest using a weather station located 100 m away from the experimental field.

Plant water status and soil moisture content

Relative water content (RWC) was evaluated at 40, 60 and 70 DAT based on the method of Krammer (1980). RWC was measured using the second or third expanded leaves from the top of the main stem and 5 plants per plot. The leaf was cut with a disc borer with 1 cm^2 in leaf area, and leaf fresh weight was determined. The leaf disces were put in dH_2O for 8 h, and then turgid weight determined. The leaf disces were then oven-dried at 80˚C for 48 h or until weight were constant, and leaf dry weight was determined. Relative water content was calculated as:

$$RWC = \frac{FW\text{-}DW}{TW\text{-}DW} \times 100$$

Where FW: sample fresh weight, TW: sample turgid weight and DW: sample dry weight.

Soil moisture was measured by gravimetric method at 14 DAT and harvest at the depth of 30, 60 and 90 cm for both years. The soil sample was taken from each plot using a soil sampler through the whole column and then the soil wet weight was recorded. The soil samples were oven-dried at 105˚C for 72 h or until weight were constant, and the moisture percentage was calculated. Soil moisture volume fraction was also measured at weekly intervals throughout the course of the experiment at the depths of 30, 60 and 90 cm using a neutron probe (Type I.H. II SER. No NO152, Ambe Diccot Instruments Co., Ltd., England) for each water regime in a replication.

Measurements of plant height and crop maturity of Jerusalem artichoke

Plant height was measured at 40, 60, 70 DAT and harvest from the bases of the main stems to the highest nodes of the same 5 plants in each plot throughout the course of the experiment using a meter ruler. The crop maturity date was calculated from the first day of transplanting until the crop reached harvest maturity. The plants were harvested at maturity, which was determined by leaf senescence of 50% from each plot and stem browning.

Measurements of yield and yield components of Jerusalem artichoke

Yield and yield components, including tuber size (weight of individual tubers), number of tubers per plant and individual tuber fresh weigh were determined at harvest. Fourteen bordered plants in an area of 2.1 m^2 were harvested. Tubers were washed in tap water to remove adhering soil. Tuber fresh weight was recorded and the fresh weights of the samples were converted to fresh weight of one tuber. Number of tubers per plant was counted and the total number of tubers was averaged and reported on per plant basis. Tuber diameter was measured from 10 tubers from each plot using vernier caliper (mm) and tuber length was measured using a ruler (cm).

Statistical analysis

Data were represented as mean ± standard deviation (SD) of 4 replicated and graphical presentation was performed using Microsoft Excel 2007. Analysis of variance was performed for each character followed a strip plot design (Gomez and Gomez, 1984) using statistix 8 (Statistix8, 2003). Combined analysis of variance was performed for all characters with variance homogeneity. Significant differences were compared by Duncan's multiple range test (DMRT) using MSTAT-C package (Freed and Nissen, 1992). All analyses were performed at the $P \leq 0.05$ level.

Cluster analysis

A data matrix of the 40 genotypes of Jerusalem artichoke was constructed using the means of yield, yield components and days to maturity. The cluster analysis based on Ward's method and squared Euclidian distance was performed and the dendrogram was constructed. All calculations were performed with SAS 6.12 software (SAS, 2001).

RESULTS

Meteorological conditions

The meteorological data are shown in Figure 1. Maximum and minimum air temperatures (T-min and T-min) were slightly different among years. Mean of T-min and T-max were 18.4 and 30.3˚C and 19.5 and 30.5˚C in the first and the second years, respectively. Daily pan evaporation ranged from 2.0 to 7.7 mm in the first year and 2.2 to 9.8 mm in the second year. The relative humidity values in the first and second years ranged from 69 to 98% and 71 to 99%, respectively. There was no rainfall in 2010/11 but rainfall of 174.6 mm was recorded in 2011/12 at 1-6 days after transplanting (DAT). The rainfall resulted in a better crop establishment in second year. However, the rainfall did not cause significant differences among water treatments because it occurred during the pre-treatment period when all water treatments received the same amount of water.

Soil moisture and plant water status

Water regimes (W1–W3) were clearly different in soil moisture content at the soil depth of 30 cm, starting 21 DAT after the commencement of drought. The differences in soil moisture content among water regimes were highest in the top soil and lower in the sub soil (Figure 2). W1 water gradient was slightly lower than field capacity. However, W1 was higher than W2 and W2 was higher than W3.

Water regimes were also different for relative water contents (RWC) at 40, 60 and 70 DAT (Table 3). W1 was higher than W2 across sampling times and years, whereas W2 was higher than W3. The results indicated that the soil moisture treatments resulted in clear plant water status differences.

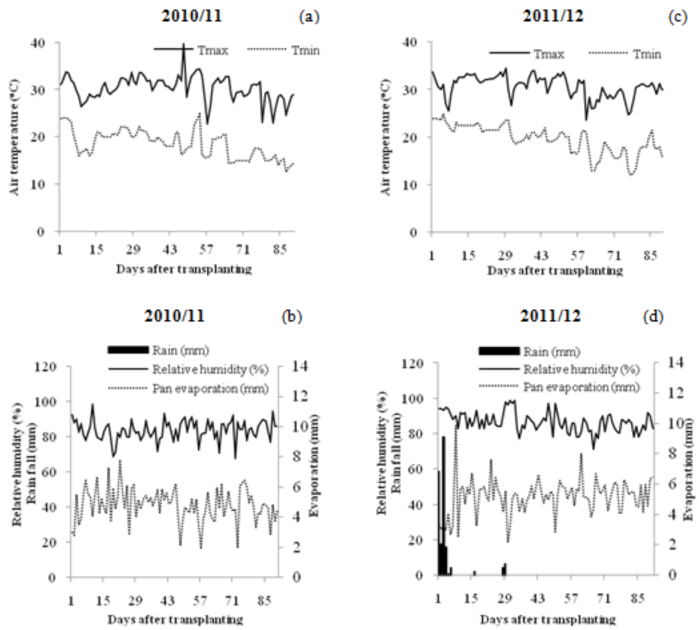

Figure 1. Maximum temperatures (T-max), minimum air temperatures (T-min) (˚C) and rainfall (mm), pan evaporation (mm), relative humidity (%) during the crop growth period of 40 Jerusalem artichoke genotypes in 2010/11 (a and b) and 2011/12 season (c and d), respectively.

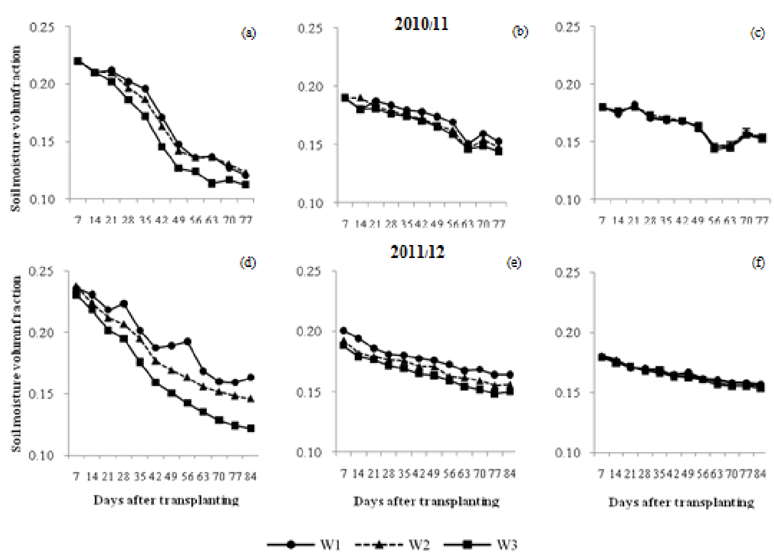

Figure 2. Soil moisture volume fractions for three soil water regimes of three soil depths at 30 cm (a and d), 60 cm (b and e) and 90 cm (c and f) in the dry seasons 2010/11 and 2011/12.

Table 3. Relative water content (%) at 40, 60 and 70 days after transplanting (DAT) of 40 Jerusalem artichoke genotypes grown under different water regimes in the dry season 2010/11 and 2011/12.

Water regimes	Relative water content (%) in 2010/11			Relative water content (%) in 2011/12		
	40 DAT	60 DAT	70 DAT	40 DAT	60 DAT	70 DAT
W1	78.9±0.6 a	78.9±0.6 a	74.3±0.9 a	86.1±0.5 a	86.1±0.6 a	77.9±0.6 a
W2	75.0±0.6 b	71.1±0.6 b	64.9±0.7 b	80.6±0.4 b	78.0±0.7 b	69.9±0.7 b
W3	73.1±0.6 c	64.7±0.7 c	57.8±0.6 c	76.0±0.5 c	70.3±0.8 c	61.8±0.8 c

Means in the same column followed by the same letter(s) are not significantly different at $P < 0.05$ probability levels by Duncan's multiple range test (DMRT). Date are presented means ±SD (n=4). W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop.

Combined analysis of variance

Water regime (W) and Jerusalem artichoke genotype (G) were significantly different in tuber number per plant, tuber width, tuber length, tuber size and days to maturity (Table 4). Genotypes contributed to large portions of total variations for tuber number (39.1%), tuber width (52.3%), tuber length (24.7%), tuber size (55.8%) and days to maturity (55.0%). Water regime was also a rather large source of the total variation in tuber length (35.2%), tuber number (11.7%), tuber width (9.8%) and tuber size (18.8%). However, the differences among water regimes for days to maturity were low, accounting for only 2.4% of the total variation. Years were significantly different for most characters except for tuber length and tuber size, and accounted for small percentages of variations in all traits (0.0–12.3%). The interactions between sources of variations contributed to small portions of total variations for all characters (tuber number per plant, tuber width, tuber length, tuber size and days to maturity), ranging from 0.1-0.7% of the interaction between year and water regime and ranging from 1.9-12.8% for interaction between year and genotype and ranging from 1.7-5.0% for interaction between water and genotype. The interaction effects were lower than main effects (genotypes and water regime) for these traits. As the interactions between genotype and year and interaction between genotype and water regime were significant for all traits, data were analyzed for separate years and water regimes.

Genotypic variation and response of Jerusalem artichoke to water regimes

Plant height

Drought reduced plant height in both years and the differences were found among three water regimes at 40, 60, 70 DAT and harvest. Height for W1 was higher than those for W2 at all sampling dates, whereas W2 was higher than those for W3 (Figure 3). In 2010/11, the ranges of plant height under W1, W2 and W3 varied from 24.3 to 79.8 cm, 17.6 to 78.0 cm and 15.0 to 69.0 cm, respectively. In 2011/12, the ranges of plant height under W1, W2 and W3 varied from 32.5 to 112.6 cm, 24.8 100.2 cm and 20.2 to 83.6 cm, respectively.

JA89, HEL65, HEL246, HEL53, HEL256, KKUAc001, JA102 X JA89 (8), HEL 253, HEL 231 and JA 15 had consistently the tallest plants across water regimes in 2010/11. Most genotypes with the tallest plants in 2010/11 also had the tallest plants in 2011/12 except for JA15 showing tallest plants in 2010/11 only and HEL 61 showing tallest plant in 2011/12 only (data not shown).

Tuber number per plant

The genotypes with high tuber in 2010/11 under W1, W2 and W3 ranged from 6.75 to 23.00 tubers per plant, 7.00 to 19.00 tubers per plant and 6.25 to 19.75 tubers per plant, respectively (Table 5). In 2011/12, the means under W1, W2 and W3 ranged from 8.55 to 33.11 tubers per plant, 8.02 to 25.63 tubers per plant and 6.65 to

Table 4. Mean squares for individual tuber yield and yield components of 40 Jerusalem artichoke genotypes grown under 3 water regimes (W1,W2 and W3) in the dry seasons 2010/11 and 2011/12.

Source of variation	DF	Mean square				
		Tuber number plant^{-1}	Tuber wide (cm)	Tuber length (cm)	Tuber size (g tuber^{-1})	Days to maturity
Year (Y)	1	1412.9 (5.1)*	20.986(12.3)**	0.122 (0.0)^{ns}	454.86 (2.0)^{ns}	926.3 (5.9)*
Rep within Year	6	128.4 (2.8)	0.401 (1.4)	9.138 (3.8)	125.53 (3.3)	123.2 (4.7)
Water regimes (W)	2	1637.3 (11.7)**	8.331 (9.8)**	252.311(35.2)**	2150.21 (18.8)**	186.8 (2.4)**
Y×W	2	102.3 (0.7)**	0.571 (0.7)**	1.634 (0.2)^{ns}	43.49 (0.4)^{ns}	9.8 (0.1)^{ns}
Error (a)	12	8.3 (0.4)	0.034 (0.2)	3.449 (2.9)	12.78 (0.7)	8.8 (0.7)
Genotypes (G)	39	280.6 (39.1)**	2.283 (52.3)**	9.066 (24.7)**	327.58 (55.8)**	222.5 (55.0)**
Y×G	39	91.5 (12.8)**	0.148 (3.4)**	1.359 (3.7)**	11.23 (1.9)**	19.7 (4.9)*
Error (b)	234	15.4 (12.9)	0.063 (8.7)	0.754 (12.3)	6.52 (6.7)	12.5 (18.6)
W×G	78	16.9 (4.7)**	0.052 (2.4)**	0.784 (4.3)**	14.54 (5.0)**	3.5 (1.7)**
Y×W×G	78	8.3 (2.3)**	0.039 (1.8)**	0.360 (2.0)^{ns}	3.44 (1.2)**	1.7 (0.9)^{ns}
Error (c)	468	4.5 (7.6)	0.025 (7.0)	0.335 (10.9)	2.13 (4.3)	1.8 (5.3)
CV (%) (a)		21.4	9.44	36.09	37.35	3.78
CV (%) (b)		29.11	12.93	16.87	26.68	4.51
CV (%) (c)		15.8	8.18	11.24	15.23	1.71

ns, *, ** = non-significant and significant at $P < 0.05$ and $P < 0.01$ probability levels, respectively, Number within the parentheses are percentages of sum squares. W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop.

Table 5. Ten selected genotypes with the highest performance for tuber number and days to maturity and 10 selected genotypes with the lowest performance for these selected from 40 Jerusalem artichoke genotypes in the dry season 2010/11.

Group	No.	Genotypes	Tuber number plant^{-1}			Genotypes	Days to maturity (days)		
			W1	W2	W3		W1	W2	W3
High	1	HEL 256	23.00 a	17.50 a-d	19.75 a	HEL 62	85.7 a	84.3 a	84.3 a
	2	JA 92	22.75 ab	13.50 e-k	12.75 d-g	HEL 246	81.2 b	79.3 bcd	77.8 b-f
	3	HEL 246	21.50 abc	17.00 a-e	11.75 d-i	JA 125	81.0 bc	80.5 b	80.5 ab
	4	JA 15	20.00 a-d	18.00 abc	11.50 e-j	KKUAc001	80.7 bc	80.3 b	80.5 ab
	5	HEL 257	19.50 a-e	13.25 e-k	11.50 e-j	JA 77	80.5 bcd	80.3 b	80.3 abc
	6	JA 46	18.75 a-f	11.75 h-n	10.25 e-m	HEL 257	80.5 bcd	80.0 bc	80.0 abc
	7	JA102XJA89 (8)	18.50 a-f	19.00 a	19.75 a	JA 67	80.5 bcd	80.0 bc	80.0 abc
	8	JA 5	18.00 b-f	10.50 j-p	8.00 i-n	HEL 253	80.5 bcd	78.0 b-g	77.8 b-f
	9	JA 6	18.00 c-g	11.00 i-o	8.25 i-n	HEL 256	80.5 bcd	77.3 b-i	76.5 d-i
	10	CN52867	17.00 c-g	18.75 ab	17.25 abc	JA 132	80.0 bcd	77.3 b-i	77.3 c-h
Low	1	JA 1	6.75 r	10.75 i-p	9.75 e-n	JA 16	72.3 j	74.0 i-l	74.0 i-l
	2	HEL 62	7.75 qr	8.25 m-p	6.50 mn	JA 6	72.8 j	72.3 l	72.3 kl
	3	JA 76	8.75 pqr	8.00 nop	6.25 n	JA 36	73.3 ij	73.0 kl	73.0 jkl
	4	JA 61	8.75 pqr	12.75 g-k	12.25 d-h	HEL 324	73.5 ij	76.5 d-j	76.5 d-i
	5	HEL 324	9.00 o-r	7.00 p	7.50 k-n	JA 3	73.8 ij	73.3 jkl	73.3 jkl
	6	JA 21	9.00 o-r	11.50 h-n	9.75 e-n	JA 89	74.5 hij	74.8 g-l	74.5 g-l
	7	HEL 65	9.25 n-r	8.75 l-m	9.25 g-n	JA 21	74.8 g-j	75.5 f-l	75.5 f-j
	8	JA 122	9.50 n-r	10.75 i-p	10.50 e-l	JA 70	75.3 f-j	74.3 h-l	74.3 h-l
	9	HEL 231	10.25 m-r	8.75 l-m	8.75 h-n	CN 52867	75.5 f-j	73.0 kl	72.8 jkl
	10	KKUAc001	10.25 m-r	14.50 c-i	8.25 i-n	JA 15	75.5 f-j	75.8 e-k	75.8 e-j
Max			23.00	19.00	19.75		85.7	84.3	84.3
Min			6.75	7.00	6.25		72.3	72.3	72.3
Mean			13.85	12.56	10.98		78.3	77.0	76.9
F-test			**	**	**		**	**	**

Maximum, minimum and mean values were calculated from 40 genotypes, Means in the same column followed by the same letter(s) are not significantly different at $P < 0.05$ probability levels by Duncan's multiple range test (DMRT). W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop; ** Significant at $P < 0.01$ probability level.

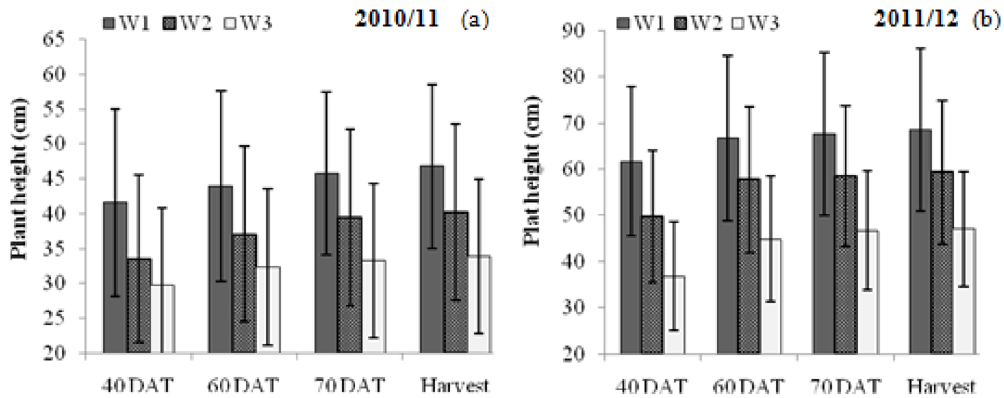

Figure 3. Plant height (cm) under three water regimes at 40, 60, 90 days after transplanting (DAT) and harvest of 40 Jerusalem artichoke genotypes in the dry seasons 2010/11(a) and 2011/12 (b)**.**

22.23 tubers per plant, respectively (Table 6). The top-ten genotypes for tuber numbers per plant under fully-irrigated condition in 2010/11 were HEL256, JA92, HEL246, JA15 HEL257, JA46, JA102xJA89 (8), JA5, JA6 and CN52867, whereas HEL256, JA 92, HEL246, JA15 HEL257, JA102xJA89 (8) and CN52867 had consistently high number of tubers across water regimes. In 2011/12, JA92, JA15, JA114, JA46, JA4, JA97, JA109, JA38, JA3 and HEL 246 had high tuber number under W1, and, among these genotypes, JA92, JA15, JA114, JA4, JA97, JA38, JA 3 and HEL246 had a high tuber number across water regimes. Five genotypes (JA92, HEL246, JA15, HEL 246 and JA46) showed consistently high performance for tuber numbers per plant across years under well-watered conditions. However, JA92, HEL246 and JA15 showed consistently high number of tubers per plant across water regimes and years.

Tuber size

Water regimes and Jerusalem artichoke genotypes were significantly different for tuber size. Means of tuber size under W1, W2 and W3 in 2010/11 ranged from 5.30 to 25.80 g per tuber, 4.03 to 19.28 g per tuber and 2.35 to 14.70 g per tuber, respectively (Table 7), whereas the means under W1, W2 and W3 in 2011/12 ranged from 5.84 to 25.52 g per tuber, 5.19 to 23.06 g per tuber and 3.98 to 14.86 g per tuber, respectively (Table 8). Well-irrigated treatment had the highest tuber yield, and HEL65, HEL53, JA76, HEL231, KKUAc001, JA89, JA122, HEL253, HEL62 and HEL 335 had the biggest tubers in 2010/11. Most genotypes showing high tuber weight under fully irrigated condition also had large tuber size across water regimes except for KKUAc001 that had large tuber size under W1 only. In 2011/12, the top-ten genotypes with the biggest tubers under well-watered condition were HEL65, JA76, HEL253, HEL53, HEL62, HEL231, HEL324, HEL61, HEL335 and KKUAc001. Most genotypes showing biggest tubers under fully irrigated condition also had large tubers across water regimes except for HEL324 and KKUAc001 with high tuber weight under W1 only.

HEL65, JA76, HEL253, HEL53, HEL62, HEL231, HEL335 and KKUAc001 had consistently large tubers under W1 across the years. However, only 7 genotypes (HEL65, JA76, HEL253, HEL53, HEL62, HEL231 and HEL335) had consistently large tubers across water regimes and years.

Tuber shape

Drought stress significantly reduced tuber length and tuber width. In 2010/11, the values of tuber width ranging from 1.190 to 2.760 cm, 1.185 to

Table 6. Ten selected genotypes with the highest performance for tuber number and days to maturity and 10 selected genotypes with the lowest performance for these selected from 40 Jerusalem artichoke genotypes in the dry season 2011/12.

Group	No.	Genotypes	Tuber number plant^{-1}			Genotypes	Days to maturity (days)		
			W1	W2	W3		W1	W2	W3
High	1	JA 92	33.11 a	25.59 a	17.06 b	HEL 62	88.0 a	85.5 ab	84.8 ab
	2	JA 15	29.09 ab	25.63 a	22.23 a	HEL 65	86.8 ab	85.3 abc	84.5 ab
	3	JA 114	26.00 bc	22.52 ab	16.93 bc	HEL 256	86.0 abc	86.0 a	85.0 a
	4	JA 46	25.72 bc	19.29 b-e	12.31 d-l	HEL 253	85.0 a-d	84.3 a-e	82.8 abc
	5	JA 4	24.62 cd	18.22 c-g	14.70 b-e	HEL 335	84.5 b-e	84.5 a-d	82.0 a-e
	6	JA 97	23.41 cde	19.32 bcd	14.13 b-f	JA 132	84.0 b-f	82.3 c-h	82.3 a-d
	7	JA 109	22.80 c-f	17.73 c-g	12.13 d-l	JA 67	84.0 b-f	83.5 a-f	82.0 a-e
	8	JA 38	21.75 c-g	17.70 c-g	14.00 b-f	JA102XJA89 (8)	84.0 b-f	79.8 g-n	79.8 c-k
	9	JA 3	21.20 d-h	18.63 c-f	16.86 bc	JA 1	83.5 b-g	81.3 e-j	79.3 d-k
	10	HEL 246	21.02 d-i	20.30 bc	15.48 bcd	JA 37	83.5 b-g	82.5 b-g	80.5 c-h
Low	1	HEL 253	8.55 n	8.30 n	7.30 mno	JA 6	73.0 s	73.0 w	72.5 q
	2	HEL 62	8.70 n	8.07 n	7.06 mno	JA 16	74.3 rs	73.5 vw	73.5 pq
	3	HEL 65	9.27 n	8.02 n	6.65 o	JA 36	74.5 qrs	74.5 t-w	74.5 o-p
	4	HEL 61	9.68 n	9.45 mn	6.87 no	JA 122	74.8 qrs	74.3 t-w	74.3 o-p
	5	JA 76	9.79 n	8.91 mn	7.80 mnp	HEL 324	75.5 p-s	73.8 uvw	72.5 q
	6	HEL 53	10.47 n	9.16 mn	8.61 k-o	JA 5	75.8 p-s	75.0 r-w	74.8 o-p
	7	HEL 324	11.05 n	9.48 mn	8.43 l-o	JA 38	76.3 o-s	75.5 q-w	75.5 m-q
	8	KKUAc001	11.55 mn	10.13 lmn	9.04 j-o	CN 52867	77.0 n-r	77.3 m-t	77.3 i-o
	9	JA 67	12.18 lmn	11.47 j-n	8.57 k-o	JA 3	77.0 n-r	74.8 s-w	74.8 o-p
	10	HEL 335	12.25 lmn	10.88 lmn	8.50 k-o	JA 109	77.3 n-r	77.3 m-t	76.8 k-o
Max			33.11	25.63	22.23		88.0	86.0	85.0
Min			8.55	8.02	6.65		73.0	73.0	72.5
Mean			17.45	14.80	11.81		80.4	79.3	78.5
F-test			**	**	**		**	**	**

Maximum, minimum and mean values were calculated from 40 genotypes, Means in the same column followed by the same letter(s) are not significantly different at $P < 0.05$ probability levels by Duncan's multiple range test (DMRT). W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop; ** Significant at $P < 0.01$ probability level.

2.632 cm and 1.073 to 2.445 cm were observed among Jerusalem artichoke accessions grown under W1, W2 and W3, respectively (Table 7). In 2011/12, values of the tuber width of Jerusalem artichoke accessions grown under W1, W2 and W3 ranged from 1.483 to 3.083 cm, 1.423 to 2.805 cm and 1.310 to 2.500 cm, respectively (Table 8).

HEL65, KKUAc001, HEL53, JA76, HEL231, JA89, HEL253, HEL62, JA132 and HEL61 had a high tuber width under W1, whereas HEL65, KKUAc001, HEL53, JA76, HEL231, JA89, HEL62, JA132 and HEL61 had consistently high tuber width across water regimes. In 2011/12, HEL65, HEL231, HEL53, JA89, HEL335, KKUAc001, JA21, HEL62, JA16 and HEL61 had high tuber width under W1, and, among these genotypes, HEL65, HEL231, HEL53, JA89, HEL335 and JA21 had a high tuber width across water regimes.

Significant differences among Jerusalem artichoke genotypes were also found for tuber length. In 2010/11, the lengths of tubers ranged from 4.638 to 8.370 cm, 3.920 to 6.380 cm and 3.463 to 4.985 cm under W1, W2 and W3, respectively (Table 7), whereas, in 2011/12, the ranges of tuber length were from 4.485 to 8.210, 3.528 to 6.808 and 3.028 to 5.640 under W1, W2 and W3, respectively (Table 8). In 2010/11, JA70, JA36, JA21, JA46, JA97, JA3 JA92, JA6, JA122 and HEL 65 had high tuber length under W1, whereas JA70, JA36, JA46, JA97, JA92 and HEL65 had a high tuber length across water regimes. In 2011/12, JA70, JA36, JA5, JA21, JA46, JA122, HEL65, JA38, HEL62 and JA97 had a high tuber length under W1. Most

Table 7. Ten selected genotypes with the highest performance for tuber width, tuber length and weight of individual tubers and 10 selected genotypes with the lowest performance for these selected from 40 Jerusalem artichoke genotypes in the dry season 2010/11.

Group	No.	Genotypes	Tuber width (cm)			Genotypes	Tuber length (cm)			Genotypes	Tuber size (g tuber^{-1})		
			W1	W2	W3		W1	W2	W3		W1	W2	W3
High	1	HEL 65	2.760 a	2.623 a	2.445 a	JA 70	8.370 a	6.085 abc	4.658 b-h	HEL 65	25.80 a	19.28 a	14.70 a
	2	KKUAc001	2.365 ab	2.098 c	1.695 d-k	JA 36	8.148 a	5.958 a-d	5.380 ab	HEL 53	23.35 ab	17.88 a	11.85 b
	3	HEL 53	2.518 abc	1.948 c-g	1.745 d-j	JA 21	7.253 b	5.128 f-m	3.770 klm	JA 76	21.90 bc	13.55 bc	10.15 bc
	4	JA 76	2.452 bcd	2.083 cd	1.870 c-h	JA 46	6.970 bc	5.645 c-g	4.575 c-j	HEL 231	20.08 c	15.33 b	10.08 bc
	5	HEL 231	2.405 b-e	2.003 cde	1.910 cde	JA 97	6.898 bc	6.380 ab	4.630 b-i	KKUAc001	19.33 cd	10.05 d-g	6.75 d-j
	6	JA 89	2.300 c-f	2.413 ab	1.900 c-f	JA 3	6.853 bcd	5.735 b-f	4.435 d-l	JA 89	17.15 de	11.95 cde	7.60 d-g
	7	HEL 253	2.220 d-g	1.845 d-j	1.605 h-k	JA 92	6.818 b-e	5.593 c-g	4.750 b-f	JA 122	16.98 def	9.83 e-h	7.00 d-h
	8	HEL 62	2.202 d-h	1.813 e-k	1.785 c-j	JA 6	6.680 b-f	5.193 e-l	4.418 d-l	HEL 253	16.80 def	10.78 def	7.00 d-h
	9	JA 132	2.192 d-h	1.953 c-g	1.790 c-j	JA 122	6.610 b-g	4.195 op	3.403 m	HEL 62	16.33 efg	11.05 cde	8.48 cd
	10	HEL 61	2.186 d-h	1.850 d-i	2.035 bc	HEL 65	6.578 b-g	6.493 a	5.045 bcd	HEL 335	16.18 efg	12.50 cd	7.73 def
Low	1	JA 70	1.190 t	1.185 o	1.218 mn	HEL 253	4.638 o	4.723 j-o	4.160 e-m	JA 46	5.30 s	4.78 k-n	3.55 nop
	2	JA 36	1.370 st	1.273 no	1.215 mn	HEL 335	4.728 op	4.443 m-p	3.948 g-m	JA 36	5.68 rs	4.23 lmn	2.35 p
	3	JA 109	1.375 rst	1.458 mn	1.175 mn	JA102XJA89(8)	4.785 nop	4.510 l-p	3.800 klm	JA 70	5.80 qrs	5.68 j-n	4.70 i-o
	4	JA 114	1.450 q-t	1.208 o	1.073 n	JA 4	4.890 m-p	4.390 nop	3.958 g-m	JA 114	6.55 p-s	4.10 mn	3.80 nop
	5	JA 46	1.488 p-s	1.565 lm	1.548 jkl	KKUAc001	4.903 m-p	3.920 p	3.463 m	JA 3	7.33 o-s	4.63 k-n	3.38 op
	6	JA 77	1.568 q-s	1.305 no	1.288 lmn	HEL 61	4.933 l-p	4.870 h-o	4.090 e-m	JA 15	7.98 n-s	4.03 n	3.43 op
	7	JA 60	1.573 q-s	1.573 lm	1.535 jkl	HEL 62	4.965 l-p	4.448 m-p	4.058 e-m	JA 61	8.03 n-s	6.13 i-n	4.95 h-o
	8	HEL 246	1.583 q-s	1.608 j-m	1.555 i-l	HEL 231	5.053 l-p	4.745 i-o	4.320 d-l	JA 77	8.03 n-s	7.30 ij	4.38 k-p
	9	JA 92	1.613 q-s	1.608 j-m	1.608 g-k	JA 77	5.180 k-p	4.328 nop	3.863 i-m	JA 125	8.45 m-r	5.78 j-n	3.98 m-p
	10	JA102XJA89(8)	1.650 o-r	1.848 d-i	1.558 i-l	HEL 53	5.308 j-p	4.530 k-p	3.885 h-m	JA 4	8.60 m-q	6.40 i-n	4.93 h-o
Max			2.760	2.632	2.445		8.370	6.120	4.985		25.80	19.28	14.70
Min			1.190	1.185	1.073		4.638	3.920	3.463		5.30	4.03	2.35
Mean			1.912	1.763	1.420		5.974	5.067	4.220		11.98	9.26	6.53
F-test			**	**	**		**	**	**		**	**	**

Maximum, minimum and mean values were calculated from 40 genotypes, Means in the same column followed by the same letter(s) are not significantly different at $P < 0.05$ probability levels by Duncan's multiple range test (DMRT). W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop.
** Significant at $P < 0.01$ probability level.

Table 8. Ten selected genotypes with the highest performance for tuber width, tuber length and weight of individual tubers and 10 selected genotypes with the lowest performance for these selected from 40 Jerusalem artichoke genotypes in the dry season 2011/12.

Group	No.	Genotypes	Tuber width (cm)			Genotypes	Tuber length (cm)			Genotypes	Tuber size (g tuber^{-1})		
			W1	W2	W3		W1	W2	W3		W1	W2	W3
High	1	HEL 65	3.083 a	2.805 a	2.500 a	JA 70	8.210 a	5.605 b-g	4.533 c-h	HEL 65	25.52 a	23.06 a	14.86a
	2	HEL 231	2.848 ab	2.665 ab	2.395 ab	JA 36	7.795 ab	6.808 a	5.613 a	JA 76	22.34 ab	19.41 b	12.52bc
	3	HEL 53	2.748 bc	2.490 b-e	2.218 a-f	JA 5	7.568 abc	6.218 ab	4.570 c-g	HEL 253	20.81 bc	14.04 cde	12.58bc
	4	JA 89	2.720 bcd	2.565 abc	2.310 a-d	JA 21	7.388 a-d	5.900 a-d	5.640 a	HEL 53	19.92 bc	16.31 c	12.21bcd
	5	HEL 335	2.685 bcd	2.448 b-e	2.185 b-h	JA 46	7.290 a-e	6.203 ab	5.095 abc	HEL 62	19.23 bc	15.14 cd	10.53cde
	6	KKUAc001	2.658 b-e	2.235 e-k	2.030 d-k	JA 122	7.188 a-f	5.753 a-e	4.898 a-e	HEL 231	18.71 cd	14.96 cd	12.55bc
	7	JA 21	2.643 b-f	2.510 bcd	2.355 abc	HEL 65	7.178 a-f	5.563 b-g	4.468 c-h	HEL 324	18.53 cde	12.91 d-g	9.44e-h
	8	HEL 62	2.640 b-f	2.268 d-j	2.135 b-i	JA 38	6.903 a-g	6.220 ab	4.580 b-g	HEL 61	17.91 c-f	14.02 cde	12.77ab
	9	JA 16	2.613 b-f	2.358 c-f	2.003 e-l	HEL 62	6.860 a-g	5.228 b-i	3.840 g-l	HEL 335	17.90 c-f	12.79 d-g	10.03def
	10	HEL 61	2.613 b-f	2.433 b-e	2.195 b-g	JA 97	6.810 a-h	5.640 b-f	5.020 a-d	KKUAc001	15.91 d-g	13.92 cde	8.94e-i
Low	1	JA 70	1.483 q	1.423 r	1.310 t	HEL 53	4.485 q	3.920 klm	3.373 klm	JA 36	5.84 p	5.19 s	3.98p
	2	JA 114	1.678 pq	1.555 qr	1.405 st	JA102XJA89(8)	4.538 pq	3.875 lm	3.423 klm	JA 109	5.92 op	5.69 qrs	4.89n-p
	3	JA 46	1.688 pq	1.563 qr	1.475 p-t	HEL 253	4.553 pq	3.528 m	3.028 m	JA 15	5.95 op	5.76 qrs	5.33m-p
	4	JA 36	1.688 pq	1.530 qr	1.415 rst	KKUAc001	4.740 opq	4.050 j-m	3.433 klm	JA 114	5.98 op	5.60 qrs	4.24op
	5	JA 92	1.910 op	1.743 opq	1.580 n-t	JA 4	4.890 n-q	4.343 i-m	3.663 i-m	JA 70	5.98 op	5.32 rs	3.90p
	6	JA 109	1.915 op	1.583 pqr	1.448 q-t	JA 89	4.978 m-q	4.425 h-m	3.795 h-l	JA 46	6.52 nop	5.80 qrs	4.88n-p
	7	JA 97	1.938 nop	1.843 nop	1.550 o-t	HEL 61	5.110 l-q	4.663 e-l	3.280 lm	JA 92	7.10 m-p	6.23 p-s	5.44m-p
	8	JA 1	1.988 mno	1.885 mno	1.753 k-p	HEL 231	5.220 k-q	4.350 i-m	3.713 i-m	JA 4	8.07 l-p	6.68 o-s	6.28k-o
	9	HEL 246	2.000 mno	1.870 no	1.448 q-t	JA 132	5.335 j-q	4.550 f-m	4.070 f-k	JA 61	8.32 l-p	7.84 l-r	5.36m-p
	10	JA 37	2.013 l-o	1.903 l-o	1.705 m-r	JA 125	5.378 i-q	4.853 c-l	3.918 g-l	JA 3	8.45 l-p	7.17 n-s	5.73l-p
Max			3.083	2.805	2.500		8.210	6.808	5.640		25.52	23.06	14.86
Min			1.483	1.423	1.310		4.485	3.528	3.028		5.84	5.19	3.90
Mean			2.296	2.103	1.890		6.111	5.097	4.197		12.50	10.29	7.99
F-test			**	**	**		**	**	**		**	**	**

Maximum, minimum and mean values were calculated from 40 genotypes, Means in the same column followed by the same letter(s) are not significantly different at $P < 0.05$ probability levels by Duncan's multiple range test (DMRT).
W1= 100%ETcrop, W2= 75%ETcrop and W3=45%ETcrop.
** Significant at $P < 0.01$ probability level.

genotypes with high tuber length under W1 also had a high tuber length across water regimes except for HEL62 showing high tuber length under well-watered conditions only.

HEL 65, KKUAc001, HEL65, JA89, HEL62 and HEL61 showed consistently high tuber width under well-watered conditions across the years. However, only 4 genotypes (HEL65, HEL231, HEL53 and JA89) showed consistently high tuber width across water regimes and years. JA70, JA36, JA21, JA46, JA97 and HEL 65 had a high tuber length under well-watered conditions across the years, whereas JA70, JA36, JA46, HEL 65 and JA97 showed consistently high tuber length across water regimes.

Days to maturity

Drought stress reduced days to maturity and there was a significant difference in days to maturity among genotypes (Tables 5 and 6). In 2010/11, numbers of days to maturity ranged from 72.3 to 85.7 days, 72.3 to 84.3 days and 72.3 to 84.3 days under W1, W2 and W3, respectively, and, in 2011/12, numbers of days to maturity ranged from 73.0 to 88.0 days, 73.0 to 86.0 days and 72.5 to 85.5 days under W1, W2 and W3, respectively.

In 2010/11, HEL62, HEL246, JA125, KKUAc001, JA77, HEL 257, JA67, HEL253, HEL256 and JA132 had the longest days to mature under W1 (80.0 to 85.7 days), whereas JA16, JA6, JA36, HEL324, JA3, JA89, JA21, JA70, CN52867 and JA15 had the fewest days to mature under W1 (72.3 to 75.5 days).

In 2011/12, HEL62, HEL65, HEL256, HEL253, HEL335, JA132, JA67, JA102xJA89(8), JA1 and JA37 had the longest days to maturity under W1 (83.5 to 88.0 days), whereas JA6, JA16, JA36, JA122, HEL324, JA5, JA38, CN52867, JA3 and JA109 showed the shortest days to maturity under W1 (73.0 to 77.3 days).

Cluster analysis

Based on tuber size, tuber width, tuber length and days to maturity under 2 levels of drought, the dendrogram was able to classify forty Jerusalem artichoke genotypes into 4 groups at the coefficient of determination (R^2) of 0.89 (Figure 4). Cluster 1 had 4 genotypes and this group had a slender-shaped tubers (length) and the smallest tuber width and tuber size. This cluster also had the smallest tubers, late maturity and rather high number of tubers. Cluster 2 consisted of 4 genotypes. This group had oblong-shaped tubers, small tuber width and rather long tubers. This cluster also had rather early maturity and high number of tubers. Cluster 3 consisted of 15 genotypes and this group had oblong-shaped tubers, large-tuber width and short tubers. This cluster also had early maturity, large tubers and rather low numbers of tubers per plant.

Cluster 4 had 17 genotypes and this group had the highest tuber width, the highest tuber length and largest tubers. This group also had late maturity and the lowest number of tubers per plant.

DISCUSSION

Knowledge on the responses of Jerusalem artichoke to water stress for yield and yield components is important for crop breeding and crop management for drought conditions. In this experiment, the soil physicochemical properties were slightly different between years (Table 2). The soil chemical properties in in 2010/11 were lower than in 2011/12 for available phosphorus (P), exchangeable potassium (K), exchangeable calcium (Ca) and pH. The soil chemical properties demonstrated that soil fertility was lower than optimum condition for growth of Jerusalem artichoke. Electrical conductivity values in both years indicated that the soil was not saline (≤0.03 dS/m) (Geng-mao *et al.*, 2008). Potassium was intermediate and nitrogen was not sufficient, whereas phosphorus was sufficient for normal growth and acceptable yield (Lebot, 2009). As soil nutrient values fell into the same ranges and basal dose was applied, the difference in soil fertility between years would not cause significant differences in yield and yield components of Jerusalem artichoke. Relative water content and soil moisture content clearly separated degrees of drought in plant and water regimes.

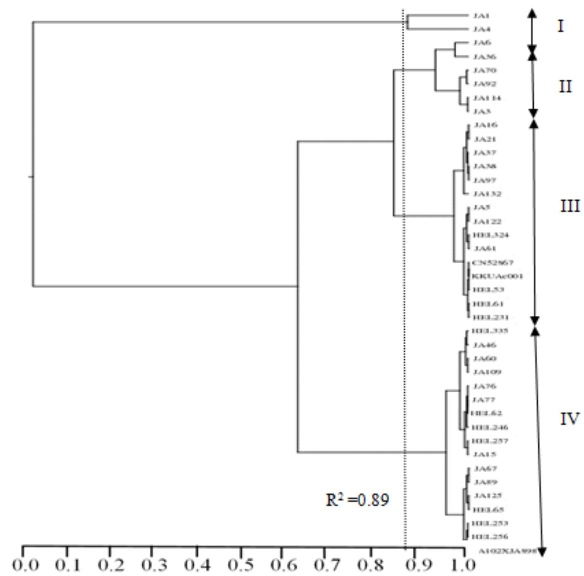

Figure 4. Dendrogram of 40 Jerusalem artichoke genotypes based on yield components (tuber width, tuber length, tuber size, tuber number per plant) and maturity days under drought conditions for 2 years.

The significance of genotype by environment interaction for yield indicated differential responses of Jerusalem artichoke to the environments. Tuber yield in 2011/12 was higher than in 2010/11. The difference in tuber yield between the 2 years was likely due to higher rainfall in 2011/12 that enhanced performance of genotypes. The differences caused by rainfall would be minimized as rainfall occurred during the crop establishment period and the drought was not imposed on the crop until 14 DAT. However, rainfall at the beginning of the growing period in 2011/12 promoted better establishment of the crop and subsequent crop performance than in 2010/11. Minimum and maximum air temperatures in 2010/11 (18.4–30.3˚C) were lower than in 2011/12 (19.5–30.5˚C). The optimum air temperatures for growth and development of Jerusalem artichoke are in the range of 6 to 26˚C (Kay and Nottingham 2008). In this study, Jerusalem artichoke was grown in the tropical region where the temperature was higher than optimum temperatures.

Genotype contributed to significant proportions of the total variations in tuber number per plant (39.1%), tuber width (52.3%), tuber length (24.7%), tuber size (55.8%) and days to maturity (55.0%), indicating that it is possible to use these characters for selection of Jerusalem artichoke varieties for better performance under drought conditions. In a previous study, genotypes contributed only 16% of the variation in days to maturity (Puttha *et al*., 2013). The difference between studies might be due to growing seasons with differences in air-temperatures, light intensity and photoperiod (Conde *et al*., 1991; Rattanaprasert *et al*., 2012).

Other agronomic characters are also important for breeding of Jerusalem artichoke for drought resistance. Variations in biomass, fresh tuber yield and inulin content have also been reported in previous studies (Puttha *et al*., 2012; Rattanaprasert *et al*., 2014), and the genotypic variation in inulin content was constant across planting dates (Puangbut *et al*., 2012). However, water use efficiency for inulin yield was increased under drought conditions (Puangbut *et al*., 2015) and these traits are also important to develop high-yielding cultivars with improved drought tolerance in Jerusalem artichoke.

Water regime also contributed to significant variation for these traits (2.4-18.8%), but it was still lower than the contribution of genotype except for tuber length (35.2%). In this study, tuber length is highly variable across water regimes. The results indicated that tuber length was more sensitive to water stress than other characters. In this study, tuber size under W1 ranged from 5.30 to 25.80 g per tuber and the size was reduced greatly under drought stress, ranging from 4.03 to 23.06 g per tuber and 2.35 to 14.86 g per tuber under W2 and W3, respectively. Pimsaen *et al*. (2010) reported that the tuber size ranged between 29 and 262 g per tuber depending on the environments, whereas the difference among cultivars was rather low. Likewise, Losavio *et al*. (1997) observed that average tuber weights ranged between 26.5 and 40.4 g per tuber depending on cultivars, irrigations and years.

Comparison of tuber numbers with previous works is difficult because in some environments, the tubers are highly-branched and very small, and also researchers used different criteria when counting. Tuber numbers in both years ranged from 6.75 to 33.11 tubers per plant under W1, and 6.25 to 25.63 under two drought conditions. Pimsaen *et al*. (2010) reported that tubers per plant ranged from 11 to 60 tubers per plant depending on cultivars and the environments in evaluation of 15 genotypes. While, Losavio *et al*. (1999) reported that numbers of tubers per plant in 3 genotypes ranged from 21.5 to 30.8 tubers depending on drought stress, cultivar and year.

The results showed that the ranges of the tuber number and tuber size were different from other studies. Differences in the results from different studies are due to difference in genotypes, drought intensity, soil fertility and higher G x E interaction in these traits (Pimsaen *et al*., 2010). However, the results from this study showed that genotypes with high tuber fresh weight tended to have late maturity which is similar to previous studies. Putta *et al*. (2012) reported that days to maturity was well correlated with fresh tuber yield (r = 0.26*) and biomass (r = 0.54**).

As mentioned above, drought can significantly reduce the yield of Jerusalem artichoke. However, some genotypes of Jerusalem artichoke are more tolerant to drought stress. The genotypes with high tuber number, tuber width, tuber length and size were identified. JA92, HEL246 and JA15 had high tuber numbers per plant across water regimes and years, whereas HEL65, HEL231, HEL53 and JA89 had high tuber width across water regimes and years. JA70, JA36, JA46, HEL 65 and JA97 had high tuber length across water regimes and years, whereas HEL65, JA76, HEL253, HEL53, HEL62, HEL231 and HEL335 had high tuber size across water regimes and years. The results were in agreement with those reported in previous studies, confirming that the genotypes with large tubers yield better than the genotypes with small tubers. Ruttanaprasert *et al*. (2014) reported that HEL65, JA76, HEL53, HEL231 and HEL335 had consistently high tuber dry weigh across water regimes and seasons. It's interesting to note here that the genotypes that had high performance in this study, also had high performance in others traits in the previous investigation. Ruttanaprasert *et al*. (2015) reported that JA 89 and HEL 65 performed well for root dry weight, root diameter, root length and low drought tolerant index for all root traits under drought conditions. Drought tolerance in these Jerusalem artichoke genotypes could be due to its high yield potential under full-irrigated conditions, low reduction in yield under drought conditions or both high yield potential and low reduction (Ruttanaprasert *et al*., 2014).

Cluster analysis based on tuber width, tuber length, tuber size, tuber number per plant and days to maturity under drought conditions clearly classified Jerusalem artichoke accessions into different groups with high or low performance in these characters. However, the dendrogram of phenotypic differences in days to harvest and yield components of the Jerusalem artichoke was slightly different from that based on the data of 3 water regimes. The reasons for this difference could be the differential response of Jerusalem artichoke genotypes to water deficits. Evaluation of genetic diversity can be useful in breeding Jerusalem artichoke with drought tolerance by selection of parental lines in Jerusalem artichoke breeding program.

CONCLUSION

Water regime had small effects on tuber width, tuber number per plant, tuber size and days to harvest, but it had a large effect on tuber length. Genotypic differences contributed to a large proportion of the total variance in most characters. The results showed that there were significant genetic variations in tuber width, tuber number per plant, tuber size and days to harvest in this set of Jerusalem artichoke genotypes and indicated that it is possible to use these characters for select Jerusalem artichoke for better performance under drought conditions. JA92, HEL246 and JA15 had a high tuber number per plant across water regimes and years, whereas HEL65, HEL231, HEL53 and JA89 had a high tuber width. JA70, JA36, JA46, HEL 65 and JA9765 had a high tuber length across water regimes and years, whereas HEL65, JA76, HEL253, HEL53, HEL62, HEL231 and HEL335 had large tubers across water regimes and years. The genotypes identified will be useful for both production and breeding of Jerusalem artichoke aiming to increase productivity of this crop especially under drought conditions.

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