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Differential response of some potato varieties grown under drought conditions

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Abstract

The current investigation was conducted to test the response of five potato varieties; *i.e.*, Arizona, Diamant, Markies, Spunta and Valor, to different irrigation levels during the summer seasons of 2018 and 2019 under Egyptian conditions. The irrigation levels were 100, 75 and 50% of evapotranspiration (ET). Different traits of vegetative growth, some chemical characters and yield were increased with increasing irrigation levels from 50 to 100% of ET for all tested varieties. There were increased bound water and proline content in leaves as well as dry matter and starch content percentages in tubers under drought conditions. Concerning potato varieties, Diamant in both growing seasons gave the highest value for most growth measurements, tuber yield and its components as well as, some parameters of growth analysis, physical and chemical characters and water use efficiency (WUE), followed by the Arizona variety. In terms of the interaction between potato varieties and irrigation levels, Diamant and Arizona were the most drought-tolerant cultivars, with 75 and 50 % ET, respectively, whereas Spunta *cv.* was the most sensitive. Furthermore, bound water and proline content in leaves, as well as the dry matter and starch content percentage in tubers, increased with decreasing irrigation levels.

Key words: Potato, *Solanum tuberosum,* irrigation, water stress, evapotranspiration, growth, yield, WUE

Introduction

The potato is one of the most important foods and cash crops cultivated worldwide under a wide range of climatic conditions. Currently, it is the fourth most important food crop in the world in terms of production, after wheat, rice and maize, FAOSTAT (2021). In Egypt, about 414 thousand feddans (Feddan = 0.42 hectare) are cultivated in three seasons, fall, winter and summer per year which produce about five million tons of potato tubers (Egyptian Ministry of Agriculture statistics, 2017). While Egypt exported 701 thousand tons of fresh potato tubers in 2018-2019 season (Egyptian agricultural quarantine, 2019). Potatoes provide both food and income in many of the world's most densely populated areas. Because of this double purpose, the potato crop plays an important role in improving the rural livelihood system in many countries (Gildemacher, 2012). To meet the increase in global food demands, crop production should be increased by more water and nutrient efficiency (Tilman *et al.*, 2011).

Saving water in the agricultural sector is an important objective of Egypt's water strategy to serve the growing population with limited resources, especially after the crisis of the Renaissance Dam in Ethiopia. Thus, providing support to farmers and producers to improve their agricultural skills regarding water saving has been an area of activity for many Egyptian organizations, including the Agricultural Research Center and the National Water Research Center.

Irrigation of crops sensitive to water stress, such as potatoes, requires a systematic approach to irrigation scheduling (Ayas, 2013). This entails preventing the soil water deficit from falling below a certain threshold level for a specific crop and soil condition. Irrigated potatoes by drip irrigation with different levels of evaporation (40, 60, 80, 100 %) gain a significant increase in growth parameters, particularly tuber yield, from an increased irrigation level (Badr *et al*., 2012). Also, the management practices that influence soil moisture, include irrigation techniques, irrigation strategies and mulching practices (Chukalla *et al*., 2015).

Generally, the potato crop is sensitive to drought; even a short period of water shortage can affect tuber production and quality. However, the field potato crop undergoing mild water deficit conditions may acclimate to the subsequent severe water deficits. Responses may be both acclimation and genotype-dependent. Few studies have examined whole plant physiological factors leading to enhanced drought stress resistance. However, there are reports of genetic variability for drought stress resistance. Identification of these key factors may increase selection efficiency in breeding programs. In an agricultural context, farmers and breeders tend to define drought-tolerant cultivars as those that maintain their yield under drought conditions. Drought reduces plant growth, shortens the growth cycle (Kumar *et al*., 2007) and reduces the number and size of tubers. Drought also reduces nitrate reductase activity, which affects nitrogen uptake (Eiasu *et al*., 2007 and Schafleitner *et al*., 2007). Furthermore, Mafakheri *et al*. (2010) indicated that drought stress during vegetative growth significantly decreased chlorophyll a, chlorophyll b and total chlorophyll content. As a result, drought sensitivity in potatoes can be attributed to stress effects on foliage characteristics (Soltys-Kalina *et al*., 2016; Romero *et al*., 2017) and its shallow root system (Zarzyska *et al*., 2017). Aliche *et al*. (2018) and Hill *et al*. (2021) recently reported that water restriction reduces leaf growth as well as having negative effects on growth, tuber formation, and tuber enlargement under drought stress.

This study examined the effects of drought acclimation on drought stress tolerance in five potato cultivars under Egyptian conditions, aiming to determine the tolerance of some major potato varieties grown under drought conditions.

Materials and methods

Experimental site: The field experiment was carried out at the Experimental Vegetable Research Farm of Kaha, Qalyubia Governorate, Egypt during the two successive summer seasons of 2018 and 2019. The site is located at an altitude of 21.1 m above sea level, latitude 30°16' N and longitude 31°12' E. with clay loam soil in texture. The chemical and physical properties of the experimental soil are shown in Table 1 measured according to the procedures described by Jackson (1973).

Table 1. The physical and chemical properties of the experimental soil

Physical Properties (%)	Seasons		Nutrient (available) (ppm)	Seasons	
	2018	2019		2018	2019
Clay	61.52	60.28	N	82.80	90.28
Silt	17.73	18.98	P	5.25	4.98
Sand	20.75	20.74	K	200.12	189.46
Texture class	Clay loam		pH (1- 2.5 suspension)	7.50	7.42

Plant material: Five potato varieties with different genotypic responses were tested (Table 2). Tubers were planted on 10th and 15th of January in 2018 and 2019, respectively. The weather for both two seasons is shown in Table 3.

Table 2. List of cultivars used in the experiment, showing the origin and the maturity type

Varieties	Imported from	Maturity
Arizona	Netherlands	Middle early
Diamant	Netherlands	Intermediate to late
Markies	Netherlands	Late
Spunta	Netherlands	Medium early
Valor	Scotland	Intermediate to late

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The experiment contained: Three levels of irrigation were applied at different rates of evapotranspiration (100, 75 and 50 % ET) on five potato varieties (Arizona, Diamant, Markies, Spunta and Valor). Interaction between levels of irrigation and the potato varieties was also studied. The treatments were arranged in a split-plot design with three replicates, where irrigation levels and varieties were arranged as main and subplots, respectively. Irrigation treatments were applied at first February in both seasons. Drip irrigation system was used and the distance between drippers was 20 cm.

The area of the experimental plot was 17.75 m^2 consisting of 5 ridges 5 m in length and 0.71 m in width whereas, one row was left without planting as a guard ridge between plots to avoid overlapping filtration. All agricultural practices were applied as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

The amount of water irrigation was calculated according to the Class A pan evaporation method. Class A pan evaporation data for the Qalyubia region was obtained from the Egyptian Meteorological Authority and expressed in mm/day. Reference crop evapotranspiration (ETo) was obtained according to Allen *et al.* (1998) as the following formula:

ETo = Kp x Epanopen (mm/day).
CU = ETo x Kc (mm/day).
WR = CU + L% (mm/day).
Where, ETo = potential evaporation.
Epan = Pan evaporation in mm daily
Kp = Pan coefficient 'constant'
CU = Water consumption
Kc = crop coefficient (cf FAO Irrigation and Drainage, 24, paper 33, Table 18).
L% = Leaching factor '10%'
WR= Water requirement 'mm/daily'

During the period from January to May, the final daily water requirement was calculated using monthly averages of Epan, K*P*= 0.85, and Kc= 0.50, 0.65, 0.8, 1.11, 1.14, and 0.92 for January to May, respectively.

Vegetative growth characters: After 60, 75, and 90 days from planting, three plants from each treatment were harvested and measured for stem length, main stem numbers, leaves per plant, tubers per plant, leaf area per plant, total plant fresh weight, and total plant dry weight, which was determined after oven-drying samples at 70 °C for 48 hours. The leaf area index (LAI) was calculated according to Watson (1958) using the following formula:

LAI = (Leaf area / plant) / (Land area/ plant).

Growth analysis

Crop growth rate (CGR): Crop growth rate calculated as per Mahata *et al*. (2018), using following formula:

$$CGR = \frac{W2-W1}{T2-T1} \text{ g/week}$$

Relative growth rate (RGR): Dry weight accumulated per unit of plant dry weight per unit of time was calculated as per Mahata *et al*. (2018), using following formula:

$$RGR = \frac{\ln W2-\ln W1}{T2-T1} \text{ g/week}$$

Where, W1 and W2 are the total dry weight at times T1 and T2

Table 3. Air temperature (°C), average precipitation, average precipitation and pan evaporation (mm) during growing season in the years of study (2018 and 2019)

Month	First Season					Second Season				
	Air temperature (°C)			Average precipitation	Pan evaporation	Air temperature (°C)			Average precipitation	Pan evaporation
	Max	Min	Average			Max	Min	Average		
January	19	10	14	5.12	-	18.3	9.4	13.9	5.08	-
February	20	11	15	3.01	2.60	20.0	10.0	15.0	4.40	2.40
March	23	13	18	1.15	4.30	22.8	12.3	17.6	2.54	4.01
April	28	15	22	0.00	5.50	27.8	15.0	21.4	2.54	5.50
May	32	19	25	0.00	7.80	31.7	17.8		0.00	7.00

respectively, and T2-T1 equals period in unit of time between the two consecutive samples.

Physical and chemical properties: Proline content was determined in mg/g dry weight according to Bates *et al*. (1973). Total chlorophyll in representative samples of leaves chlorophyll was determined as mg/g fresh weight spectrophotometrically following Jeffrey and Humphrey (1975). Relative water content**:** was determined according to Barrs and Weatherley (1962) formula:

$$RWC\ (\%) = \frac{FW-DW}{TW-DW} \times 100$$

Where, FW = *in situ* fresh weight of leaf discs, TW = full turgor weight after the discs were floated on distilled water for 6 hours in Petri dishes under laboratory light and temperature conditions then blotted before weighting and DW = dry weight of discs (at 105 ^oC for 48 hours). A cork borer was used to punch leaf discs at upper, middle and bottom portions of three plants from each sub-plot. Discs were cut midway between the base and tip of each leaflet blade excluding the midrib.

Plant water relations: Total, free and bound water (%), cell sap and osmotic pressure in the fourth upper leaf of potato plants were determined for every experimental unit at 60, 75 and 90 days after planting in both seasons according to the method described by Gosev (1960).

Yield and its components: The parameters were recorded at harvesting time. It included a number of produced tubers per plant, average tuber weight (g), tuber yield per plant (kg) and total yield (ton/fed.).

Tuber quality: Tuber dry matter (%) was determined by drying the tuber slices at 70 ˚C for 72 hours according to the method of Dogras *et al*. (1991). Total carbohydrate (%) was determined calorimetrically in fresh tubers, as described by the method of Michel *et al*. (1959). Starch content in tubers was determined using AOAC (1990) method.

Water use efficiency (WUE): It was defined as the units of total yield produced from each experimental unit per unit volume of the used water. WUE = Yield (kg) / Water (m^3).

Statistical analysis: All recorded data were subjected to statistical Analysis of Variance and least significant differences (Duncan, 1955) at P=0.05 level of probability to separate means.

Results and discussion

Vegetative growth characters: Data (Tables 4 and 5) illustrate that the highest values of stem length, number of main stems, number of leaves, number of tubers, total plant fresh weight, tubers fresh weight per plant, leaf area (LA), and leaf area index (LAI) at 75 days after planting resulted from irrigation with the level of 100% evapotranspiration (ET), while, irrigation at 50% ET led to a significant decrease in the same parameter.

In terms of the effect of potato varieties on vegetative growth, the five varieties showed significant differences in stem length, number of main stems, number of leaves, number of tubers, total plant fresh weight, tubers fresh weight per plant, LA and LAI (Tables 4 and 5). The data revealed that Diamant had the highest number of main stems, total plant fresh weight, number of tubers, tubers fresh weight per plant, LA and LAI than Arizona, Valor, Markies, and Spunta varieties in both the seasons, The potato variety Markies, on the other hand, had the longest stem length. Valor, produced the maximum leaves per plant in both the seasons. Interaction between irrigation levels and potato varieties indicated that the highest values of most vegetative growth parameters were recorded in Diamant irrigated at 100% ET. Whereas, Spunta plants under a low level of irrigation (50 % ET) showed a significant decrease in all growth characters in both seasons.

Table 4. Impact of different irrigation levels on stem length, main stem number, leaf number, tuber number and total plant fresh weight per plant of five potato cultivars in two seasons of 2018 and 2019

Evapotranspiration (ET)	Variety	Stem length (cm)		Main stem (Number /plant)		Leaf (Number /plant)		Tubers (Number /plant)		Total plant F.W. (g)	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
50% ET		45.6C	44.5C	3.3C	3.7C	36.7C	39.5C	4.4C	4.7C	388.8C	408.3C
75% ET		50.7B	49.5B	3.7B	3.8B	52.6B	57.1B	5.9B	6.5B	549.1B	609.0B
100% ET		58.4A	56.5A	4.7A	4.3A	73.9A	76.7A	7.7A	8.1A	730.9A	775.3A
	Arizona	52.0B	50.0C	3.7A	3.8B	52.0C	53.9D	5.8C	6.3C	579.9AB	626.1A
	Diamant	51.3B	52.4B	4.0A	4.1A	55.2B	56.2CD	7.4A	7.7A	592.6A	640.9A
	Markies	59.2A	56.7A	3.8A	3.9AB	55.7B	57.4BC	5.4C	6.1C	573.7AB	623.2A
	Spunta	47.0C	45.2E	3.2B	3.3C	51.2C	54.8B	4.6D	4.9D	490.5C	535.8B
	Valor	48.3C	46.6D	3.8A	3.9AB	57.9A	63.6A	6.7B	7.1B	544.4B	561.5B
50% ET	Arizona	48.0F	46.0G	3.3BC	3.3B	32.7G	36.7J	4.7GHI	4.7H	459.0CDF	484.2DF
	Diamant	42.7GH	48.6F	3.7AB	3.3B	40.3F	42.3I	5.3F	5.7FG	440.6DE	470.9E
	Markies	54.3CDE	52.0DE	3.3BC	3.3B	40.0F	43.0HI	4.3HI	4.7H	420.6EF	444.3E
	Spunta	40.7H	36.3J	2.7C	2.7C	27.3H	30.0K	3.0J	3.3I	268.8G	299.8F
	Valor	42.3GH	39.7I	3.7AB	3.7B	43.3E	45.3H	4.7GHI	5.3GH	354.8F	342.1F
75% ET	Arizona	52.7DE	50.7E	3.7AB	3.7B	51.0D	54.3G	5.3FG	6.3DEF	557.8B	639.8B
	Diamant	51.9E	52.9D	4.0AB	4.3A	53.3C	56.0G	8.0BC	8.3AB	580.2B	659.3B
	Markies	57.7BC	56.3B	3.7AB	3.7B	54.7C	58.7G	5.0FGH	6.0EFG	563.6B	629.3BC
	Spunta	44.7FG	42.7H	3.3BC	3.7B	50.7D	56.0E	4.3I	4.7H	510.4BCD	553.9D
	Valor	46.7F	45.0G	3.7AB	3.7B	53.3C	60.7F	6.7DE	7.0CD	533.6BC	562.6CD
100% ET	Arizona	55.3CDE	53.3CD	4.0AB	4.3A	72.3B	70.7C	7.3CD	8.0B	723.1A	754.4A
	Diamant	59.4B	55.8B	4.3A	4.7A	72.0B	73.3D	9.0A	9.0A	757.1A	792.5A
	Markies	65.7A	61.7A	4.3A	4.7A	72.3B	76.7C	7.0D	7.7BC	737.1A	795.9A
	Spunta	55.7CD	56.7B	3.7AB	3.7B	75.7A	78.3B	6.3E	6.7DE	692.4A	753.8A
	Valor	56.0BCD	55.0BC	4.0AB	4.3A	77.0A	84.7A	8.7AB	9.0A	744.6A	779.7A

Note: In each column, mean of each treatment followed by the same letter (s) are not significantly different at P=0.05 by Duncan's Multiple Range Test (DMRT)

Tables 5. Impact of different irrigation levels on tuber fresh weight, leaves area per plant (LA), leaf area index (LAI), crop growth rate (CGR) and relative growth rate (RGR) of five potato cultivars in two seasons of 2018 and 2019

Evapotranspiration (ET)	Varieties	Tubers FW per plant (g)		LA/ plant (cm^2)		LAI		CGR (g/week)		RGR (g/week)	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
50% ET		270.8C	275.7C	4179.0C	4431.2C	2.2C	2.4C	15.6C	16.9C	0.12B	0.10B
75% ET		354.1B	355.9B	6541.7B	6860.6B	3.5B	3.6B	24.2B	24.6B	0.13A	0.12B
100% ET		430.1A	445.1A	7810.69A	7667.0A	4.2A	4.1A	39.3A	36.6A	0.14A	0.14A
	Arizona	347.5AB	342.1B	6422.3AB	6445.1AB	3.4AB	3.4B	27.6AB	28.0AB	0.14A	0.14A
	Diamant	362.0A	382.4A	6567.1A	6641.5A	3.5A	3.5A	30.4A	28.7A	0.15A	0.15A
	Markies	355.3AB	367.9A	6216.3ABC	6317.8AB	3.3ABC	3.4B	25.9D	24.6C	0.12B	0.11B
	Spunta	342.6B	343.2B	5760.9C	6013.9B	3.1C	3.1B	23.9CD	23.3C	0.10C	0.08C
	Valor	350.9AB	358.6A	5919.1BC	6179.7AB	3.2BC	3.3B	26.6BC	25.6BC	0.13B	0.11B
	Arizona	311.2D	304.3DEF	4692.6EF	4957.6D	2.5EF	2.6D	18.6EF	20.5HIJ	0.16A	0.15AB
	Diamant	272.7E	290.1EF	5075.1E	5043.3D	2.7E	2.7D	20.3EF	21.7GHI	0.15ABC	0.19A
50% ET	Markies	252.7EF	280.1EF	3988.6F	4516.0D	2.1F	2.4D	15.8F	16.7J	0.13CD	0.13BC
	Spunta	237.0F	226.7G	2912.9G	3048.3E	1.6G	1.6E	8.6G	7.9K	0.13CD	0.10CDE
	Valor	280.5E	2782F	4225.9EF	4590.9D	2.3EF	2.5D	14.9F	17.6IJ	0.14BC	0.11CDE
	Arizona	327.2D	329.2D	6563.6CD	6621.2C	3.5CD	3.5C	28.1CD	26.4EF	0.13CD	0.13BCD
	Diamant	383.4C	390.2C	6592.4CD	7191.8ABC	3.5CD	3.8ABC	28.4CD	29.1DE	0.15AB	0.13BC
75% ET	Markies	383.4C	390.2C	6954.0BCD	7072.9BC	3.7BCD	3.8BC	21.4E	24.8EFG	0.13CD	0.12CDE
	Spunta	333.2D	326.7DE	6444.3D	6892.1BC	3.4D	3.4BC	19.2EF	18.6IJ	0.11E	0.10DE
	Valor	343.3D	343.1D	6154.0D	6525.1C	3.3D	3.5C	23.8DE	24.4FGH	0.13CD	0.11CDE
	Arizona	404.3BC	393.0C	8010.8A	7756.5AB	4.3A	4.1AB	42.4AB	37.2B	0.13CDE	0.13BCD
	Diamant	429.8AB	467.0AB	8033.7A	7689.5AB	4.3A	4.1AB	41.3AB	35.3BC	0.15AB	0.13BC
100% ET	Markies	429.8AB	433.7B	7706.2AB	7364.5ABC	4.1AB	3.9ABC	31.5C	32.3CD	0.11DE	0.08EF
	Spunta	457.5A	476.3A	7925.2A	8101.3A	4.2A	4.3A	44.0A	43.4A	0.08F	0.05F
	Valor	428.8B	455.3AB	7377.5ABC	7423.2ABC	3.9ABC	4.0ABC	37.4B	34.8BC	0.11DE	0.12BCD

Note: In each column, mean of each treatment followed by the same letter (s) are not significantly different at $P=0.05$ by Duncan's Multiple Range Test (DMRT)

On potato, Samy (2006) and Youssef (2007), Mabhaudhia *et al.* (2013), El-Zohiri and Abdel-Al (2014), and Amira (2018) found similar results and they suggested that as irrigation levels increase, vegetative growth characters improve as a result of increased cell division and enlargement, which require more water, as well as sufficient water supply favour gibberellin biosynthesis, which improves vegetative growth characters. Furthermore, a decrease in root growth and inhibition of leaf elongation rate is linked to an increase in abscisic acid (ABA) concentration in leaves, as well as a decrease in cytokinin production and export. Furthermore, when the water potential falls below 0.6 MPa, potato plants close their stomata to conserve moisture (Monneveux *et al*., 2013 and Hill *et al*., 2021). Differences in genetic factors could explain the differences in most vegetative growth parameters between potato varieties. Drought tolerance was higher in Diamant, Arizona, Valor, and Markies varieties than in *cv.* Spunta.

Growth analysis: The results demonstrate that CGR and RGR were significantly affected by water supply. In this regard, increasing water supply to the maximum level, *i.e.,* 100 percent of evapotranspiration, significantly increased CGR and RGR in both growing seasons during the period (60-90 days after planting). Furthermore, the lowest level of evapotranspiration (50 percent ET) resulted in the greatest reduction in both CGR and RGR during this time period (Table 5).

Furthermore, the data show that there were statistically significant differences between varieties. Diamant variety showed a significant increase in CGR and RGR during the first 60-90 days after planting. Meanwhile, when compared to other varieties such as Valor, Markies, and Spunta, the Diamant and Arizona varieties significantly recorded higher values in CGR and RGR in the second season. The obtained data demonstrated that the interaction between irrigation levels and the effect of potato varieties on CGR and RGR was statistically significant (Table 5). When compared to the other treatments, the Spunta variety had the lowest CGR and RGR under drought conditions (irrigation by 50 and 75 percent ET) in both seasons. The *cv.* Spunta, on the other hand, produced the highest value in CGR and RGR under irrigation when grown under 100 % ET (control). These results may be explained by the activation of growth parameters because of the presence of high moisture in the soil. The reduction in nutrition uptake that occurred during the drought could be responsible for disrupting the needed physiological processes for plant growth. Drought reduced leaf area, photosynthesis, and chlorophyll content (Sayed, 2019). According to Samy (2006), as the water stress increased, the relative growth rate of potato plants increased. In addition, Engelbrecht *et al*. (2007) and Hill *et al*. (2021) demonstrated that drought causes a wide variety of changes in plant morphology, physiology, growth, stem elongation, leaf expansion, ion and nutrient imbalance, and photosynthesis.

Physical and chemical properties: Table 6 show the effect of various irrigation levels for leaf proline content in five potato varieties. The results indicate that the highest leaf proline content was observed during drought compared to both levels of irrigation under high ET levels. Contrastingly, variety had a significant effect in both summer seasons. Diamant yielded the highest leaf proline content in both seasons and the lowest was by Spunta variety. However, Diamant, Arizona, Valor and Markies all recorded the highest proline content at 50 % ET. They showed the same trend, as stated by Mafakheri *et al*. (2010) and Moralesa *et al*. (2013). In addition, Orlikowska *et al*. (2009) found that drought-tolerant genotypes showed higher growth and proline accumulation than susceptible genotypes.

Tables 6. Impact of different irrigation levels on proline content, total chlorophyll, RWC, FWC and BWC of five potato cultivars in two seasons of 2018 and 2019

Evapotranspiration (ET)	Varieties	Proline content (mg/g)		Total chlorophyll (mg/L)		RWC (%)		FWC (%)		BWC (%)	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
50% ET		7.1A	7.1A	1.1B	1.1B	57.0C	54.4C	26.3C	25.6C	48.3A	50.1A
75% ET		6.3B	6.3B	1.4A	1.4A	59.1B	57.3B	33.6B	32.0B	43.4B	47.1B
100% ET		4.5C	4.5A	1.4A	1.4A	60.7A	60.2A	41.0A	37.4A	40.8C	44.9C
	Arizona	6.1C	6.1C	1.3A	1.3A	61.3A	59.2A	37.9A	36.6A	36.6E	45.6C
	Diamant	6.2A	6.2A	1.3A	1.3A	59.7B	58.0B	32.9D	31.1B	31.1B	44.6B
	Markies	6.0D	5.9D	1.3A	1.3A	55.7C	55.4D	30.07E	29.2C	30.8A	43.7A
	Spunta	5.5E	5.5E	1.3B	1.2B	59.3B	56.3C	35.12B	30.8B	29.2D	42.8B
	Valor	6.2B	6.2B	1.2A	1.3A	59.3B	57.8B	33.8C	30.9B	30.9C	44.2B
	Arizona	7.1C	7.2C	1.1DE	1.1C	58.8EFG	56.5DE	28.3F	24.9F	46.8B	49.1CD
	Diamant	7.3A	7.3A	1.0E	1.0C	58.7FG	56.3DE	25.7G	24.9F	48.7A	50.3AB
50% ET	Markies	7.0D	7.0D	1.0E	1.0C	50.8I	52.5F	23.3H	23.3G	48.8A	50.9A
	Spunta	6.9E	7.0E	1.1DE	1.3B	58.0GH	50.6G	28.5F	30.4E	48.5A	49.9BC
	Valor	7.2B	7.2B	1.0E	1.0C	58.7FG	56.3DE	25.7G	24.0FG	48.7A	50.3AB
	Arizona	6.8G	6.8F	1.4BC	1.3B	60.3BC	58.5C	38.1C	34.0C	42.2D	46.5FG
	Diamant	6.9F	6.9F	1.4C	1.4B	59.6CD	56.9D	31.6E	31.5D	44.2C	47.6E
75% ET	Markies	6.0H	6.1G	1.3C	1.4B	57.3H	57.0D	28.9F	30.7DE	46.2B	48.0DE
	Spunta	5.0I	5.1H	1.3C	1.5A	59.6CDE	55.8E	36.0D	31.8D	42.4D	47.1EF
	Valor	6.85F	6.9F	1.3C	1.4B	60.3BC	58.5C	38.1C	34.0C	42.2D	46.5FG
	Arizona	4.3N	4.4L	1.4BC	1.5A	64.7A	62.6A	47.2A	45.2A	39.4G	43.2J
	Diamant	4.4L	4.5K	1.5A	1.6A	60.6B	60.8B	41.3B	37.0B	40.9E	45.0HI
100% ET	Markies	4.7J	4.8I	1.5AB	1.5A	58.9DEF	58.5C	37.7C	33.8C	41.8D	45.8GH
	Spunta	4.5K	4.6J	1.2D	1.0C	60.3BC	60.5B	40.9B	36.6B	40.1F	44.8I
	Valor	4.4M	4.5K	1.5A	1.5A	58.9DEF	58.5C	37.7C	33.8C	41.8D	45.8GH

Note: In each column, mean of each treatment followed by the same letter (s) are not significantly different at P=0.05 by Duncan's Multiple Range Test (DMRT)

Data presented in Table 6 show that the total chlorophyll concentration in potato leaves was also significantly affected by irrigation levels. There were no significant differences in total chlorophyll concentration between irrigating by 100 and 75 % ET. Also, irrigating with 50 % ET decreased the total chlorophyll concentration in both seasons.

Table 6 shows the total chlorophyll content in potato variety leaves. There was no significant difference between Diamond, Valor, Arizona, and Markies for both summer seasons. Thus, the Diamant potato variety had the highest total chlorophyll concentration among the different varieties. Additionally, the Spunta variety gave the lowest total chlorophyll concentration in leaves in both seasons.

An interaction between irrigation levels and potato varieties led to significant effects on total chlorophyll concentration, where the highest values were found in Diamant, Valor, and Arizona plants irrigated with 100 % ET in both seasons 2018 and 2019 (Table 6). while the reverse was true in the varieties under low level of irrigation (50 % ET).

Changes in chlorophyll content that occurred due to drought stress could be the cause of the inhibition of photosynthesis. Mafakheri *et al*. (2010) discovered that under drought stress, the percentage of chlorophyll a, chlorophyll b, and total chlorophyll all decreased. Damage to chloroplasts under drought stress causes a decrease in chlorophyll.

Water contents in potato leaves: Data in Tables 6 and 7 clearly show that as the amount of water available to the soil increases, the percentage of free and total water content in potato leaves also increases. The high percentages of the above-mentioned characters were obtained through irrigation with 100 % ET, as opposed to 50 or 75 % in both growing seasons. In addition, the low water supply (50 % ET) resulted in reduced relative, total, and free water contents. Conversely, drought has caused bound water content to increase.

Relative water content (RWC), free water content (FWC) and total water content (TWC) in leaves were highest in Arizona variety. Additionally, significant differences in bound water contents were recorded between Markies variety and other varieties in both seasons.

In different irrigation levels, different potato varieties exhibited drastically different interaction effects. Arizona variety provided the highest values when it was watered with 100 % ET as compared to Diamant, Valor, and Markies. Considering the interactions in both seasons, bound water contents increased in Markies, Diamant and Valor.

It can be concluded that increasing the amount of water supplied to the soil increased amount of water absorbed by the plant, as well as increasing the total and free water contents in plant leaves. The results show that as the amount of water supplied decreased, the percentage of bound water in potato leaves increased until irrigation by 50 % of evapotranspiration gave the highest percentage of bound water. Bound water in potato leaves decreases with plant maturity (Samy, 2006; Youssef 2007), potatoes and cowpea (Merwad *et al.,* 2018).

Yield and its components: Water quantity recorded a notable significant effect on tubers per plant, tuber average weight, and total yield (per plant and ton/fed) at harvesting time in both seasons. In general, yield and its components were influenced by irrigation levels. The gradual reduction in yield and its components (tuber average weight, tubers number and total yield per plant and per feddan) was resulted by decreasing the amount of water that was supplied. Diamant followed by Arizona

Tables 7. Impact of different irrigation levels on total water contents, total yield, tubers number per plant, average tuber weight of five potato cultivars in two seasons of 2018 and 2019

Evapotranspiration (ET)	Varieties	TWC (%)		yield per plant (g)		Total yield (ton/fed.)		Tubers No./plant		Average tuber weight (g)	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
50% ET		74.6C	75.7C	171.0C	172.8C	5.1C	5.0C	5.5C	5.8B	30.9C	29.5C
75% ET		77.5B	79.2B	327.0B	325.9B	11.0B	10.5B	5.8B	6.1B	57.1B	54.2B
100% ET		81.8A	82.3A	504.3A	505.7A	17.4A	17.0A	6.6A	6.7A	77.5A	76.5A
	Arizona	80.7A	82.8A	343.9B	337.1B	11.4B	11.2A	6.0C	5.9C	56.3B	56.6A
	Diamant	77.5D	78.7B	366.3A	373.0A	11.9A	11.9A	6.9A	7.0A	53.9BC	52.4B
	Markies	75.6E	77.5C	312.2D	321.9BC	11.0C	10.7B	5.7D	6.1B	53.9BC	51.5BC
	Spunta	78.80B	78.1BC	313.2D	314.6C	10.6D	10.1C	4.9E	5.2D	61.2A	59.2A
	Valor	78.1C	78.4B	327.0C	331.7BC	11.0C	10.6B	6.3B	6.8A	50.9C	47.8C
	Arizona	86.6A	88.4A	189.4H	182.7H	5.7H	5.5H	7.0B	6.3CD	36.7E	32.7GH
	Diamant	82.2B	81.6B	229.9G	222.6G	5.8H	6.0H	7.6A	7.8A	36.5E	35.0G
50% ET	Markies	79.5D	79.8CD	150.3I	166.8H	4.8I	4.4I	6.2DE	6.7C	28.2F	29.1GHI
	Spunta	81.0C	81.8B	118.0J	120.9I	3.9J	3.4J	5.3FGH	5.5FGH	27.4F	24.5I
	Valor	79.5D	79.8CD	167.2HI	171.1H	5.5H	5.7H	6.8BC	7.3B	25.5F	26.3HI
	Arizona	80.3CD	80.3BC	341.1D	335.6E	11.3E	11.1E	5.7EF	5.7FG	63.9C	59.2D
	Diamant	75.8G	79.4CD	370.3C	372.3D	12.6D	12.0D	6.9B	6.8BC	60.4CD	54.9DEF
75% ET	Markies	75.1GH	78.4D	305.7F	313.4EF	10.6F	10.1F	5.5FG	6.0DEF	55.6D	52.2EF
	Spunta	78.4E	78.6D	308.9EF	293.6F	10.0G	9.0G	4.8HI	5.2GH	53.7D	56.9DF
	Valor	80.3CD	80.3BC	330.3DF	327.2E	10.7F	10.2F	6.2DE	6.7C	53.7D	49.4F
	Arizona	75.1GH	79.8CD	501.1AB	492.9BC	17.4B	17.6A	5.2GH	5.6FG	94.2A	78.0B
	Diamant	74.4H	75.2E	500.6AB	524.1AB	17.0C	16.6B	6.3CD	6.4CD	78.0B	67.2C
100% ET	Markies	72.1I	74.2EF	480.5B	485.4C	17.7AB	17.5A	5.3FGH	5.7EFG	71.7B	73.0BC
	Spunta	77.0F	73.9F	513.6A	529.2A	17.9A	17.6A	4.6I	5.0H	71.7B	96.3A
	Valor	74.4H	75.2E	483.5B	496.7BC	16.8C	15.9C	6.1DE	6.5CD	71.6B	67.8C

Note: In each column, mean of each treatment followed by the same letter (s) are not significantly different at P=0.05 by Duncan's Multiple Range Test (DMRT)

produced the highest values for tuber number and total yield per plant/fed. comparing with other varieties in both the seasons, whereas, Spunta variety provided the highest tuber average weight. In contrast, Spunta produced the lowest tubers per plant compared to other varieties in summer 2018 and 2019.

The study revealed that water regime and potato variety interact significantly with yield (per plant and ton/fed.). The data presented in Table 7 shows that the maximum tuber average weight, yield per plant, or feddan was obtained when *cv.* Spunta was irrigated to a higher level, *i.e.*, 100 % ET (17.93 tons/fed in 2018 and 17.57 tons/fed in 2019). Contrary to this, in 2018 and 2019 summer seasons, increased irrigation helped the Diamant and Arizona potato varieties be more drought-resistant than when watered with 75 or 50 % of evapotranspiration.

High levels of water and vegetative growth lead to increased leaf area and photosynthetic processes, which in turn produced more carbohydrates, and therefore yield (Ghosh *et al*., 2000 and Widuri *et al*., 2020). Additionally, stomatal closure at a relatively high leaf water potential may already limit photosynthesis, reducing assimilates production and causing reduced tuber yield and quality (Hill *et al*., 2021).

Higher applied water quantity to plants resulted in increased water content in plant tissues, which resulted in heavier tubers. Water stress elevates the abscisic acid/cytokinin ratio, and this inhibits plant growth. Sayed (2019) observed the effect of adequate water supply on ABA and cytokinin, GA and auxin resulted in growth, yield, and dry matter content. ABA is also synthesized by roots under water stress, which results in ABA transport to different plant parts, like leaves and other organs (Bhargava and Sawant, 2013). Additionally, the findings are in agreement with Samy (2006) and Youssef (2007) who found that increasing water supply significantly increased potato yield. Though tuber yield decreased, the supply of water remained the same. Likewise, Aliche *et al*. (2018) reported that drought conditions negatively impact tuber growth, maturation, and enlargement. Potato varieties' greater yield can be attributed to the variety growth and tolerance to drought.

Tuber quality: Harvesting in both seasons had significant differences in tuber dry matter, starch, and total carbohydrate contents between the five varieties irrigated at three levels of evapotranspiration (Table 8). The dry matter content of the potato tubers decreased with increasing irrigation levels up to the maximum level (100 % ET). Conversely, total carbohydrate significantly increased by increasing irrigation levels up to the maximum water supply level (100 % ET). Diamant variety's starch and total carbohydrates values both decreased in both 2018 and 2019. Consequently, it was observed that high irrigation (100 % ET) together with the variety caused higher starch content and total carbohydrates percentage (Table 8). A reduction in tuber dry matter and starch content was observed after harvest, while total carbohydrates were the highest. Due to the higher moisture content of the tubers and the significant decrease in the dry matter during drought exposure, the dry matter percentage of potato tubers decreased (Widuri *et al*., 2020). Similar results were found by Samy (2006) and Youssef (2007) on potato, where higher carbohydrate levels in tubers lead to the enhancement of photosynthesis and enzyme activity. However, dry matter, starch content, and total carbohydrates all significantly increased in Diamant, Arizona, Valor, and Markies cultivars, when compared to Spunta. These differences can be attributed to genetic factors.

Water use efficiency (WUE): Table 8 shows that the highest benefit to WUE was obtained from applying 50 % ET in irrigation, compared to using 75 and 100 % ET. The WUE values decreased as the water supply increased from 50 to 100 % of evapotranspiration. Results showed that Diamant and Arizona potato varieties gave the highest value of WUE when compared

Tables 8. Impact of different irrigation levels on dry matter, starch content, total carbohydrates and water use efficiency of five potato cultivars in two seasons of 2018 and 2019

Evapotranspiration (ET)	Varieties	Dry matter (%)		Starch (%)		Total Carbohydrates (%)		WUE(kg/m^3)	
		2018	2019	2018	2019	2018	2019	2018	2019
50% ET		22.2A	22.2A	12.0A	12.0A	19.8A	19.5A	8.3A	9.5A
75% ET		20.7B	20.7B	14.4B	14.5B	18.0B	17.9B	7.9B	9.1B
100% ET		18.00C	18.0C	15.8C	15.8C	15.1C	14.9C	6.9C	8.0C
	Arizona	20.5B	20.6B	14.3B	14.4B	17.9B	17.8B	8.0B	9.2B
	Diamant	22.7A	22.7A	16.2A	16.2A	20.4A	20.1A	8.4A	9.7A
	Markies	20.3BC	20.3B	14.1BC	14.1B	17.7BC	17.5B	7.5D	8.5D
	Spunta	17.7D	17.7C	11.8D	11.8C	14.8D	14.6B	6.9E	7.9E
	Valor	20.1C	20.1B	13.9C	13.9B	17.5C	17.2C	7.7C	8.9C
	Arizona	22.6BC	22.8B	18.3A	18.3A	20.3BC	20.3B	9.1B	10.1BC
	Diamant	25.0A	25.0A	16.5B	16.5B	23.0A	22.7A	9.4A	11.0A
50% ET	Markies	22.0D	22.0BC	16.2BC	16.3B	19.6D	19.4BC	7.7C	8.2E
	Spunta	19.0G	19.0EF	15.8CD	15.6BC	16.3G	16.0EF	6.3H	6.2H
	Valor	22.3CD	22.0BC	15.6D	15.6BC	19.9CD	19.4BC	8.8B	10.4B
	Arizona	20.9E	21.0CD	14.7E	14.7CD	18.4E	18.2CD	8.1C	9.1D
	Diamant	23.0B	23.0B	14.6E	14.7CD	20.7B	20.5B	9.0B	9.8C
75% ET	Markies	21.0E	21.0CD	13.9F	14.0D	18.5E	18.3CD	7.6D	8.2E
	Spunta	18.0H	18.0F	13.8F	13.8DE	15.1H	14.9F	7.1EF	7.3G
	Valor	20.1F	20.2D	12.9G	12.9EF	17.5F	17.4D	7.6D	8.3E
	Arizona	18.0H	18.0F	12.0H	12.0F	15.1H	14.9F	6.8FG	7.6FG
	Diamant	20.0F	20.0DE	12.0H	12.0F	17.4F	17.1DF	6.8FG	8.0EF
100% ET	Markies	18.0H	18.0F	12.0H	12.0F	15.1H	14.9F	7.1EF	8.0EF
	Spunta	16.0I	16.0G	12.0H	12.0F	12.9I	12.7G	7.2E	8.1E
	Valor	18.0H	18.0F	10.3I	10.3G	15.1H	14.9F	6.8G	7.3G

Note: In each column, mean of each treatment followed by the same letter (s) are not significantly different at *P*=0.05 by Duncan's Multiple Range Test (DMRT)Range Test (DMRT)

to other interactions in 2018 and 2019. Table 8 shows that at 50 % ET irrigation, Diamant variety recorded the highest WUE. However, Spunta variety under irrigating conditions by 100 % of ET had the highest WUE in both seasons.

According to Samy (2006) and Youssef (2007), the water use efficiency was higher under conditions of low water supply. Additional studies report that a water deficit improves water use efficiency, and Badr *et al*. (2012) and Cantore *et al*. (2014) concluded that deficit conditions can enhance WUE.

In conclusion, the Diamant, Arizona and Valor potato varieties produced the highest CGR, RGR, and WUE under drought stress, whereas the Spunta variety produced the lowest values under drought stress. Diamant, Arizona, and Valor varieties are recommended for cultivation in drought-prone environments.

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