Differential response of two cultivar groups of *Solanum aethiopicum* to water deficit stress

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Abstract

Two groups of *Solanum aethiopicum* were evaluated for drought stress under screenhouse conditions in a factorial experiment laid in a completely randomized design with four replications. The evaluation was done at three stages of growth (seedling, vegetative and flowering). Watering was done until a desired stage was reached respectively. Data was collected on different yield parameters (leaf length, leaf width, number of green leaves) and plant status parameters which included, chlorophyll, stomatal conductance and visual wilting score. Soil moisture content per pot was also routinely monitored. Results from the general analysis of variance exhibited significant differences between groups, stage and well-watered vs stressed. There was a significant decrease ($p<0.01$) in number of green leaves, leaf length, leaf width, stomatal conductance and soil moisture content with increasing stress. On the other hand, a general increase ($p<0.01$) was recorded in chlorophyll content and leaf wilting score was observed with increasing stress. At all evaluated developmental stages, water deficit stress negatively affected both Shum and Gilo groups of *Solanum aethiopicum.* However, the vegetative stage was greatly constrained as compared the other stages. Despite the significant constraint for both groups under water deficit stress at vegetative stage, different drought tolerance mechanisms are exhibited. Furthermore, The Shum group depicted a relatively higher degree of drought tolerance as compared to Gilo thereby providing a more reliable source of drought tolerant genes which could be transferred to other Solanum species.

Keywords:
Drought tolerance mechanisms; plant growth stage; plant health status; *Solanum aethiopicum* Gilo; *Solanum aethiopicum* Shum

Introduction

The Gilo and the Shum cultivar groups of the African eggplant (*Solanum aethiopicum*) are one of the most widely cultivated and consumed vegetables in Sub-Saharan Africa The Gilo group is cultivated for fruit while Shum for leaves (Plazas et al., 2014). This crop has got both economic and nutritional importance. The nutritionally rich African eggplant production is an important occupation to many people that contributes significantly to household income and diets (Omulo, 2016). It is low in calories, has high carotene content and is a good source of iron, thiamine, riboflavin, and nicotinic acid (Chinedu *et al.,* 2011; Sodamade *et al*., 2015). Increased vegetable production of this crop is constrained severally by water stress among other challenges (Limbu et al., 2018; Ssekabambe and Odongo, 2011; Zziwa and Kabirizi, 2015). Breeding for drought tolerance is considered as an important strategy in mitigating drought effects, therefore, identification of parental material for drought resistance is key. Given the increasing drought episodes that is complimented with limited research, development of drought-tolerant varieties suitable for water deficit environment becomes a feasible option for improving production (Kumar *et al*., 2016). However, development of drought-tolerant varieties requires a good understanding of the different drought adaptation mechanisms which are dependent on cultivars (Limbu et al., 2018; Zandalinas et al. (2016a, 2017). Furthermore, understanding the drought adaptation mechanism from different cultivars will unfold the possibility of transforming drought tolerance genes across cultivars. Different crop cultivars have evolved morphologically, physiologically and biochemically in order to adapt to different environment using different strategies (Zu et al., 2017) for example, the Gilo cultivar of *Solanum aethiopicum* has stellate hairy leaves while the Shum cultivar has glabrous leaves. The hairiness nature helps to prevent excessive evapotranspiration thereby enabling the plant leaves to maintain its turgor.

Drought causes significant reduction in production by reducing leaf size, plant height, shoot biomass and number of leaves (Bbebe *et al*., 2015). This reduced productivity is as a result of reduced water uptake which ultimately affects nutrient uptake from the soil. Plant cells then lose turgor causing wilting and the stomata closure in order to regulate excessive water loss. Stomatal closure ultimately results in reduced metabolism and un-sustained photosynthesis and is visibly identified by wilting symptoms. The extent to which plants withstand these effects of drought in highly stage specific and greatly dependent on cultivars (Haddadin et al., 2013).

Due to the limited research carried out on these crops, there is little information on the response to drought screening within *S.aethiopicum* cultivar groups. The stage of growth that is most affected by drought is also not clearly determined in these cultivars. Research in some other crops such as rice (Silveira et al., 2015), millet (Seghatoleslami et al., 2008) has been done to exhibit resilience amidst water stress at critical stages of seedling establishment and reproductive stages of development (Bbebe *et al*., 2015) however there is little similar literature in *Solanum aethiopicum.* Therefore, this study was carried out to characterize Shum and Gilo in relation to their water requirement in order to identify the appropriate soil moisture level for screening of *S. aethiopicum* groups for drought tolerance. And specifically, to determine an appropriate growth stage for drought tolerance screening based on morphology and physiology thereby defining a protocol that can be applied for screening large germplasm.

Materials and Methods

Study location

This study was conducted in Mukono district, at Uganda Christian University in a screenhouse. Mukono lies at an altitude of 1158 m to 1219 m above sea level and receives two wet seasons with an annual rainfall ranging between 1100 mm to1400 mm. The temperature ranges between 21^0C to 29^0C with coordinates 00^020'N 32^045'E. However, during two seasons were experienced a dry season from December 2017 up to March 2018 and wet season from April to June. This experiment generally run from December, 2017 to June, 2018 and the temperature ranged between 18^0C to 42^0C.

Plant material and experimental conditions

Two genotypes of *Solanum aethiopicum* (Gilo- and Shum-) from the seed bank at Uganda Christian University were evaluated. A factorial experiment was laid in a completely randomized design with four replications. Serial planting was done for each stage of evaluation. Seedling stage was evaluated in January, 2018; vegetative stage in February, 2018 while flowering stage was evaluated in April, 2018. Seed was directly sown in pots with a mixture of sterilized loam soil: manure in a ratio of 3:1. Plants were watered on a daily basis after emergence, maintaining field capacity (47-49%) after soil moisture determination. Drought stress was imposed to plants at three developmental stages: seedling stage (four weeks after planting-4WAP); vegetative stage (six weeks after planting-6WAP) and reproductive stage at flowering (eight weeks after planting-8WAP) respectively.

Data collection

For each developmental stage and water level, eighty plants were evaluated and data was collected on all individual plants every after two days. The information captured included: leaf length, leaf width (Vitra et al., 2019), number of leaves (Zhang et al., 2015), wilting score (Fang and Xiong, 2015), stomatal conductance (Blackman et al., 2018) and chlorophyll content. Leaf length and leaf width was taken using a meter ruler considering the longest point of the leaf (from the tip to the start of the petiole) and the widest part of the leaf respectively. Wilting score was visual and a scale of 1-5 was used where 1=No stress at all and 5 = complete wilting of the plant. Stomatal conductance was measured using a leaf porometer while chlorophyll was measured using a hand held chlorophyll meter on the third most upper fully open leaf. Soil moisture content, screen house temperature and relative humidity were also recorded on a daily basis.

Statistical Analysis

To investigate the effect of treatment and group in each developmental stage, the obtained data were subjected to general analysis of variance (ANOVA) using LSD test at the significance level of 0.05. This was done after data entry in Microsoft excel and sorting. A correlation analysis was conducted to evaluate the relationship between yield traits and plant status traits. Separate regression analysis was performed to determine the relationship between soil moisture content and chlorophyll, leaf length and leaf wilting score. All analyses were done using STATA/MP 14.0 and Genstat software twelfth version

Results

Drought stress response of *S. aethiopicum* Shum and Gilo based on; leaf length, leaf width, number of leaves, wilting score, stomatal conductance and chlorophyll content

During drought stress, yield traits such as leaf length, leaf width and number of leaves as more stable traits according to Kabod et al. (2018) plus plant health status traits like chlorophyll, stomatal conductance and leaf wilting score are critical in screening for water deficit tolerance. All evaluated yield traits decreased with decreasing soil moisture while plant health status traits increased with decreasing soil moisture content. The duration of drought to leading to critical levels was shorter at vegetative stage, followed by flowering stage and then seedling stage. The results showed that under well-watered conditions both *S. aethiopicum* Shum and Gilo significantly gave better growth ability than under water-stressed conditions as shown in Table 1, 2 and 3. *Solanum aethiopicum* Shum comparatively had the highest growth ability group under both conditions. In *Solanum aethiopicum*, growth potential under water deficit is dependent upon the number of green leaves per plant, leaf size, chlorophyll content, and stomatal conductance in relation to the moisture content in the soil. In this study, the reduction in plant growth under water stress was associated with all studied traits.

Difference in drought response of *S. aethiopicum* Shum and Gilo at seedling stage

At seedling stage across days the Shum had a mean of 13.7±4.1, 11.0±2.5; 11.4±3.6, 9.2±2.3; 174.7±86.6, 109.8±45.6; 9±5.8, 4±0.4; 1±0.0, 2±0.9; 345.4±67.8, 139.8±78.4; 36.7±3.9, 58.9±22.2; and 46.5±1.1,17.5±11.6 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively (Well-watered, Stressed). Gilo had different means for well-watered and control; mean 15.1±4.6, 12.3±3.2; 12.2±4.2, 9.4±2.3; 202.9±114.7, 123.3±66.9; 4±1.0, 3±1.2; 1±0.9, 2±1.1; 335.5±79.5, 178.9±154.4; 50.5±18.5, 63.1±27.1; and 46.5±1.1, 14.1±11.2 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively.

Table 1: Changes in Growth and plant health status traits of *S. aethiopicum* Shum and Gilo under different moisture levels at seedling stage

Group	Day	LBL		LBW		LA		LPP		LWS		SC		CHL		SMC	
		WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	W
	1	5.9	5.5	4.8	4.3	31.1	26.1	3	3	1	1	401.0	174.3	27.1	24.0	47.2	3
	2	5.9	8.1	4.9	6.6	31.7	57.4	3	4	1	1	311.0		35.0	31.0	48.3	3
	3	8.9	8.7	7.5	7.1	72.5	67.4	4	4	1	1	287.6	273.7	34.6	32.5	48.6	3
Shum	4	10.9	11.0	9.6	9.5	112.6	108.4	4	4	1	1	397.8		37.2	39.5	47.6	2
	5	12.0	11.4	10.6	9.7	135.5	116.5	5	4	1	1	319.3	125.7	43.2	44.7	46.5	1
	6	14.7	13.5	13.1	11.8	192.7	162.9	6	4	1	1			43.7	60.9	46.9	1

	7	15.0	13.5	13.2	11.8	210.2	162.3	6	4	1	2	215.8	134.9	38.2	61.3	47.5	1
	8	17.0	12.8	15.0	11.4	261.5	149.6	8	4	1	2			36.7	69.1	46.0	
	9	14.6	11.7	10.4	9.1	156.7	109.3	9	4	1	2	404.9	74.6	35.6	71.6	46.4	
	10	17.3	11.9	16.5	10.0	291.0	112.3	13	4	1	3			38.9	75.8	45.3	
	11	19.1	14.7	16.4	12.2	320.1	181.4	10	4	1	3	320.3	55.5	34.0	85.2	45.6	
	12	16.4	10.1	13.3	8.3	223.3	86.9	15	4	1	3			38.2	85.6	45.2	
	13	16.2	10.1	12.7	8.3	210.3	86.9	17	4	1	3	441.7		36.9	84.7	45.1	
	14	15.8		11.9		195.0		19		1				35.3		45.5	
	15	15.3		11.2		176.9		20		1		354.9		35.8		46.1	
	Mean	**13.7**	**11.0**	**11.4**	**9.2**	**174.7**	**109.8**	**9**	**4**	**1**	**2**	**345.4**	**139.8**	**36.7**	**58.9**	**46.5**	**1**
	Stdev	**4.1**	**2.5**	**3.6**	**2.3**	**86.6**	**45.6**	**5.8**	**0.4**	**0.0**	**0.9**	**67.8**	**78.4**	**3.9**	**22.2**	**1.1**	**1**
Gilo	1	8.6	19.8	7.0	14.5	60.1	293.3	3	7	3	1	400.1	461.5	85.3	45.0	47.5	3
	2	8.3	8.7	6.6	6.5	56.8	58.9	3	3	4	1			87.2	19.4	46.3	2
	3	8.5	13.3	6.3	10.3	54.9	141.7	4	4	1	1	339.0	241.3	25.5	33.8	48.3	1
	4	13.0	13.5	10.2	10.4	136.7	145.3	4	3	1	1			36.5	33.8	45.9	1
	5	13.7	14.7	10.7	10.9	149.6	163.1	4	4	1	2	255.0	145.7	33.1	48.7	47.1	1
	6	15.5	14.2	11.6	10.7	181.2	154.2	5	4	1	2			46.7	51.6	46.3	
	7	16.1	12.1	12.5	9.8	203.5	121.3	4	3	1	3	377.3	110.1	49.0	82.2	45.9	
	8	19.2	11.8	16.7	9.3	323.4	112.3	6	3	1	3			52.1	83.2	45.9	
	9	18.3	11.2	15.9	9.0	294.6	103.5	5	3	1	3	223.9	65.8	48.0	88.8	46.3	
	10	20.8	10.5	18.3	8.2	383.3	88.2	5	2	1	3			52.0	84.8	45.1	
	11	19.2	8.6	16.3	6.6	315.4	58.1	5	2	1	4	417.8	49.1	48.1	86.3	45.1	
	12	19.5	9.1	14.0	6.9	275.2	40.3	6	2	1	4			43.0	99.5	48.6	
	Mean	**15.1**	**12.3**	**12.2**	**9.4**	**202.9**	**123.3**	**4**	**3**	**1**	**2**	**335.5**	**178.9**	**50.5**	**63.1**	**46.5**	**1**
	Stdev	**4.6**	**3.2**	**4.2**	**2.3**	**114.7**	**66.9**	**1.0**	**1.2**	**0.9**	**1.1**	**79.5**	**154.4**	**18.5**	**27.1**	**1.1**	**1**

Where LBL-leaf blade length, LBW-leaf blade width, LA- leaf area, LPP- number of green leaves per plant, LWS-leaf wilting score, SC-stomatal conductance, CHL-chlorophyll content and SMC-soil moisture content.

Difference in drought response of *S. aethiopicum* Shum and Gilo at Vegetative stage

At vegetative stage *S. aethiopicum* Shum had the following means across days where the first value represents the well-watered and the second represents the stressed; 15.5±0.9, 11.7±0.8; 13.3±0.8, 9.8±0.9; 211.6±23.4, 101.2±43.2; 8±3.1, 3±1.3; 1±0.0, 3±1.4; 426.5±42.8, 262.4±142.2; 44.9±1.7, 72.1±12.5; and 44.8±1.1, 11.9±6.1 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively. Gilo had the following means across days; 21.1±2.8, 14.4±0.7; 15.8±2.4, 10.8±1.1; 353.8±89.3, 122.7±54.8; 8±0.8, 3±1.0; 1±0.0, 3±1.2; 296.3±30.9, 163.8±24.2; 35.4±3.8, 49.6±10.3; and 44.8±0.5, 9.4±5.8 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively.

Table 2: Changes in Growth and plant health status traits of *S. aethiopicum* Shum and Gilo under different moisture levels at vegetative Stage

Group	Day	LBL		LBW		LA		LPP		LWS		SC		CHL		SMC	
		WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	W[illegible]
	1	13.8	12.6	11.8	10.9	168.8	141.2	5	5	1	1	463.8	419.4	42.3	91.3	45.5	[illegible]
	2	15.3	12.5	13.1	10.7	205.5	139.5	6	5	1	1	406.4		44.2	52.7	42.6	[illegible]
	3	15.7	11.4	13.8	9.5	216.8	117.2	7	4	1	3	392.5	142.4	45.5	69.1	45.8	[illegible]
	4	15.7	11.6	13.7	9.6	219.8	112.5	11	3	1	3	388.8		47.3	77.1	45.1	[illegible]
	5	16.4	11.1	14.2	9.1	238.0	60.5	7	3	1	4	480.9	225.4	44.5	69.8	44.8	[illegible]
Shum	6	16.2	10.7	13.4	8.8	220.9	36.1	13	1	1	4			45.6	72.9	45.0	[illegible]
	Mean	**15.5**	**11.7**	**13.3**	**9.8**	**211.6**	**101.2**	**8**	**3**	**1**	**3**	**426.5**	**262.4**	**44.9**	**72.1**	**44.8**	[illegible]
	Stdev	**0.9**	**0.8**	**0.8**	**0.9**	**23.4**	**43.2**	**3.1**	**1.3**	**0.0**	**1.4**	**42.8**	**142.2**	**1.7**	**12.5**	**1.1**	[illegible]
	1	18.4	15.6	14.0	11.9	276.5	197.2	7	5	1	2	316.6	181.0	36.2	49.6	44.8	[illegible]
	2	17.9	14.2	12.9	9.9	251.2	150.1	7	3	1	3			36.6	57.8	44.0	[illegible]
	3	23.5	14.4	18.4	11.5	442.7	127.5	9	3	1	3	260.7	146.7	40.8	62.0	45.0	[illegible]
	4	23.8	14.1	18.0	11.1	440.4	71.7	8	3	1	4			32.3	39.1	45.0	[illegible]
Gilo	5	21.7	13.8	15.8	9.4	358.0	67.0	8	3	1	4	311.7		31.2	39.8	45.1	[illegible]
	Mean	**21.1**	**14.4**	**15.8**	**10.8**	**353.8**	**122.7**	**8**	**3**	**1**	**3**	**296.3**	**163.8**	**35.4**	**49.6**	**44.8**	[illegible]
	Stdev	**2.8**	**0.7**	**2.4**	**1.1**	**89.3**	**54.8**	**0.8**	**1.0**	**0.0**	**1.2**	**30.9**	**24.2**	**3.8**	**10.3**	**0.5**	[illegible]

Where LBL-leaf blade length, LBW-leaf blade width, LA- leaf area, LPP- number of green leaves per plant, LWS-leaf wilting score, SC-stomatal conductance, CHL-chlorophyll content and SMC-soil moisture content.

Difference in drought response of *S. aethiopicum* Shum and Gilo at Flowering stage

Across days at flowering stage *S. aethiopicum* Shum had the following means for well-watered and stressed; 14.8±1.4, 13.5±2.2; 2.1±1.6, 10.8±2.2; 185.9±41.5, 148.8±59.5; 19±3.5,12±3.4; 1±0.0, 3±1.1; 483.4±120.5, 116.9±66.8; 37.3±3.3, 62.4±12.0; and 45.1±0.4, 11.9±12.8 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively. *Solanum aethiopicum* Gilo had the following; 18.1±2.3, 16.9±3.1; 13.7±2.1, 13.1±2.6; 258.2±74.2, 210.9±115.6; 16±7.8,8±2.2; 1±0.0, 3±1.3; 443.2±73.2, 100.6±35.5; 36.5±3.2, 59.3±11.7; and 45.3±1.7, 10.2±12.8 for leaf blade length, leaf blade width, leaf area, green leaves per plant, leaf wilting score, stomatal conductance, chlorophyll, and soil moisture content respectively.

Table 3: Changes in growth and plant health status traits of *S. aethiopicum* Shum and Gilo under different moisture levels at Flowering Stage

Group	Day	LBL		LBW		LA		LPP		LWS		SC		CHL		SMC	
		WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	W[illegible]
	1	15.8	16.3	13.6	13.7	220.6	223.4	12	14	1	1	569.9	196.2	39.1	42.9	45.2	[illegible]
	2	16.0	15.5	13.4	12.9	216.0	204.7	18	17	1	1	595.4	160.3	43.5	43.2	45.3	[illegible]
	3	15.3	14.4	12.5	11.7	196.8	175.1	18	18	1	2	613.8	223.4	39.7	55.7	45.8	[illegible]
	4	15.1	13.7	12.6	10.9	193.8	155.0	18	11	1	3	522.5	84.7	39.8	61.1	45.5	[illegible]
	5	16.7	15.5	14.2	12.7	246.2	201.3	20	10	1	2	637.8	93.9	35.1	61.7	45.1	[illegible]
	6	15.4	15.2	12.7	12.6	205.4	196.7	17	8	1	3	317.0	59.6	35.9	69.0	45.0	[illegible]
	7	13.6	11.0	10.5	8.1	143.5	82.3	23	11	1	3	322.5	64.9	34.2	68.1	44.7	[illegible]
	8	13.3	10.9	10.3	8.2	140.8	82.3	22	10	1	3	399.6	52.3	36.5	75.2	44.8	[illegible]
	9	12.3	11.3	9.2	8.4	112.6	86.8	24	10	1	4	455.1		36.4	74.2	44.9	
Shum	10	14.8	11.1	11.9	8.5	183.4	80.2	21	9	1	4	400.3		32.2	73.1	44.4	[illegible]
	Mean	**14.8**	**13.5**	**12.1**	**10.8**	**185.9**	**148.8**	**19**	**12**	**1**	**3**	**483.4**	**116.9**	**37.3**	**62.4**	**45.1**	[illegible]
Gilo	**Stdev**	**1.4**	**2.2**	**1.6**	**2.2**	**41.5**	**59.5**	**3.5**	**3.4**	**0.0**	**1.1**	**120.5**	**66.8**	**3.3**	**12.0**	**0.4**	[illegible]

1	22.2	21.2	17.3	16.6	400.9	361.4	8	9	1	1	364.0	132.4	33.8	37.0	44.8	4
2	21.7	21.2	15.9	16.5	354.6	357.2	9	9	1	1	480.8	175.1	38.5	46.0	44.1	1
3	17.9	21.2	14.5	16.5	264.6	357.2	11	9	1	2	403.1	88.2	37.5	55.2	50.0	1
4	18.0	17.1	14.4	14.1	265.2	246.5	11	11	1	3	592.4	73.3	39.2	59.2	44.6	[illegible]
5	18.1	15.5	14.4	12.5	266.5	198.6	18	8	1	3	532.1	70.6	32.7	51.4	45.1	[illegible]
6	18.2	14.5	14.5	11.1	269.2	164.4	18	6	1	3	407.6	86.4	40.6	70.3	45.2	[illegible]
7	16.2	15.5	12.2	12.3	202.8	151.4	17	5	1	4	359.3	92.0	36.4	72.8	44.6	[illegible]
8	16.5	14.4	12.3	11.4	208.7	141.5	17	5	1	4	429.3	87.0	34.8	66.9	45.1	[illegible]
9	15.8	13.5	11.3	10.1	184.1	84.0	21	5	1	4	431.3		40.5	66.9	45.4	[illegible]
10	15.9	14.6	10.3	9.9	165.5	47.1	35	8	1	5	432.6		31.5	67.5	44.1	
Mean	**18.1**	**16.9**	**13.7**	**13.1**	**258.2**	**210.9**	**16**	**8**	**1**	**3**	**443.2**	**100.6**	**36.5**	**59.3**	**45.3**	**1**
Stdev	**2.3**	**3.1**	**2.1**	**2.6**	**74.2**	**115.6**	**7.8**	**2.2**	**0.0**	**1.3**	**73.2**	**35.5**	**3.2**	**11.7**	**1.7**	**1**

Where LBL-leaf blade length, LBW-leaf blade width, LA- leaf area, LPP- number of green leaves per plant, LWS-leaf wilting score, SC-stomatal conductance, CHL-chlorophyll content and SMC-soil moisture content.

Effects of Drought Stress on yield and plant health status traits of S. aethiopicum Shum and Gilo at different stages of growth

Imposing drought stress to *Solanum aethiopicum* Shum and Gilo resulted into a highly significant ($p < 0.05$) differences in all evaluated variables. A general analysis of variance indicated that there was a significant difference between the three stages, two water levels, and group for almost all evaluated variables except for stomatal conductance between groups (<0.775). Based on interactions (Group x Water level), stomatal conductance, leaf width and soil moisture did not exhibit any significant differences. All variables exhibited significant differences with stage X Water level (WL) interaction. Group x Stage x Water level interaction did not exhibit significant differences with Chlorophyll, Stomatal conductance, wilting score and soil moisture content (Table 4).

Table 4: Summary of F.Pr for different evaluated traits

Source of variation	Degrees of freedom	Chlorophyll	Conductance	No. of green leaves	Leaf wilting score	Leaf length	Leaf width	Soil moisture content
Group	1	<.001	**0.775**	<.001	<.001	<.001	<.001	0.02
Stage	2	<.001	<.001	<.001	<.001	<.001	<.001	<.001
WL	1	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Group.WL	1	<.001	**0.762**	**0.012**	<.001	<.001	**0.117**	0.122
Stage.WL	2	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Group.Stage.WL	2	0.153	0.405	<.001	0.249	<.001	<.001	0.228

The effect of drought stress was determined at three different stages; seedling, vegetative and reproductive stage. A significant difference was observed in how both groups respond to drought at different stages (Table 4). The vegetative stage had the highest water requirement and highest wilting score over few days; six days for Shum and five days for Gilo. (Figure 1 and Figure 2).

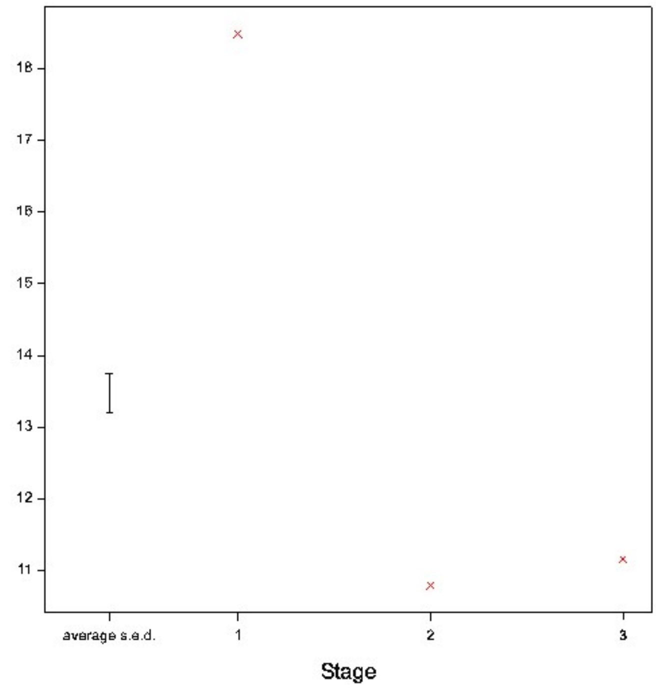

Figure 1: Water requirement for S. aethiopicum Shum and Gilo at different stages (1-Seedling stage, 2-Vegetative stage, and 3-Flowering stage

Relationship between yield and plant health status traits of S. aethiopicum Shum and Gilo with moisture content

To determine the relationship between yield and plant health status traits, a correlation analysis was conducted as in table 5 below. Both negative and positive strong correlations were observed among all evaluated traits. Basing on relationship between soil moisture content and all the other evaluated traits, some traits were selected for further analysis.

Table 5: Correlation between evaluated yield and drought tolerance indicator traits at vegetative stage

	LBL		LBW		LA		LPP		LWS		CHL		SMC	
	Shum	Gilo	Shum	Gilo	Shum	Gilo	Shum	Gilo	Shum	Gilo	Shum	Gilo	Shum	Gilo
LBL	1.000	1.000												
LBW	0.997	0.984	1.000	1.000										
LA	0.975	0.981	0.978	0.948	1.000	1.000								
LPP	0.809	0.983	0.821	0.958	0.806	0.971	1.000	1.000						
LWS	-0.804	-0.863	-0.828	-0.797	-0.883	-0.915	-0.665	-0.925	1.000	1.000				
CHL	-0.750	-0.558	-0.721	-0.593	-0.696	-0.423	-0.554	-0.619	0.461	0.437	1.000	1.000		
SMC	0.928	0.904	0.934	0.867	0.933	0.917	**0.759**	0.966	-0.881	-0.975	-0.809	**-0.611**	1.000	1.000

LBL-leaf blade length, LBW-leaf blade width, LA-leaf area, LPP=Number of green leaves per plant, LWS-Leaf wilting score, CHL-Chlorophyll, SMC-Soil moisture content

Considering the vegetative stage (the most affected stage), the difference in drought response between Gilo and Shum was determined. Without stress both the evaluated cultivars grew well however with increasing stress, to escape the harsh conditions, the Chlorophyll content of Shum drastically reduced by the third day at moisture content of approximately 14%, it thereafter increased to obtain its peak by the ninth day when soil moisture had dropped to 11% after which it become relatively constant. Gilo exhibited relatively lower amounts of chlorophyll compared to Shum despite the fact that it had a slightly different trend. The difference in the trend is that Gilo had a gradual increase in chlorophyll content from day one to the sixth day at approximately 10% soil moisture content where it obtained its peak thereafter gradually reduced until the last day when the plant completely wilted on the twelfth day (4%). Polynomial standard curves were generated with R^2=0.86(Gilo) and 0.78(Shum) for chlorophyll as in Figure 1 below

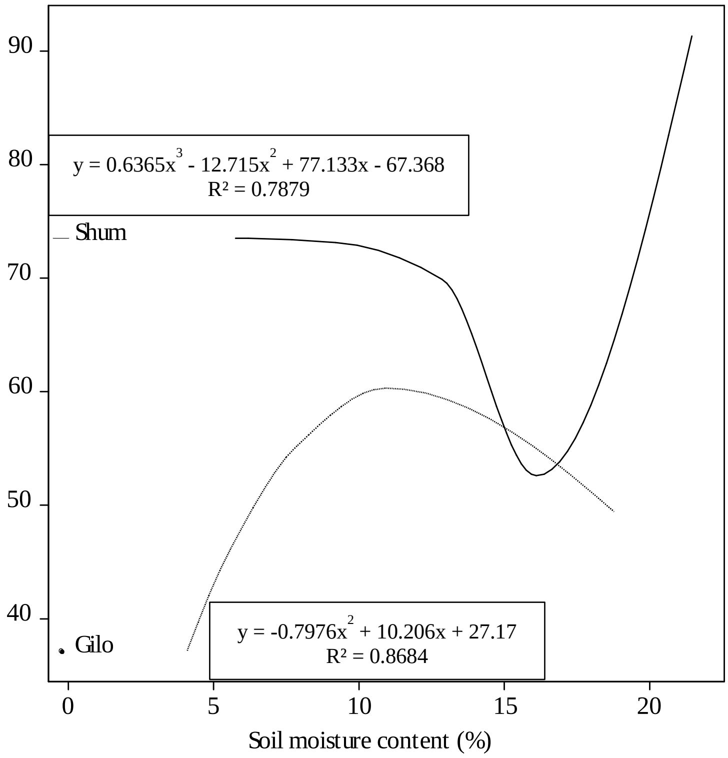

Figure 2: Relationship between chlorophyll content and soil moisture content for S. aethiopicum Shum and Gilo at vegetative stage

Leaf blade length was determined as the distance from the point where the petiole begins to the tip of the leaf. With increasing stress, leaf blade length for both Shum and Gilo decreased gradually. The curve for Gilo was above the curve for Shum. Linear standard curves were generated with R^2=0.79(Gilo) and 0.74(Shum) for leaf blade length under drought stress at vegetative stage (Figure 2).

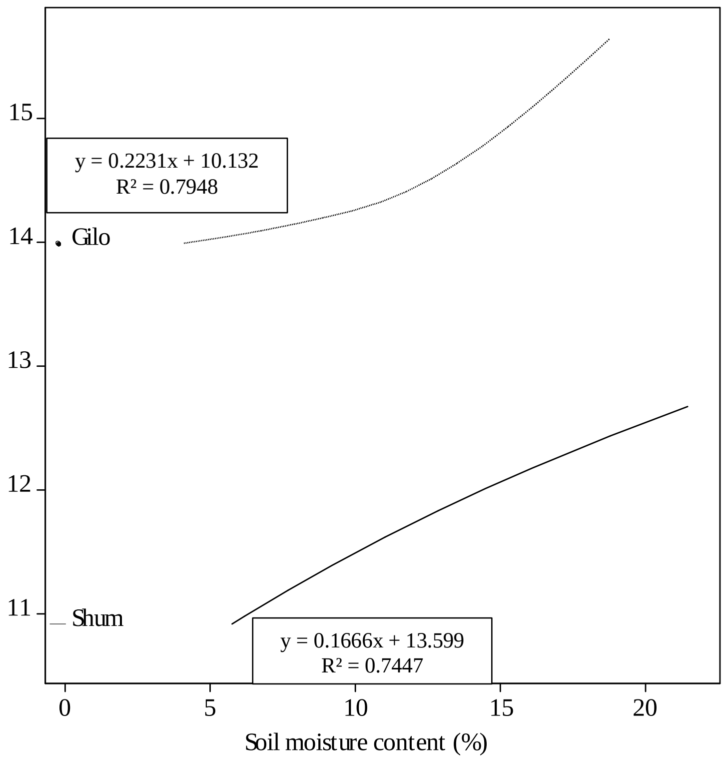

Figure 3: Relationship between leaf blade length and soil moisture content for S. aethiopicum Shum and Gilo at vegetative stage

The mean soil moisture content and mean leaf wilting score of Gilo is slight lower than that of Shum despite the fact that both graphs follow the same trend. When a visual wilting score was made over time, the highest mean score (4) was recorded at 6% soil moisture content by the sixth day while for Gilo, the highest mean score was recorded at 3% soil moisture content by the fifth day. Between 10-15% soil moisture content both Shum and Gilo had the same wilting score of 2.5(37% of leaves have wilted). Linear curves Both Gilo and Shum were generated with R2=0.93(Gilo) and 0.96(Shum) for leaf wilting score.

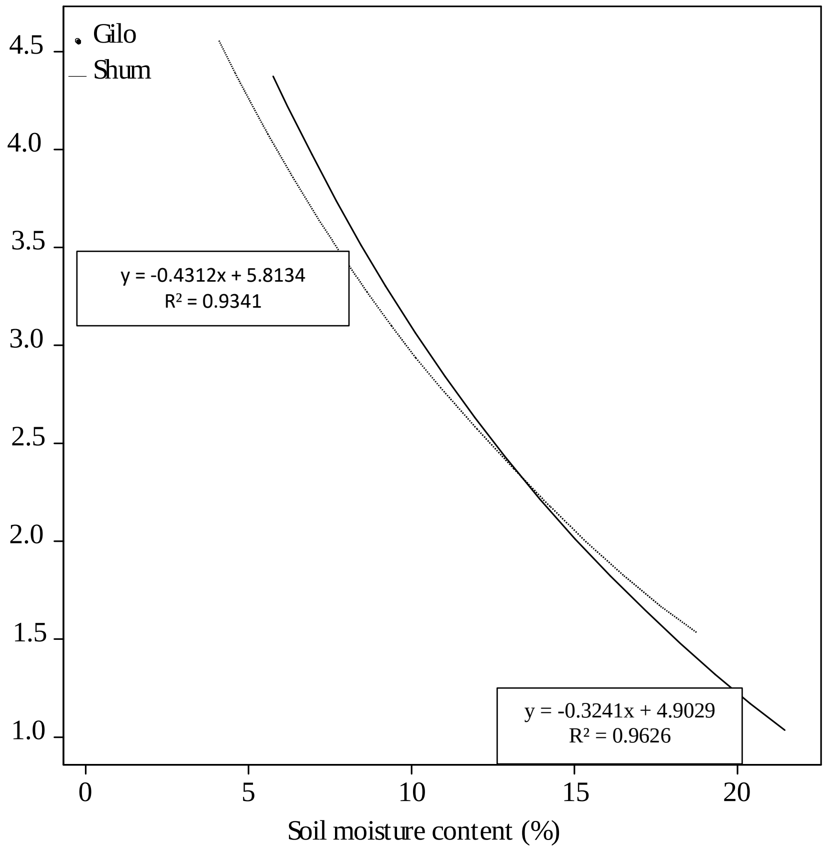

Figure 4: Relationship between leaf wilting score and soil moisture content for S. aethiopicum Shum and Gilo at vegetative stage

Discussion

Effect of drought at different stages

The significant differences imply that the response of *Solanum aethiopicum* to drought is dependent on the stage of growth and group. Different growth stages have different water requirements therefore drought tolerance of these plants at one developmental stage does not predict tolerance of the same plant at another developmental stage. This also met that despite the fact that the evaluated *S. aethiopicum* groups are from the same species, they may have different adaptive strategies to drought. Basing interactions as reported significant by Sseremba et al., 2018, not all evaluated variables exhibited significant differences with group x water level interactions. This implied that at both water levels; stomatal conductance, leaf width and soil moisture responded with a similar trend hence not involved in further analysis.

Both yield and health status traits in response to drought stress were significantly constrained at vegetative stage compared to seedling and flowering stage for both groups. This makes vegetative stage more suitable for drought screening in *Solanum aethiopicum.* It also implies that this stage has more water requirement compared to other stages. This may be attributed to the rapid metabolic processes such as photosynthesis that take place at this stage. Plants tend mobilize food and energy in preparation for the next developmental stage of flowering.

A reduction in stomatal conductance, number of green leaves, leaf length and leaf width at all stages for both Shum and Gilo was recorded which confirms the results obtained in sesame by Boureima and collegues, 2012. This is because as drought stress increases, the stomata will close as a mechanism to reduce metabolism thereby resulting into un-sustained photosynthesis. The number of green leaves reduced due to the wilting effect which in a long run causes the leaves to dry and drop off. Leaf Length and leaf width reduces due to the loss of cell turgor (Jaleel et al., 2009) and hinderance in cell division. Usually, the amount of chlorophyll reduces with increasing stress (Sarani *et al*., 2014; Bansal *et al*., 2016; Zu et al., 2017) however in this study the amount of chlorophyll exhibited a different pattern as it increased with increased drought stress which agreed with the results reported by Khayatnezhad (2011) and Alaei (2011) in wheat genotypes. There findings were attributed to the varying intensity of the water stress imposed which I would agree with since watering was stopped at one and each day that passed imposed more stress. Besides, this may also be attributed to the physiological change of converting chlorophyll a to chlorophyll b which is a better at tolerating dry conditions (Fani, 2012). This can further be explained by the effect of heat shock proteins.

Response of Shum and Gilo to drought stress

There was a significant difference in how *Solanum aethiopicum* Gilo and Shum respond to drought. Gilo was observed to be more drought sensitive compared to Shum as it attained a highest mean of leaf wilting score and lowest soil moisture content in fewer days (5) as compared to Shum. The lowest soil moisture content may indicate that Gilo requires more water at all the evaluated developmental stages. Basing on Chlorophyll, Gilo exhibited a clear curve compared to Shum whose trend was not clear. This implies that chlorophyll as a good indicator of health status, can be a more reliable trait for drought screening in *Solanum aethiopicum* Gilo as compared to Gilo. There was a more significant difference in leaf blade length compared to leaf blade width based on group x water level interactions. This was contrary to the finds from the previous study on Shum group as leaf blade width was more correlated to leaf size (Nakanwagi et al., 2018). These results suggest that while leaf blade width can be basis for determining leaf size in Shum, leaf blade length is more appropriate for Gilo. Despite the fact that the two groups are close relatives from the same species, it is evident that they use different avoidance approaches of managing drought stress (Ali *et al*., 2013). Their differences could also be attributed the drought resistance genes present on both groups. It is normal for plants under stress to maintain their metabolic and structural capacity. In the venture to do so, plants tend to modify gene expression accordingly.

Conclusion

Both groups used in the study showed good ability to withstand drought stress. However, the Shum group's ability to withstand drought superseded that of Gilo. Hence the Shum group seem to have more drought tolerance genes as compared to Gilo. The differentiation between the two groups was based on the vegetative stage as it emerged the most appropriate stage for drought screening. Despite the fact that both groups were greatly affected at vegetative stage, it is important to note that the traits that are more appropriate for drought screening in *Solanum aethiopicum* groups may be different. This suggests the different drought tolerance and escape mechanism genes which can be identified and transferred to other Solanum species in induce drought tolerance in those species. Therefore, this study provides breeders with information concerning the most probable source of drought tolerance genes as well as the most appropriate stage for screening for drought tolerance. This study also provides farmers with alternative crops to grow during the drought seasons since consumers of Gilo and in most cases the same consumers of Shum.

Acknowledgment

The equipment used in this study was acquired at Uganda Christian University through The World Academy of Sciences (TWAS/UNESCO) Grant Number 16-163 RG/BIO/AF/AC_I – FR3240293342.

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