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Water stress as a component of climate change affects potato growth, tuber yield and processing quality

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The effect of water stress measuring 80-100 kPa soil water tension was studied on a Danish processing potato variety known as 'Royal' to investigate the response of potato plant to transient and fluctuated water stress at early and late growth stages. The stress was imposed for 10 and 15 days at full emergence and tuber-bulking stages, and fluctuated throughout the growing period. The effect of the stress at full emergence was significant (P<0.05) on plant height, number of main stems per plant and tuber fresh weight. However, the stress at tuber-bulking stage did not show significant effect on plant height and number of main stems but on tuber fresh weight and different quality parameters. The highest tuber fresh weight reduction (40%) was accounted to fluctuated water stress as compared to the transient stress treatments which caused 7-18% yield reduction. Quality parameters such as tubers' specific gravity, dry matter, and starch concentration were significantly (P<0.05) affected when the stress was imposed at tuber-bulking stage. The highest reduction was caused by fluctuated water stress followed by the transient stress treatments. Likewise, tubers' sugar concentrations were significantly (P<0.05) increased by the stress at tuber-bulking stage, although an increase in the level of the sugar did not cause significant browning on potato chips. The study concluded that, the effect of early water stress at full emergence is more on vegetative growth and tuber yield than quality compared to its effect at tuber-bulking stage; while fluctuated water stress caused more severe effect on both yield and quality than that of the transient water stress.

Key words: browning; drought; reducing sugars; *Solanum tubersosum*; transient and fluctuated water stress; tuber-bulking; vegetative.

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INTRODUCTION

Water has been reported as a critical core resource influencing agriculture, amongst several economic sectors, which are projected to be most affected by climate change. Regional climate-change models in Europe projected more frequent and intense summer droughts, particularly in the South, where the problem may be more pronounced because of an increasing demand for water due to elevated temperatures. Drought spells and shifts in precipitation pattern during summer are also reported to alter both the availability of water and the demand for water for uses such as agriculture (EEA, 2007).

Potato (*Solanum tubersosum* L.) is widely recognized as a sensitive crop to water stress (Haverkort and Mackerron, 2001). Consequently, water stress during the growing season is considered the most significant climate dependent factor that affects yield and quality of potatoes (Holden and Brereton, 2006). The significant effect of water stress on yield and quality mainly depends on the growth stage of the crop, severity and duration of water stress (King et al., 2003). Early water stress during vegetative growth stage was found to reduce total tuber yield (Lynch et al., 1995; King et al., 2003), whereas late water stress in the season during tuberization and tuber-bulking stages affected tubers' quality components such as specific gravity, dry matter, starch and reducing sugar concentrations (Lynch et al., 1995; Gunel and Karadogan, 1998; Haverkort and Mackerron, 2001; Haverkort and Verhagen, 2008). Hence, these consequences of the stress would be a challenge for potato growers and processing industries competing for sustainable production and supply of high quality potato products in the market. Although research findings clearly showed on how water stress affects potato production, the extent that yield and mainly quality components of potatoes that are potentially affected by water stress under the current unpredictable climate change scenarios is not well known. Under such circumstances, a need was raised to investigate how potato plants respond to different water stress situations, which might happen at different physiological growth stages during the season.

Hence, the present study evaluated water stress of 80-100 kPa soil water tension (SWT) at full emergence and tuber-bulking growth stages of a potato variety for transient (temporary) periods and fluctuated water stress conditions. The study investigated the response of different growth parameters such as plant height, number of stems per plant, tuber yield and some processing qualities of a potato variety to the stress treatments and identified the critical water stress and growth stages under which tuber yield and quality are significantly affected.

MATERIALS AND METHODS

Experiment site

The experiment was carried out in a greenhouse at Højbakkegård Alle 21, 2630, Faculty of Life Sciences, University of Copenhagen, Tåstrup from January through July 2009. During the course of the experiment, the greenhouse compartment had average day/ night temperatures of 17.8/14.5 ^{o}C, 62.8 % relative humidity, and 380ppm ambient CO_2 concentration. High Pressure Sodium Lamps (HPS) were used as source of supplementary light in the greenhouse during the period of 16/8 hours of day and night period.

Plant materials, experimental setup and treatment Randomization

Seed tubers of processing potato variety 'Royal' were obtained from the Danish Potato Breeding Foundation (LKF), Vandel, Grindstedvej, Denmark. Seed tubers were planted (1 tuber per a 10 liter rectangular plastic container) filled with peat soil at a depth of 10 cm. When plants were fully emerged (4 weeks from planting), 12 experimental potted plants were randomly assigned for each water stress treatment (experimental unit) in three replications for a total of six treatments, which were arranged using a completely randomized design (CRD).

Description and application of water stress treatments

Stress treatments were applied based on the successful irrigation criteria set for potatoes grown in different soil types (Shock et al., 2006). SWT of 80-100 kPa for water stress, 20-30 kPa for time to irrigation, and 10 kPa for field capacity were used in the experiment to schedule and apply the stress treatments.Six water stress treatments were evaluated in the experiment including one control treatment. The treatments included 10 days water stress at full emergence (10DWSV);10 days water stress at tuber-bulking (10DWSTb); 15 days water stress at full emergence (15DWSV); 15 days water stress at tuber-bulking (15DWSTb); fluctuated water stress throughout the growing period (WSF) and zero stress (control). 10DWSV, 15DWSV and WSF were applied starting from the 4th week when potato plants were fully emerged while; 10DWSTb and 15DWSTb were applied from the 9th week when plants seized tuber set and entered in to tuber-bulking stage. End of tuber set and beginning of tuber-bulking was determined from indicator plants which were planted alongside the experimental plants and often checked for this growth period. Tuber set is normally synchronized with end of flowering time in potato plants.10DWSV, 15DWSV and WSF were applied by withholding irrigation (drip irrigation) water until the SWT dropped down to 80-100 kPa. In the case of the first two treatments (10DWSV and 15DWSV), plants were irrigated back to field capacity of the soil after the stress period was over and continued to be irrigated normally until irrigation was stopped at maturity. However, WSF was applied by switching the SWT between field capacity (10 kPa) and stress (80-100 kPa) from the onset of the stress until irrigation was stopped by supplying and with holding irrigation water. When 10DWSV, 15DWSV and WSF were applied, plants of the rest of the treatments (10WSDTb and 15DWSTb) were irrigated similar to the control plants and their SWT was maintained at field capacity until their stress window was open (tuber-bulking stage). At tuber-bulking stage (9 weeks from planting), 10WSDTb and 15DWSTb were applied in similar fashion as before by withholding irrigation water until SWT dropped down to 80-100 kPa and kept for 10 and 15 days respectively. The plants were then irrigated back to normal and continued to be irrigated until maturity.

During the first 4 weeks after planting, in which water stress treatments were not applied, all plants were supplied with the same amount and frequency of irrigation water guided by the daily soil water tension readings. The amount of irrigation water supplied to the plants was determined by calculating the amount of water loss measured at the time of irrigation based on the field capacity of the soil. The soil moisture was kept between 75-85 % field capacity during stress-free periods, in which the soil water tensions could be maintained between 20-30 kPa.

Installation of moisture sensors

A wet moisture sensor was installed per treatment in each replication in a soil at a depth of 10-15 cm, where plants' root system could spread through and function. Electrodes attached to one end of the sensors were kept outside the soil and used to measure the SWT with a digital soil moisture meter (watermark, model 200SS, THE IRROMETER COMPANY, INC. 1425 Palmyrita Ave., Riverside, CA 92507).

Data measurement

Soil water tension (SWT)

SWT readings were recorded daily in the morning from each moisture sensor installed per experimental unit using a digital moisture meter since the date of planting through the entire stress period. Curves (figure 1-1 and 1-2) were produced from average SWT readings per treatment using a CoHort Statistical software (version 6.204, 2003, USA). The curves depicted how the soil moisture status of potato plants were kept within the field capacity (10-30 kPa) during stress free periods and back to the stress window (80-100 kPa) when stress periods commenced.

Since the experiment was done in peat soil, the SWT took more number of days than expected to reach down to the stress window (80-100kPa) after irrigation was cut off. Therefore, the first week after the commencement of the stress treatment was not considered in the stress period. The curves also show that the demand for irrigation water by the plants was increased starting from 2 months from planting towards tuber set(March to April) and tuber-bulking stages. This might be due to the fact that potato plants utilize high amount of water during these growth stages and at the same time the rate of evapotranspiration could be high due to increased temperature in the months of March and April compared to the temperature in January and February. At tuber-bulking stage, potato tubers accumulate water along with nutrients and dry matter (INSAM, 2007).

Plant height and number of main stems per plant

Plant height (cm) and number of main stems per plant were measured and counted respectively for five consecutive weeks starting from full emergence (4^{th} week after planting) until end of flowering (9^{th} week after planting). Data for plant height and number of main stems per plant were measured on 12 plants per treatment in three replicates.

Tuber yield and size distribution

At maturity (12 weeks from planting), vines were topped off one week before harvest to enhance tuber's skin set. On the 13^{th} week from planting, each plant was harvested separately, and tubers were cleaned, weighed, counted and graded into three sizes: 'Big' (>55 mm), 'Medium' (40-55 mm), and 'small' (<40 mm) in diameter based on the available tuber size distribution. Data measurements on tuber yield and size distribution were done on 12 plants per treatment in three replicates.

Determination of tuber's specific gravity, dry matter and starch concentration

Non-destructive method was used to determine tubers' specific gravity (SG), dry matter and starch concentration.SG of the tubers were first determined by dividing weight of tubers in the air by the difference between weight of tubers in the air and water (*SG= weight of tubers in air/(weight of tubers in air - weight of tubers in water*)) (Henderson, 2000; Hass, 2004). The SG was then used in the regression equations to calculate tubers' dry matter and starch concentrations: *Starch (% FW) = -182 + (183 X SG) and Dry matter (%) = -210+ (213 X SG* (Haas, 2004). SG, dry matter and starch concentration were calculated from 5 randomly selected medium sized tubers harvested from each plant for a total of 12 plants per treatment in three replicates.

Color measurement on potato chips

Two medium sized tubers were randomly taken from a mix of tubers harvested per experimental unit for frying. Tubers were peeled and 2 slices were made from each tuber with a slicer at 2 mm thickness and dried with tissue

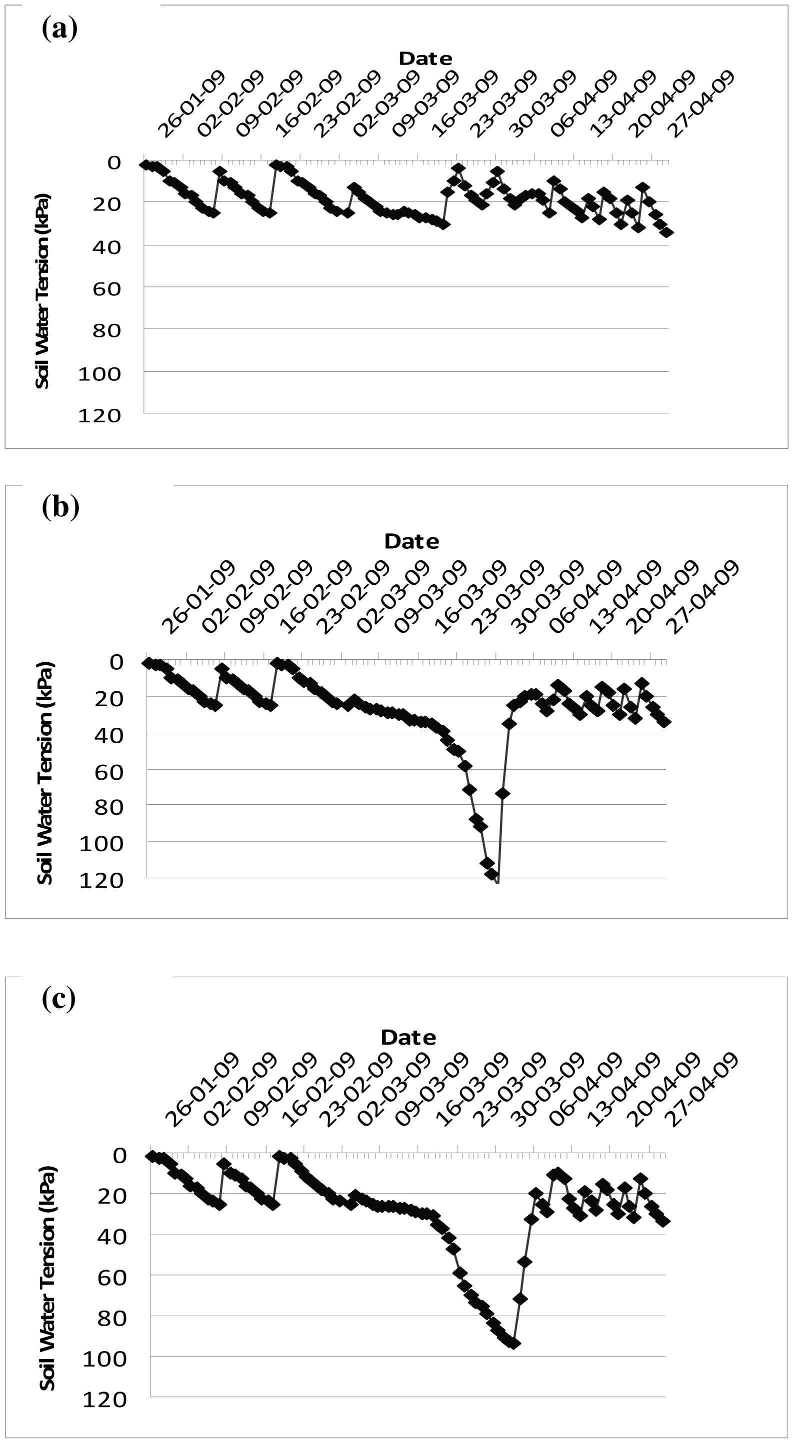

Figure 1-1. Soil water tension curves which were achieved after the water stress treatments: (a) Control, (b) 10DWSV and (c) 15DWSV were applied during the course of the experiment. Curves were produced from the daily records of average of the sensors' readings.

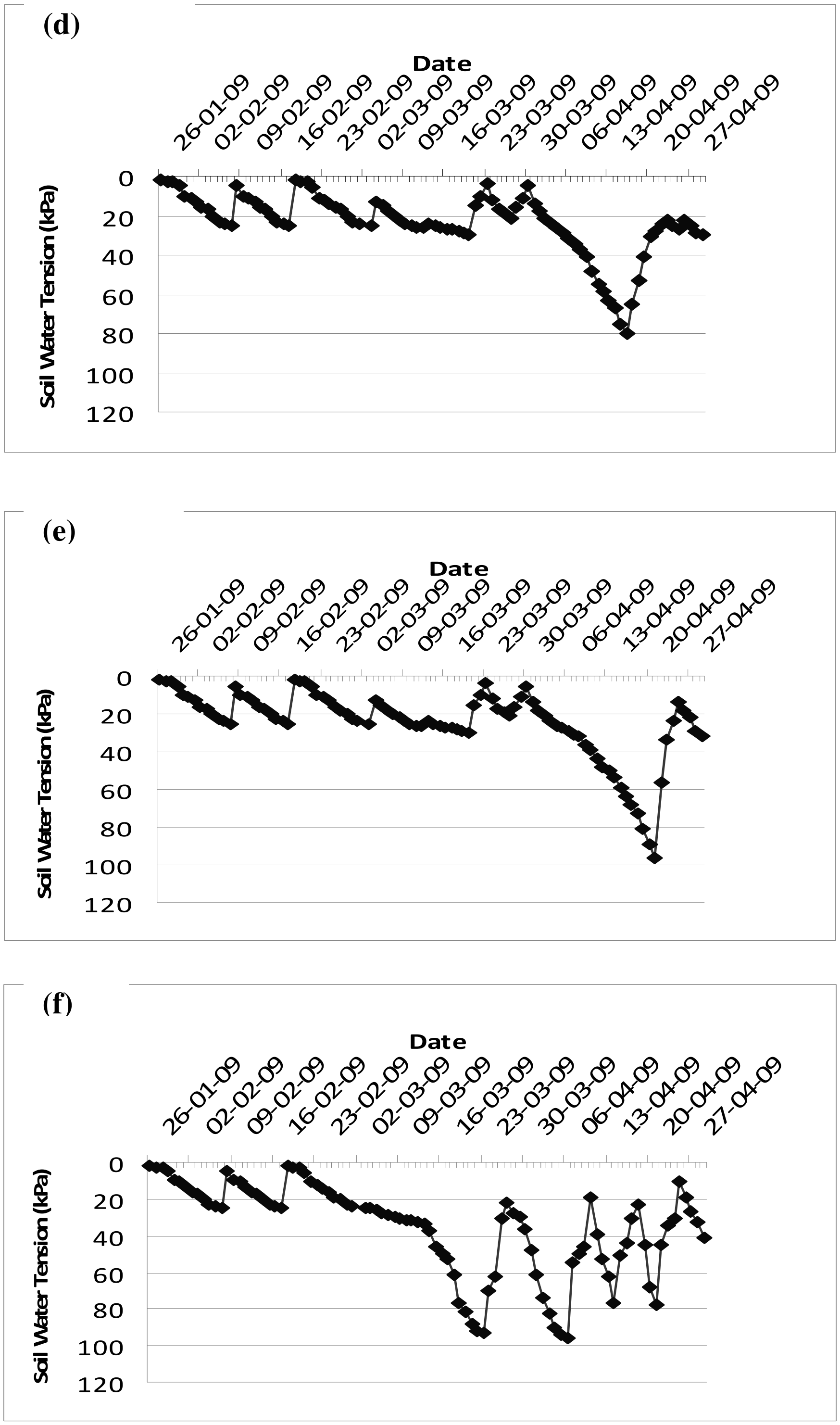

Figure 1-2. Soil water tension curves which were achieved after the water stress treatments: (d) 10DWSTbl, (e) 15DWSTb or (f) WSF were applied during the course of the experiment. Curves were produced from the daily records of average of the sensors' readings.

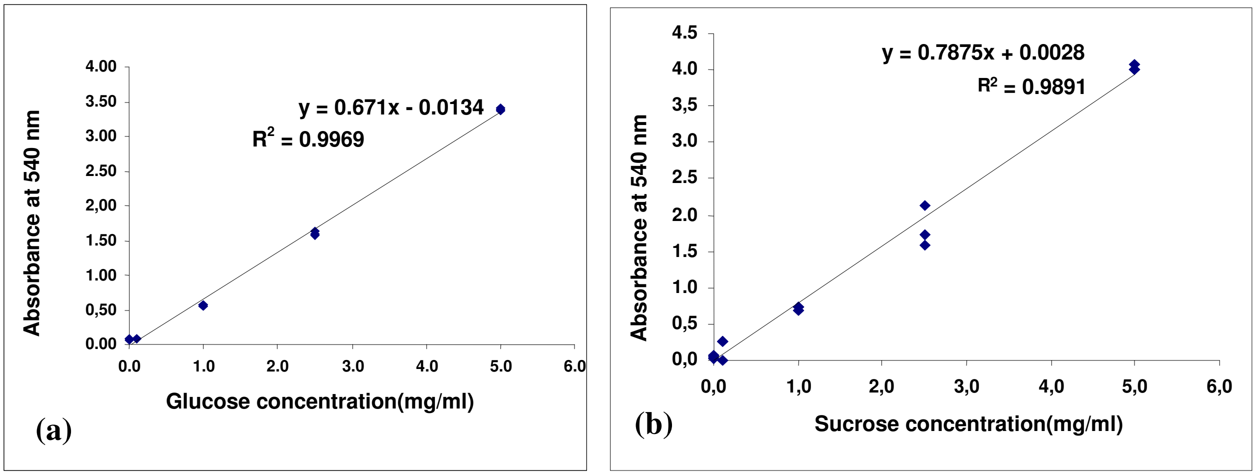

Figure 2. Standard curves developed from known concentrations of(a) glucose and (b) sucrose for the determination of sugars in the tubers.

paper to remove the starch sticked to it just before frying. The slices were fried in hot vegetable oil at 180 °C for 90 seconds (Takada et al., 2005). The fried potato chips were measured for color with Minolta Chroma Meter (CR-300) for “L”, “a” and “b” values to evaluate for the intensity of darkness (sugar ends) or color change after frying. L stands for the degree of lightness from dark to white, while a and b for color directions, where +a is for the red and –a is for the green direction, while +b and –b for the yellow and blue directions respectively (http://www.konicaminolta.com). Each measurement was done in triplicates.

Sugar extraction and measurement

For sugar extraction, HPLC (High Pressure Liquid Chromatography) sugar analysis method was used (Wicklund et al., 2005). Two medium sized randomly selected potato tubers per experimental unit were peeled and grated in to small pieces separately. About 1g of fresh sample was blended with 30 ml of Ethanol (96%), and mixed with 10 ml of deionized distilled water for 30 minutes. After 1 hour incubation at 4°C, the mixture was centrifuged at 3500 x *g* for 30 minutes at 4°C and the supernatant was thawed and kept at 4°C until analyzed.

Preparation of standard curves for glucose and sucrose

Before potato extracts were analyzed for sugars, standard curves were made from 4 known concentrations of glucose and sucrose (0, 0.1, 1, 2.5 and 5 mg/ml) by diluting stock solutions of glucose (50 mg/ml) and sucrose (50 mg/ml) in water (Rodriguez-Sanona and Wrolstad, 1997). Dinitrosalicylicacid (DNS) method was used to measure absorbance (color intensity) by mixing 0.5 ml of each glucose concentration with 1.5 ml of DNS reagent in a test tube and boiled at 90 °C in the water bath for 15 minutes (Miller, 1959). Then the mixture was cooled down in tap water and absorbance was measured with spectrophotometer at 540 nm and standard curve for glucose was produced (figure 2a). The sucrose solutions were first hydrolyzed to yield reducing sugars (glucose and fructose) followed by measuring absorbance at 540 nm using the same DNS method. The standard curve for sucrose was developed (figure 2b). Absorbance for each concentration solution for both glucose and sucrose was measured in triplicates.

Glucose and sucrose determination

DNS method was used to determine the concentration of glucose and sucrose in the tubers (Miller, 1959) following the procedure used for glucose and sucrose assays (http://www.eng.umd.edu). According to Sengupta *et al.* (2000), DNS reagent, containing 1% DNS, 2% NaOH (sodium hydroxide) and 20% sodium potassium tartrate (w/v), was prepared by dissolving each component in a minimum volume of water (50 ml) and then mixing DNS and tartrate solutions together followed by slowly adding the alkali solution (NaOH) in the mixture. About 1.5 ml of DNS reagent was then mixed with 0.5 ml of the sugar extract in a test tube and boiled at 90 °C in a water bath for 15 minutes. Then, the mixture was cooled down in tap water and absorbance was measured with

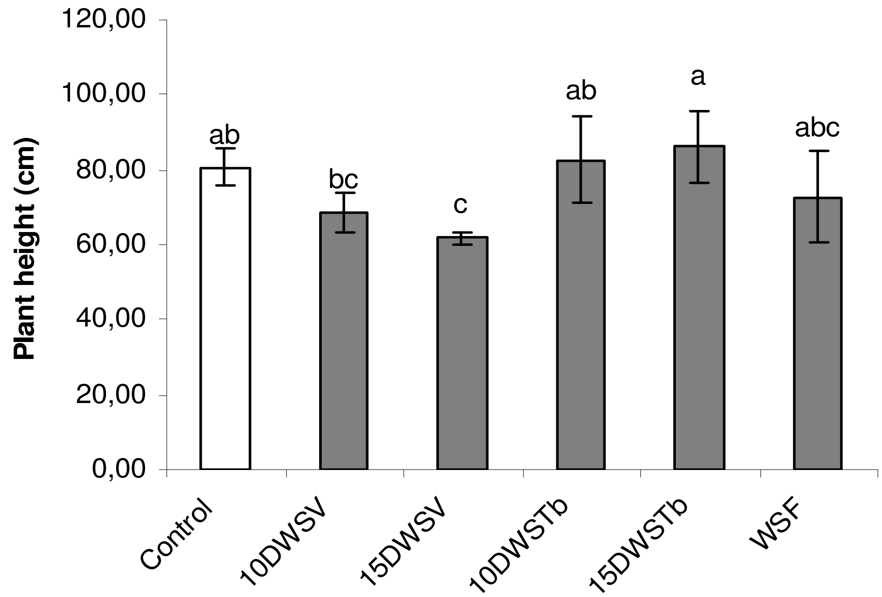

Figure 3. Effect of water stress on potato plant height. Mean plant height ± SD (n=12). Bars with different letters are significantly different (P<0.05). The mean values were compared using the Least Significance Difference (LSD) of 14.94. The treatments were 10 and 15 days of water stress (80-100kPa) at full emergence (10DWSV, 15DWSV), tuber bulking (10DWSTb, 15DWSTb), fluctuated throughout the growing period (WSF)and zero stress (control).

spectrophotometer at 540 nm.

The concentration of glucose in each sample was then calculated by using the linear regression equation: $y=0.671x-0.0134$, $R^2=0.9969$ obtained from the standard curve (figure 2a), where x stands for glucose concentration (mg/ml) and y for absorbance measured at 540nm due to the presence of reducing sugars (glucose). For sucrose determination, the sugar extract was first hydrolyzed by mixing 20 µl of concentrated HCL solution with 1ml of sugar extract in a test tube and boiled at 90°C in water bath for 5 minutes. The hydrolyzed sample was neutralized by adding 0.05ml of 5N KOH solution (http://www.eng.umd.edu). The same DNS method was followed to measure absorbance of the hydrolyzed samples with spectrophotometer at 540nm. The difference in absorbance between the hydrolyzed and the non-hydrolyzed samples were considered as absorbance due to sucrose and the concentration of sucrose was then calculated from the linear regression equation: $y=0.7875x+0.0028$, $R^2=0.9891$ obtained from the standard curve (figure 2b). Each sample of the sugar extract was measured in triplicates.

Data analysis

Data were analyzed using CoHort statistical software (version 6.204, 2003, USA) (http://www.cohort.com) and statistical differences between treatment means were detected using the Least Significance Difference (LSD) test at P<0.05 level.

RESULTS AND DISCUSSION

Plant height and number of main stems per plant

The effect of water stress on plant height and number of main stems per plant was significant (P<0.05). Water stress at full emergence significantly reduced plant height (figure 3) and number of main stems per plant (figure 4) as compared to the effect at tuber-bulking stage. The result showed potato plants could be able to recover from

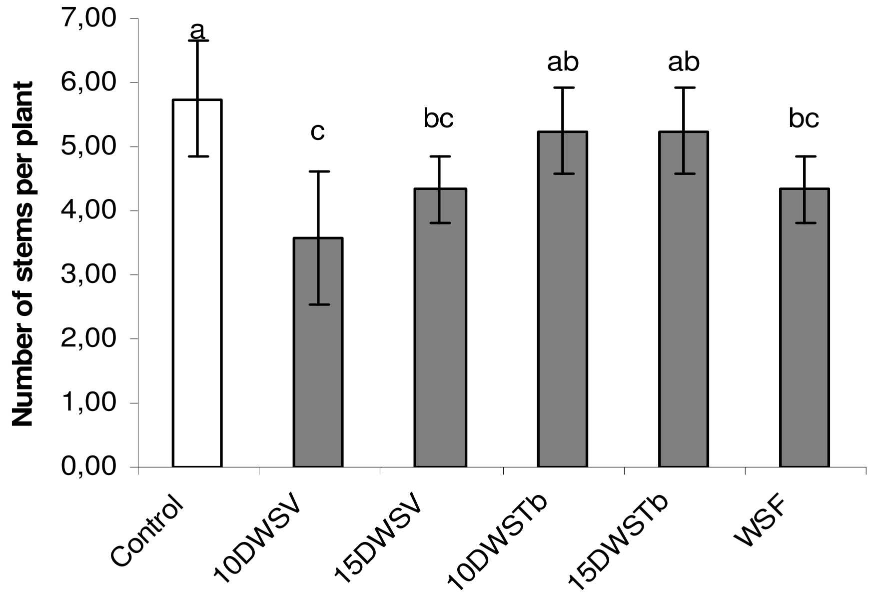

Figure 4. Effect of water stress on stem numbers per plant. Mean stem numbers ± SD (n=12). Bars with different letters are significantly different (P<0.05). The mean values were compared using the Least Significance Difference (LSD) of 1.33. The treatments were 10 and 15 days water stress (80-100kPa) at full emergence (10DWSV, 15DWSV), tuber bulking (10DWSTb, 15DWSTb),fluctuated throughout the growing period (WSF) and zero stress (control).

water stress fluctuation (WSF) than from transient water stress, which was imposed at full emergence(10DWSV and 15DWSV). However, significant difference was not obtained between the latter two stress treatments on plant height and number of stems. On the other hands, the two treatments at tuber bulking stage(10DWSTb and 15 DWSTb) did not cause significant difference on plant height and number of stems per plant. When the latter two treatments were applied (9 weeks after planting), vegetative growth including growth in plant height and changes in number of stems per plant are unlikely to happen and this contributed to the non-significant results.

The result also showed how water stress negatively influence potato plant growth when occurred during the vegetative growth stage, in which plants responded to the stress by slowly decreasing their growth in plant height and number of stems after the 6^{th} week (2 weeks from the onset of the stress) (figure 5 and figure 6). Potato production with limited water stress by King et al. (2003) stated that water stress during the vegetative growth stage reduced plant height and other vegetative growth parameters such as leaf area, root expansion and also caused delay in canopy development (the later three parameters are not included in this study).

Tuber fresh weight

The effect of water stress on tuber fresh weight per plant was significant (P<0.05). Water stress at both vegetative and tuber-bulking stages reduced tuber fresh weight. WSF caused the highest yield reduction (40%) followed by the temporary stress which stayed for 15 days at vegetative (15DWSV) or tuber-bulking stages (15DWSTb). The latter two stress treatments caused similar yield reduction (18%) compared to that of the zero stress (control) (figure 7, Table 1). King et al. (2003) showed yield loss from 7 to 14 % when potato plants were exposed to water stress from moderate (10 days) to severe (14 days) condition at tuber-bulking stage. Water stress fluctuation (WSF) caused double yield loss as compared to the yield loss caused by temporary stress

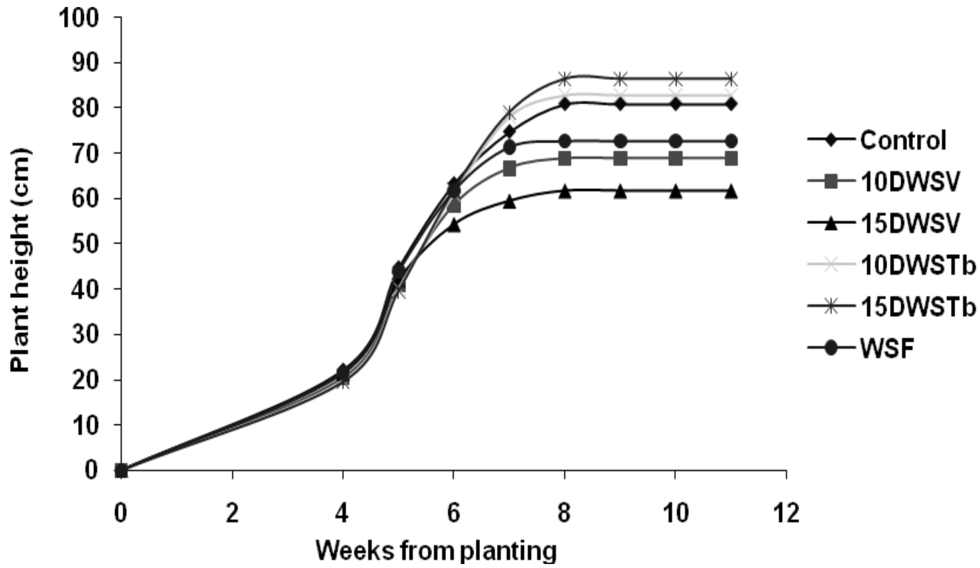

Figure 5. Potato plant growth in height as affected by water stress during vegetative or tuber bulking stages. Growth in plant height under water stress treatments (10 or 15 days water stress at vegetative growth stage(10DWSV, 15 DWSV) or water stress fluctuation, WSF) started to decline after the 6th week, whereas 10 or 15 days water stress at tuber bulking growth stage (10DWSTb, 15DWSTb) did not show any change on plant height as the plant already seized growing in height when the stress was imposed.

stayed for15 days at vegetative (15DWSV) or tuber bulking (15DWSTb) stages.

Tubers distribution by size

All water stress treatments showed non-significant effect on tuber numbers produced per plant (P<0.05). Despite the non-significant differences in tuber number between the stress treatments, the result showed the dominance of the 'medium' sized tubers (40-55mm) over the 'small' (<40mm) and 'large' sized (>55mm) tubers respectively in each of the stress treatments (Table 2). About 50-65 % of the tubers produced per plant were medium sized tubers followed by small (20-28%) and large (14-22%) sized tubers in all the treatments (Table 2). It was also observed that, plants under WSF treatment showed tuber cracks and some symptoms of common scab (data not available) on tubers' surfaces.

The results of tuber size distribution indicated the fact that the water stress treatments evaluated in this study were not severe enough to affect the number of tubers produced per plant and did not significantly affect tubers' size distribution. King et al. (2003) stated that water stress during vegetative growth stage reduced total number of tubers produced per plant. This effect on tuber numbers might not be the direct cause for the yield differences in this study. Other factors could contribute to the yield loss. The stress at vegetative stage observed in the present study such as on plant height (figure 3 and figure 5) might reduce the total amount of assimilates to be synthesized in the leaves and transported to the tubers. Whereas the stress at tuber-bulking stage might interfere with the dry matter accumulation and contributed to the yield loss. Other possible cause for the non-significant result on tuber size distribution could be of the nature of the soil (peat soil) used in the experiment. We observed that the peat soil used in our experiment retains moisture for extended period of time than expected and this might reduce the accuracy of some treatment applications such as 10WSTb and 15DWSTb and may led to affect the result.

Specific gravity, dry matter and starch concentration

Effect of water stress on specific gravity, dry matter and starch concentrations of tubers were significant (P<0.05).

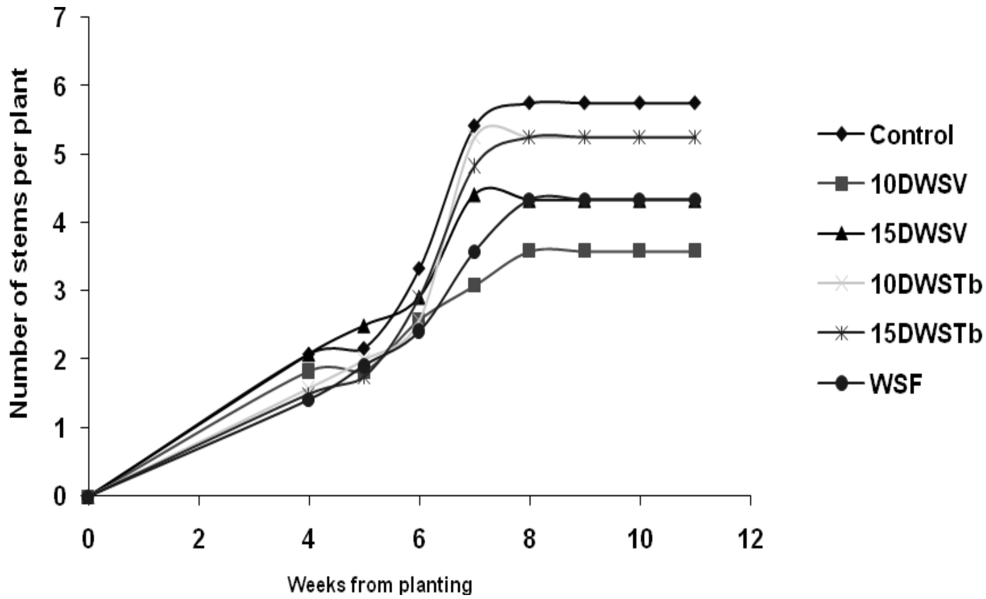

Figure 6. Plant growth in stems number as affected by water stress during vegetative and tuber bulking stages. Stem number under water stress treatments (10 or 15 days water stress at vegetative growth stage(10DWSV, 15 DWSV) or water stress fluctuation, WSF) started to decline after the 6th week, whereas 10 or 15 days water stress at tuber bulking growth stage (10DWSTb, 15DWSTb) did not show any change on number of stems, as plant growth in stem number already seized when the stress was imposed.

Table 1. Effect of water stress on tuber fresh weight produced per plant.

No.	*Water stress treatments	Fresh tuber Weight (g/plant)	% loss in tuber weight per plant relative to the control treatment
1	Control(zero stress)	579.82±38.50	-
2	10DWSV	501.715±4.99	13
3	15DWSV	475.27±11.66	18
4	10DWSTb	541.00±55.87	7
5	15DWSTb	474.81±19.27	18
6	WSF	348.37±29.14	40

Note: * 10DWSV and 15DWSV stand for 10 and 15 days water stress at vegetative stage; 10DWSTb and 15DWSTb stand for 10 and 15 days water stress at tuber-bulking stage; whereas WSF if for water stress fluctuation.

Temporary water stress for 15 days at tuber-bulking stage (15DWSTb) and fluctuated water stress (WSF) had significantly reduced tubers' specific gravity, dry matter content and starch concentration followed by 10 days water stress at tuber-bulking stage (10DWSTb). However, both stress treatments at vegetative growth stage (10DWSV and 15DWSV) did not affect tubers' specific gravity (figure 8), dry matter content and starch concentration (figure 9).

Gunel and Karadogan (1998) confirmed a significant

Table 2. Average number of tubers per plant in three grade sizes.

Treatment	<40mm	40-55mm	>55mm	Total
Control	2.58	7.58	2.08	12.25
	(21)	(62)	(17)	
10DWSV	2.25	5.83	1.92	10.00
	(23)	(58)	(19)	
15DWSV	2.83	7.17	1.67	11.67
	(24)	(62)	(14)	
10DWSTb	2.83	5.08	2.17	10.08
	(28)	(50)	(22)	
15DWSTb	2.92	6.08	1.75	10.75
	(27)	(57)	(16)	
WSF	1.75	5.58	1.25	8.58
	(20)	(65)	(15)	
LSD 0.05	1.08	4.21	1.14	3.94
	NS	NS	NS	NS

Note: * 10DWSV and 15DWSV stand for 10 and 15 days water stress at vegetative stage; 10DWSTb and 15DWSTb stand for 10 and 15 days water stress at tuber-bulking stage; whereas WSF if for water stress fluctuation. $LSD_{0.005}$ stands for least significant difference at 5% probability. Numbers in brackets are percent of number of tubers produced per plant in each treatment across each grade size. Numbers with the same letters are not significantly different (P<0.05).

Table 3. Average values of glucose and sucrose concentration (mg/g) of fresh potato tubers, values of chromameter color measurement of potato chips fried potato slices (L*, a* and b*).

Treatment	Glucose (mg/g)	Sucrose (mg/g)	L*	a*	b*
Control	0.32c	0.06c	-2.47	-9.10	49.57
10DWSV	0.42c	0.11c	-0.85	-10.04	48.76
15DWSV	0.30c	0.15c	0.08	-9.61	51.14
10DWSTb	3.08a	2.34a	1.35	-9.69	51.66
15DWSTb	2.92a	2.07a	0.93	-9.45	52.08
WSF	2.03b	1.33b	1.81	-9.60	51.40
LSD 0.05	0.60	0.60	3.12	1.46	2.67
	***	***	NS	NS	NS

Note: 10DWSV and 15DWSV stand for 10 and 15 days water stress at vegetative stage; 10DWSTb and 15DWSTb stand for 10 and 15 days water stress at tuber-bulking stage; whereas WSF if for water stress fluctuation. $LSD_{0.005}$ stands for least significant difference at 5% probability. Numbers with the same letters are not significantly different (P<0.05). *L stands for the degree of lightness from dark to white, while a and b for color directions, where +a is for the red and –a is for the green direction, while +b and –b for the yellow and blue directions respectively. Numbers with different letters are significantly different (P<0.05).

increase in specific gravity, dry matter and starch content when frequent irrigation was maintained during growth stages from planting to stolon initiation and stolon initiation to tuber-bulking. King et al. (2003) also discussed the negative effect of water stress in that, dry soil conditions late in the growing season (tuber-bulking in this case), not only reduce yield, but also reduce specific gravity. According to Harverkort et al. (2008),

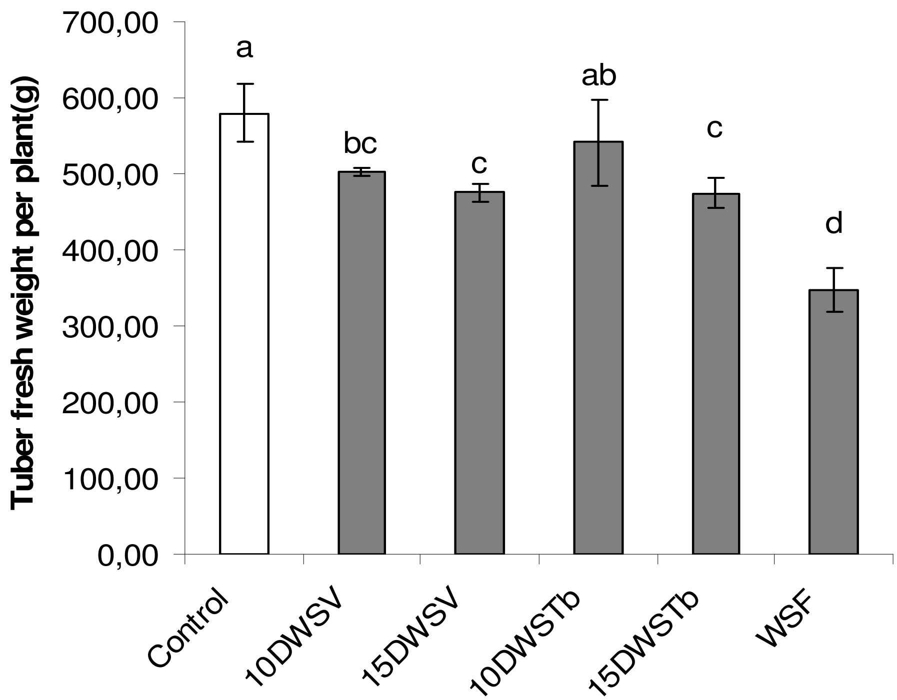

Figure 7. Mean tuber fresh weight per plant ± SD (n=12). Bars with different letters are significantly different (P<0.05). The mean values were compared using the Least Significance Difference (LSD) at 5% probability. The treatments are 10 or 15 days water stress (80- 100kPa) at vegetative (10DWSV, 15DWSV), tuber bulking (10DWSTb, 15DWSTb) or fluctuated throughout the growing period (WSF) or zero stress (control).

tubers' dry matter concentration less than 17% is un acceptable due to poor storability and processing quality. Hence, the dry matter concentration obtained from two of the treatments (15DWSTb and WSF) in the present study (14.4% and 12.57% respectively) was bellow the requirement for good storage and processing quality. Kumar et al. (2004) stated that drought can cause failure in process of deposition of starch or increase conversion of starch to free sugars. When potato plants were imposed for water stress at tuber-bulking stage, tubers undergo accumulation of water, nutrients and carbohydrates (INSAM, 2007) which might cause for lower starch and dry matter concentration.

Glucose and sucrose concentration of potato tubers

Concentration of glucose and sucrose in potato tubers were significantly affected by water stress treatments (P<0.05). Water stress at tuber-bulking stage increased the concentration of glucose and sucrose in the tubers compared to stress at vegetative stage (Table 3). Similar study by Eldredge et al. (1996) showed that temporary water stress (32-107 kPa) at tuber-bulking stage increased the amount of reducing sugars in tubers two weeks or longer after the stress was relieved. Kumar et al. (2004) discussed the role of drought in the accumulation of reducing sugars in potato tubers and suggested that failure in starch deposition process and /or increased conversion of starch to free sugars might be the reason for reducing sugar accumulation. However, despite the significant variations in concentration of reducing sugars (glucose) between the stress treatments, the color measurement of L*, a* and b* values on the potato chips showed a non-significant differences between them (Table 3).

The non-significant differences between water stress treatments for color of potato chips could be due to the

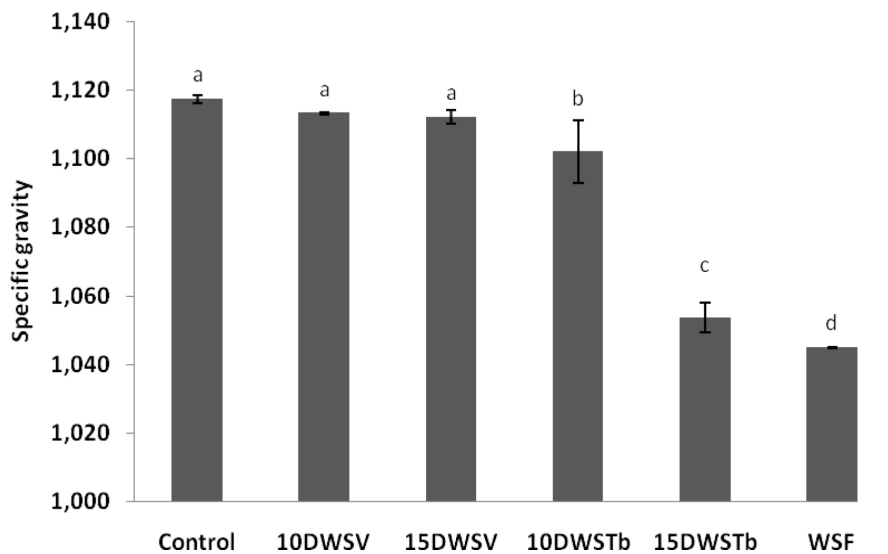

Figure 8. Effect of water stress on tubers' specific gravity. Mean tubers' specific gravity per plant ± SD (n=12). Bars with different letters are significantly different (P<0.05). The mean values were compared using the Least Significance Difference (LSD) of 0.007. The treatments are 10 or 15 days water stress (80-100kPa) at vegetative (10DWSV, 15DWSV), tuber bulking (10DWSTb, 15DWSTb) or fluctuated throughout the growing period (WSF) or zero stress (control).

low concentration of glucose in the tubers resulted from the stress on this particular cultivar 'Royal'. Pritchard and Adam (1994) confirmed that the amount of sugars in mature tubers and the resulting chip color varies between cultivars. In cultivar 'Russet Burbank' with a glucose concentration of less than 2.1 mg/g or cultivar 'Shepody' with a glucose concentration of less than 1.8 mg/g produce French fries which should meet processor specifications for color. Rodriguez-Sanona and Wrolstad (1997) suggested that reducing sugars do not completely explain or predict color quality on fried potato slices when present in low concentration (ca.<60 mg/100g), and other reactants such as amino acids, ascorbic acid and phenolic acids might explain the non-enzymatic browning of potato chips.

CONCLUSION

Early stage water stress at full emergence showed more influence on yield than quality, whereas stress at the later stage at tuber bulking was found to be more severe on tuber quality components. Besides, fluctuated water stress was found to be more critical than stress for temporary periods. This would urge growers/or breeders to develop appropriate irrigation management strategies, cultural practices (such as time of planting), or investing on breeding drought tolerant varieties in the future to cope up with such problem and sustain their production and supply of quality potato raw material. To draw a conclusive remark, this greenhouse study is not satisfactory. Therefore, we would recommend conducting more experiments out in the field and carrying out additional quality assessment on other tuber constituents, such as amino acids, ascorbic acids and phenolic acids, which were identified in other studies as important reactants to play role in color quality of potato chips during frying. It is also vital to evaluate this particular variety in storage if there is any change in reducing sugars and color of fried products. This study could have affirmative contribution to Ethiopia's potato production, where moisture shortage is critical. It may help potential potato growers to supply better raw material for those small-scale potato processing plants currently booming in most cities of the country making chips and french fries out of it. The result may also add an input to potato

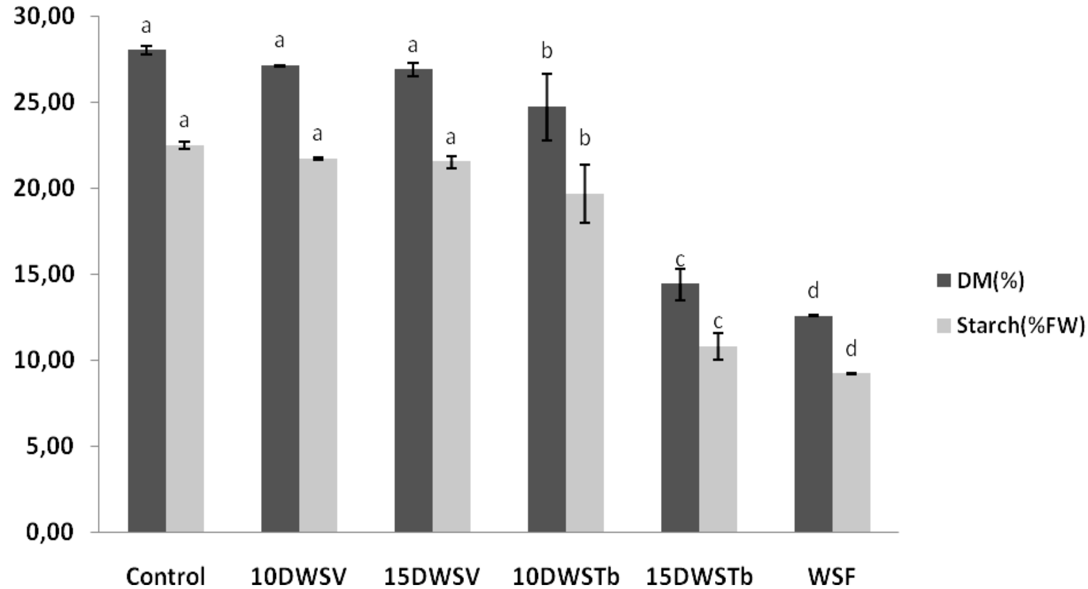

Figure 9. Effect of water stress on tubers' dry matter (%) and starch concentration (%FW). Mean tubers' dry matter or starch concentration ± SD (n=12). Bars with different letters are significantly different (P<0.05). The mean values were compared using the Least Significance Difference (LSD) of 1.40 and 1.20 for dry matter and starch respectively. The treatments are 10 or 15 days water stress (80-100kPa) at vegetative (10DWSV, 15DWSV), tuber bulking (10DWSTb, 15DWSTb) or fluctuated throughout the growing period (WSF) or zero stress (control).

breeders/ agronomists to consider quality parameters such as specific gravity, starch and dry matter contents in their research programs while selecting suitable varieties for different purposes rather than using tuber yield as a sole parameter.

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