

**Effect of water stress and soil texture on growth, yield and quality attributes of potatoes
(*Solanum tuberosum* L.)**

By

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DECLARATION

I, Cypriel Mfundo Hlatshwayo, hereby declare that this dissertation submitted in fulfilment of the requirements for the degree of Master of Science in Agriculture (Soil Science) at the Faculty of Science, Engineering and Agriculture, in the Department of Plant and Soil Sciences, University of Venda by me is of my own work and has not been previously submitted for a degree at this or any other university. Reference material contained in this proposal has been duly acknowledged.

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Dedications

This dissertation is dedicated to the memory of my beloved grandparents Dorothy Josephine Hlatshwayo (1946-12-12, 2016-07-10), and Elijah Mabhlukwane Hlatshwayo (1944-03-29, 2022-07-17) who have been an epitome of strength, and resilience.

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Abstract

Potato (*Solanum tuberosum* L.) is an annual dicotyledonous tuber herbaceous crop. The crop is relatively susceptible to water stress when compared to other major field crops. Soil texture plays a pivotal role in the correlative relationship between climate, soil, and vegetation, which are dependent on soil moisture dynamics and in correlation to vegetation water stress. This study investigated the effects of water stress and soil texture on potato growth, yield, and quality attributes. The pot experiment was conducted during the 2021(spring)/2022(winter) cropping seasons in a plastic tunnel at the University of Venda (UNIVEN) Experimental Farm situated at Thohoyandou. The experiment was laid out in a Completely Randomized Design (CRD) with two potato cultivars (Mondial and Bp1), three soil textural classes (clay, sandy clay loam, sandy loam), and three water stress levels (30%FC (field capacity), 60%FC, 100%FC) with three replicates making a total of 54 experimental units (polyethylene pots). Data collected was subjected to ANOVA using Minitab 21. Water stress \times soil texture interaction had a significant ($p < 0.05$) effect on plant height at 51 DAP (days after planting) to 72 DAP, and from 44 DAP to 86 DAP during the 2021/2022 cropping seasons, respectively. The interaction of water stress and soil texture had a non-significant ($p > 0.05$) effect on leaf area. Water stress \times soil texture interaction had a significant ($p < 0.05$) effect on stem diameter at 93 DAP, and 65 DAP during the 2021/2022 cropping seasons, respectively. There was no significant ($p > 0.05$) interaction effect between water stress and soil texture on marketable potato yield during the 2021 cropping season, but the interaction had a significant ($p < 0.05$) effect during the 2022 cropping season. This study suggested that severe water stress (30%FC) could be adopted for potato cultivation in winter season. The tuber sizes and shapes produced during the 2021 cropping season were observed to be smaller ($< 55\text{mm}$) and short-oval (1.10 to 1.29) to oval (between 1.30 and 1.49). However, during the 2022 cropping season tuber sizes and shapes obtained larger tuber sizes ($\geq 75\text{mm}$) and long oval (between 1.50 and 1.69) to long (≥ 1.70). The specific gravity (1.05 - 1.07) was suitable for the potato tubers to be used for processing. The skin colour of the Bp1 and Mondial cultivars were yellowish, while flesh colours were light yellow making them suitable for consumers and the market. Therefore, the results suggest

that 30%FC irrigation water level can be economical for production during the winter season in semi-arid region regardless of the soil texture type (clay, sandy loam, and sandy clay loam).

Keywords: Marketable potato yield, potato sizes, potato shapes, soil texture, water stress.

List of Abbreviations

a.m.s.l	= above mean sea level
AI	= Aridity index
ANOVA	= Analysis of variance
AWC	= Available water capacity
EC	= Electrical conductivity
Ep	= Water surface evaporation
DAP	= Days after planting
FC	= Field capacity
Ha	= Hectares
K	= Potassium
Kg	= Kilograms
KCl	= Potassium chloride
LA	= Leaf area
LAI	= Leaf area index
NPCK	= National Potato Council of Kenya
MAD	= Maximum Allowable Depletion
PAW	= Plant Available Water
PAWC	= Plant Available Water Content
PSA	= Potato South Africa
RLD	= Root Length Density
SG	= Specific gravity
SA	= South Africa
SMC	= Soil Moisture Content
TFI	= Tuber Form Index
UNIVEN	= University of Venda
WUE	= Water use efficiency

List of Symbols

cm	= Centimetres
cm cm ⁻³	= Centimetres per cubic centimetre
°C	= degree Celsius
g	= Grams
g/plant	= grams per plant
H ₂ O	= Water
Kg. m ⁻³	= kilograms per cubic metres
l	= Litres
M	= Molar
m	= metres
mg.dm ⁻³	= milligrams per cubic decimetres
mm	= Millilitres
m ³	= Cubic metres
N	= Nitrogen
NH ₄ ⁺	= Ammonium
NO ₃ ⁻	= Nitrate
%	= Percentage
P	= Phosphorus
<i>p</i>	= Probability
t.ha ⁻¹	= Ton per hectare

List of Figures

Figure 2.1: Map showing potato growing areas in SA.....	6
Figure 2.2: Potato growth stages.....	11
Figure 3.1: Map showing three soil collection sites in Limpopo Province.....	25
Figure 3.2: Potato plants at the University of Venda (UNIVEN) Experimental Farm during the 2021 cropping season.....	29
Figure 3.3: Potato plants in a tunnel at the University of Venda (UNIVEN) Experimental Farm during the 2022 cropping season.....	30
Figure 4.1: The interaction of water stress and soil texture on potato plant height during the 2021 cropping season at 51 DAP, 58 DAP, 65 DAP, and 72 DAP.....	39
Figure 4.2: The interaction of water stress and soil texture on potato plant height during the 2022 cropping season at 44 DAP, 51 DAP, 58 DAP, 65 DAP, 72 DAP, 79 DAP, and 86 DAP.....	43
Figure 4.3: The interaction effect of water stress and soil texture on stem diameter at 93 DAP during the 2021 cropping season.....	48
Figure 4.4: The interaction effect of water stress and soil texture on stem diameter at 65 DAP during the 2022 cropping season.....	50
Figure 4.5: The interaction effect of water stress and soil texture on potato marketable yield during the 2022 cropping season.....	54
Figure 4.6: The interaction effect of water stress and soil texture on potato tuber sizes during the 2021 cropping season.....	58

Figure 4.7: The interaction of water stress and soil texture on Potato Bp1 skin colour parameters (a) Chroma, (b) Hue angle, (c) L^* = lightness parameter (d) a^* = chromatic redness parameter and (e) b^* = yellowness chromatic parameter during the 2021 cropping season...63

Figure 4.8 The interaction of water stress and soil texture on Potato Bp1 flesh colour parameters (a) Chroma, (b) Hue angle, (c) L^* = Lightness (d) a^* = Chromatic redness parameter and (e) b^* = Yellowness chromatic parameter during the 2021 cropping season.....69

Figure 4.9: The interaction of water stress and soil texture on potato Mondial skin colour parameters (a) Chroma, (b) Hue angle, (c) L^* = Lightness (d) a^* = Chromatic redness parameter and (e) b^* = Yellowness chromatic parameter during the 2021 cropping season...75

Figure 4.10: The interaction of water stress and soil texture on potato Mondial flesh colour parameters (a) Chroma, (b) hue angle, (c) L^* = Lightness, (d) a^* = Chromatic redness parameter and (e) b^* = Yellowness chromatic parameter during the 2021 cropping season...80

List of Tables

Table 3.1: Tensiometer readings (centibars) for irrigation water stress levels under various soil textures.....	27
Table 3.2: Fertilizer application rates (g/pot).....	27
Table 3.3: Treatments combinations used during the 2021/2022 cropping season.....	28
Table 4.1a Pre - cropping soil properties (chemical, soil particle sizes and texture).....	35
Table 4.1b Experimental details and dates of phenological stages during the 2021/22 cropping seasons.....	36
Table 4.2 a: Effect of water stress and soil texture on plant height (cm) during the 2021 cropping season.....	38
Table 4.2b Effect of water stress and soil texture on plant height (cm) during the 2022 cropping season.....	40
Table 4.3a: Effect of water stress and soil texture on leaf area (cm ²) during the 2021 cropping season.....	44
Table 4.3b: Effect of water stress and soil texture on leaf area (cm ²) during the 2022 cropping season.....	45
Table 4.4a: Effect of water stress and soil texture on stem diameter (cm) during the 2021 cropping season.....	47
Table 4.4b: Effect of water stress and soil texture on stem diameter (cm) during the 2022 cropping.....	49
Table 4.5a: Effect of water stress and soil texture on potato marketable yield (g/pot) during the 2021 cropping season.....	52

Table 4.5b: Effect of water stress and soil texture on potato marketable yield (g/pot) during the 2022 cropping season.....	53
Table 4.6: Effect of water stress and soil texture on potato quality attributes (sizes (mm), shapes, specific gravity (SG)) during the 2021/2022 cropping season.....	57
Table 4.7a: Effect of water stress and soil texture on potato Bp1 skin colour during the 2021 cropping season.....	61
Table 4.7b: Effect of water stress and soil texture on potato Bp1 skin colour during the 2022 cropping season.....	64
Table 4.7c: Effect of water stress and soil texture on potato Bp1 flesh colour during the 2021 cropping season.....	67
Table 4.7d: Effect of water stress and soil texture on potato Bp1 flesh colour during the 2022 cropping season.....	70
Table 4.8a: Effect of water stress and soil texture on potato Mondial skin colour during the 2021 cropping season.....	73
Table 4.8b: Effect of water stress and soil texture on potato Mondial skin colour during the 2022 cropping season.....	76
Table 4.8c: Effect of water stress and soil texture on potato Mondial flesh colour during the 2021 cropping season.....	78
Table 4.8d: Effect of water stress and soil texture on potato Mondial flesh colour during the 2022 cropping season.....	81

Table of Content	
DECLARATION	i
Acknowledgments	ii
Dedications.....	iii
Conference presentations.....	iv
Abstract.....	v
List of Symbols	viii
List of Figures	ix
List of Tables.....	xi
1.Introduction	1
1.1 Background.....	1
1.2 Problem statement	4
1.3 Motivation.....	4
1.4 Objective	5
1.4.1 Main objective	5
1.4.2 Specific objectives.....	5
1.5 Hypothesis	5
Chapter 2.....	7
2. Literature review.....	7
2.1 Introduction	7
2.2 Potato growth requirements.....	8
2.3 Growth stages and development of potato.....	8
2.3.1 Sprouting and plant establishment (stage 1)	8
2.3.2 Vegetative stage (stage 2)	9
2.3.3 Tuber initiation (stage 3).....	10
2.3.4 Tuber bulking (stage 4).....	10
2.3.5 Tuber maturing and harvesting (stage 5)	11
2.4 Effect of water stress on potato growth, yield, and quality attributes	12
2.4.1 Growth.....	13
2.4.2 Yield.....	14
2.4.3 Quality	16
2.5 Effect of irrigation on potato growth, quality, and yield	18
2.5.1 Growth.....	Error! Bookmark not defined.
2.5.2 Yield and quality	Error! Bookmark not defined.
2.6 Effect of soil texture on potato growth, quality, and yield	18

2.6.1 Growth.....	18
2.6.2 Yield and quality	19
2.7 Quality attributes of potatoes	Error! Bookmark not defined.
2.7.1 Specific gravity.....	20
2.7.2 Tuber morphology (size and shape).....	Error! Bookmark not defined.
2.7.3 Flesh colour and skin.....	Error! Bookmark not defined.
2.8 Nutrient requirements	20
2.9 Water use efficiency	22
2.10 Agronomic factors	22
2.11 Conclusion.....	23
Chapter 3.....	24
3. Materials and methods.....	24
3.1 Study site	24
3.2 Soil collection	24
3.3 Soil analysis.....	26
3.4 Determination of Field capacity	26
3.5 Potting soil preparation and agronomic management	28
3.6 Experimental design and treatments.....	29
3.7 Growth parameters.....	31
3.7.1 Plant height and stem diameter measurements.....	31
3.7.2 Leaf area determination	32
3.8 Yield of potatoes	32
3.9 Quality attributes.....	32
3.9.1 Specific gravity determination	32
3.9.2 Sizes, shapes, and colour determination.....	33
3.10 Statistical analysis	34
Chapter 4.....	35
4. Results.....	35
4.1 Pre-cropping selected average soil chemical and physical properties	35
4.2 Effect of water stress and soil texture on growth parameters.....	38
4.2.1 Plant height	38
4.2.2 Leaf area.....	45
4.2.3 Stem diameter.....	48
4.3 Effect of water stress and soil texture on potato marketable yield.	54
4.4 Effect of water stress and soil texture on potato quality attributes.....	58
4.4.1 Sizes.....	58

4.4.2 Shapes	58
4.4.3 Specific gravity.....	59
4.3.4 Potato BP1 skin colour	62
4.3.5 Potato BP1 flesh colour.....	68
4.3.6 Potato Mondial skin colour.....	74
4.3.7 Potato Mondial flesh colour	80
Chapter 5.....	83
5. Discussion.....	83
5.1 Effect of water stress and soil texture on potato growth parameters	83
5.1.1 Plant height	83
5.1.2 Leaf area.....	85
5.1.3 Stem diameter.....	85
5.2 Effect of water stress and soil texture on yield.....	86
5.2.1 Marketable yield	86
5.3 Effect of water stress and soil texture on potato quality attributes.....	89
5.3.1 Sizes.....	89
5.3.2 Shapes	90
5.3.3 Specific gravity.....	91
5.3.4 Potato Bp1 skin colour.....	92
5.3.5 Potato Bp1 flesh	94
5.3.6 Potato Mondial skin colour.....	95
5.3.7 Potato Mondial flesh colour	97
Chapter 6.....	99
6. Conclusion & Recommendation	99
6.1 Conclusion	99
6.2 Recommendation.....	100
7. References.....	101
8. Appendices	Error! Bookmark not defined.
8.1 Determination of plant available water (PAW)	26
8.2 Pressure membrane apparatus.....	27

Chapter 1

1. Introduction

1.1 Background

Potato (*Solanum tuberosum* L) is an annual dicotyledonous tuber herbaceous crop which grows to 100 cm in height (FAO, 2008; VIB, 2021). The crop originated in Peru South America in the Andes. The potato crop belongs to the family of Solanaceae which is grouped into two genotypes that are Andigenum and Chilotanum. The difference between the two genotypes is that Andigenum is suited for short-day conditions, comprised of diploids, triploids, and tetraploids, while Chilotanum is suitable for long-day conditions, and usually comprised of tetraploids (FAO, 2008; Spooner et al., 2012). Potato is far behind rice, wheat, and maize in position as one of the most vital staple crops globally (Djebli et al., 2020). However, in consumption forms, potato is ranked number three after rice and maize as one of the crucial food crops (FAOSTAT, 2019).

The potato crop is relatively susceptible to water stress when compared to other major field crops (Wang et al., 2021). Ample irrigation water is required for its growth and development. The reason why the potato crop is easily prone to water stress is not clearly known. However, it is reported that potato crop vulnerability to water stress is linked to its shallow, sparse, and weak root systems (Wang et al., 2006; Iwana, 2008). The shallow root system of the potato crop makes it unable to restore, absorb water and nutrients effectively from deeper soil horizons (Zarzyska et al., 2017). This reduces the capacity of the crop to recuperate damaged root structures after a period of water stress (Zarzyska et al., 2017). Nevertheless, the potato crop uses water relatively efficiently compared to other major crops (Vos and Haverkort, 2007).

In South Africa (SA), potato farming covers about 50 000 hectares (ha) 92 per cent (%) of the land under irrigation (Franke et al., 2018). Provinces of Mpumalanga, Free State, Western Cape, and Limpopo are the major potato production areas (DAFF, 2019). According to DAFF

(2019), 53 011 were planted to potatoes in 2018 compared to 52 017 ha in 2017. This represented a yield decrease of 1.4%. The decline in average yield was attributed to the scarcity of irrigation water (Steyn et al., 2016), which could have been accentuated by climate change (PSA, 2018). Without irrigation, potato growth, morphological qualities, and yield can be substantially affected due to water stress periods (Obidiegwu et al., 2015). Short period of water stress followed by irrigation or rainfall results in tuber malformation, better known as secondary growth (Cantore et al., 2014). Moreover, when water application drops below sixty-five percent water stress level of soil moisture, tuber yield and qualities decrease (Geofrey et al., 2014). In contrast, Jia et al., (2022) reported that a 50% water stress level of soil moisture significantly increases tuber yield compared to 65% water stress, and 35% water stress drastically reduces yield during two consecutive seasons. This was attributed to the observations of the results of water stress levels of soil moisture at the vegetative stage, which resulted to such yield results

Soil texture and water stress play a major role in potato production. Soil texture plays a significant role in the linked relationship between climate, soil and vegetation, which are heavily reliant on soil moisture dynamics and concurrent vegetation water stress (Fernandez-Illescas et al., 2001). Sandy soils are mostly preferred in potato production due to the high aeration which is beneficial for tuber bulking, although water and nutrient conservation is poor (Wang et al., 2020). However, in South Africa potatoes are produced under various soil textures (Steyn et al., 2016). There are contradictory reports about the role of soil texture on potato growth and development. Ahmadi et al., (2010) reported that loamy sand soil texture produces greater tuber yield, and dry matter content than sandy loam and coarse sandy soil textures, whilst Martins et al., (2018) reported that sandy soils aid the growth of tubers since they are loose, unlike clayey soils which are easily compacted. In contrast, Kashyap and Panda (2003) reported that potatoes can grow well in all soil textures with good drainage. It has also been reported that potato tuber yield has a stronger correlation with soil texture (sand and clay) compared to soil chemical properties (Redtfla et al., 2002). Therefore, more

information about other soil textures except sandy soils is required for potato growth in relation to water irrigation.

Soil texture and water stress influences the growth of potato traits and that results to affecting the potato quality traits (Al-Hamed et al., 2017). Potatoes quality traits are identified by internal and exterior morphology (Mohammed, 2016). The external morphology includes tuber sizes, shape, eye depth, skin, and flesh colour, while internal quality includes specific gravity (SG), starch content, sugar content, and discoloration chip tubers (Kabira and Lemaga, 2003; Bekele and Haile, 2019). These quality aspects are significant for both marketing and processing (Werjji, 2011). South African potato farmers face limitations that affect the yield and quality of their products. External factors such as the environment (high temperature, heat waves, drought, frosts) and technical efficiencies (improper pre- and post-harvesting methods, crop rotation, high cost of fertilizers, pesticides requirements, soil degradation and improper farming methods) have been reported to affect potato production (Larkin et al., 2011). For example, harsh climatic conditions such as high temperatures, dry spells, unreliable rainfall in the potato growing regions in South Africa significantly hinder potato growth, yield and quality (Steyn et al., 1998; van der Waals et al., 2016; Franke et al., 2018). Dry spell with high temperature leads to a higher evapotranspiration, and crop water requirement (Gbode et al., 2022). Therefore, irrigation is mostly proposed during the most susceptible water stress phases. Water stress in plant cells decreases water pressure and photosynthesis. Potato traits (plant height, root biomass, shoot biomass) and tuber growth are constrained in the absence of adequate photosynthetic products (starch and sugars) and water pressure (Wagg et al., 2021). In the Czech Republic, Elzner et al., (2018) reported that water stress during the vegetative phase decreases potato yield. This was attributed due to the climatic conditions (low precipitation) experienced at both locations of the study, as the potato crop as a high water requirement.

1.2 Problem statement

Climate change significantly affects environmental conditions in which potatoes are grown, and this leads to a decrease in potato production (PSA, 2021). Limpopo Province is characterised by a semi-arid climatic condition associated with high temperatures, unreliable rainfall, limited water resources, and water stress. Therefore, water stress, and unreliable rainfall are a common occurring major factors affecting crops under semi-arid climatic conditions. Water stress is induced by the depletion of soil water, which is exacerbated by high temperatures increasing evapotranspiration, resulting in little crop water uptake during the crop growing period (Gbode et al., 2022). Water irrigation remains the only alternative option in semi-arid areas that are characterized as low, unreliable rainfall and low soil moisture. Therefore, growing crops such as potatoes in semi-arid areas is a huge challenge as the potato crop requires an ample of water. Additionally, soil texture has also been reported to affect potato yield and its quality (Ahmadi et al., 2011). Soil texture directly influences soil water holding capacity and plant available water, affecting potato tuber growth and development by causing deformed shapes and smaller tuber sizes. There are limited studies on water stress and how it affects potato production in Limpopo Province (Franke et al., 2018; Machakaire, 2021). Moreover, there are no studies reporting the effect of water stress and soil texture and their interaction on potato production. Therefore, there is a dearth of knowledge on how different water stress levels in combination with soil texture affect the growth, yield and tuber quality of potatoes. This study aims to evaluate the effect of different water stress levels and soil texture on the growth, yield, and quality of potatoes in the Limpopo Province.

1.3 Motivation

Decline in potato yield in the Limpopo Province is attributed to water stress induced by climate change. Internal and exterior morphological traits of potatoes such as tuber sizes, shapes, specific gravity, and colour are both important for processing and marketing. Exterior morphological traits are mainly accepted by consumers in the market, while both internal and

exterior are targeted by the processing industry. However, the markets and processing industries declines potato morphological traits, which do not meet the expected quality standards (Kiptoo et al., 2018). The quality of potatoes are thought to be influenced by both water stress levels and soil texture. Therefore, this study aims to generate more information about water stress levels in various soil textures and how they affect the growth, yield, and qualities of potatoes. In this way, farmers can manage their crops to improve their marketability.

1.4 Objective

1.4.1 Main objective

- The aim of the study was to determine the effect irrigation water level and soil textures on potato growth, yield and quality attributes.

1.4.2 Specific objectives

To determine the effect of irrigation at different water stress levels (30% Field capacity (FC) (severe water stress), 60% FC (moderate water stress), 100% FC (no water stress)) and soil texture (clay, sandy clay loamy, and sandy loamy) on:

- i. Potato plant growth parameters (plant height, leaf area, and stem diameter)
- ii. Yield (marketable) of potatoes
- iii. Quality attributes (sizes, shapes, specific gravity, colour (skin and flesh) of potatoes

1.5 Hypothesis

Ho: Null hypothesis

There will be no difference due to irrigation at different soil moisture levels, soil texture and their interaction on:

- a) Growth parameters (plant height, leaf area, stem diameter).

- b) Yield (marketable) of potatoes.
- c) Potato quality (sizes, shape, specific gravity, colour (skin and flesh)).

Chapter 2

2. Literature review

2.1 Introduction

Potato is a cool season crop in general, this is due to the origin of the crop from the cool Andes mountains although potato breeding work was conducted in Europe over 7000 years ago (George et al., 2017; Momcilovic, 2019). In South Africa (SA), potatoes are mostly grown under warm conditions and in various seasons. It is grown under distinct 16 major production areas (Figure 2.1) varying in climatic conditions (van der Waals et al., 2016; Gericke, 2018). Therefore, ensures the availability of potatoes on the market throughout the year (PSA, 2021). Potato is an incredible source of energy and sustenance for humans as potato tubers comprise about 79 percentage (%) water, 18 % sugars, 2 % proteins, 1 % vitamins, numerous minerals (iron, magnesium, potassium) and trace elements (Ahmadi et al., 2011; Zaheer and Akhtar, 2016; Khan et al., 2018).

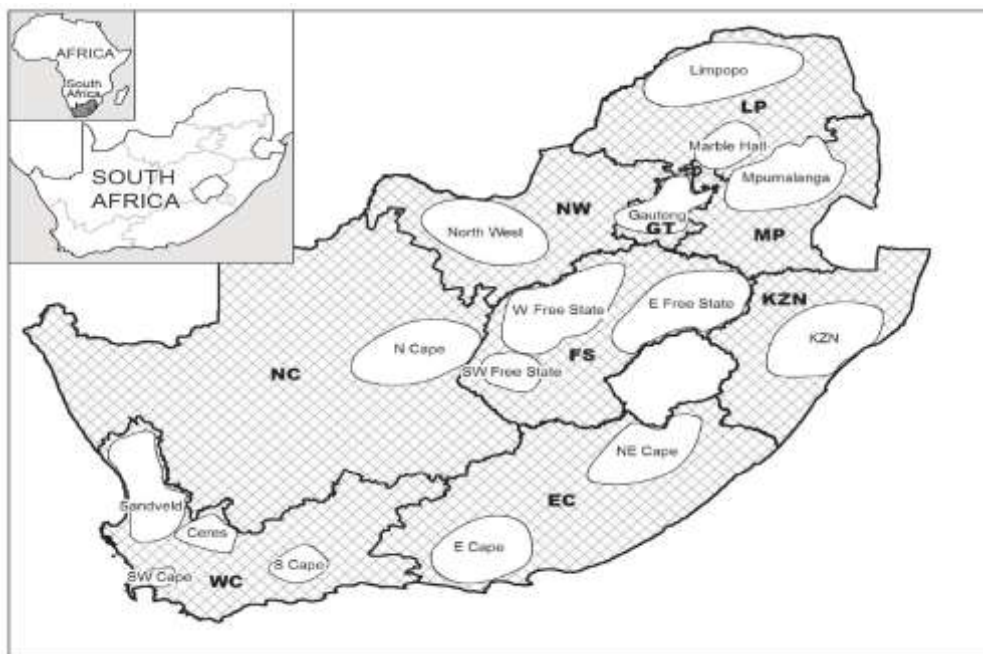


Figure 2.1: Map of SA representing the main potato growing areas (Adopted from Franke et al., 2018).

2.2 Potato growth requirements

Potato is highly susceptible to high temperatures as it is a cool-season crop (Aien et al., 2011). The crop needs a cool temperature with full sunlight, moderate daytime temperatures, and cool nights, among other suitable conditions for potato growth (Hassanpanah, 2010). Loamy to sandy-textured soils are preferred for potato production due to high soil aeration for roots (Steyn and Du Plessis, 2012; Asfaw, 2016). However, soil texture with a high tolerance to acidic conditions at pH 5.0, with larger quantities of macronutrients (nitrogen (N), phosphorus (P) and potassium (K)) is good for potato production (Hochmuth and George, 2007; Oosthuysen, 2012). Ample irrigation water is required for potato growth as the crop is highly susceptible to water stress (Lerna and Mauromicale, 2012). The potato's sensitivity to water stress varies during its growth stages and development, as there are critical growth periods when irrigation is necessary for optimum yield and quality in potatoes (Akkamis and Caliskan, 2021).

2.3 Growth stages and development of potato

2.3.1 Sprouting and plant establishment (stage 1)

Sprout development, vegetative growth, tuber initiation, tuber bulking, and maturation are the five phases of the potato plant's growth and development (Momcilovic, 2019; Mthembu et al., 2022). Sprout emerges from the tuber's eyes after the tuber finishes its endo dormancy duration (Sonnewald, 2001). The most common method for sprouting is to employ dark rooms, but this results in excessive sprouting, so de-sprouting before planting is necessary (Kabira and Lemaga, 2003). Dormancy takes a long time after tuber harvesting, even though the tubers are exposed at 15 degrees Celsius ($^{\circ}\text{C}$) to 20 $^{\circ}\text{C}$, with darkness and relative humidity of about 90% (Liu et al., 2017). However, tuber dormancy largely depends on genotype and environmental conditions (crop growth and storage) (Aksenova et al., 2012) and changes in the main tuber metabolism (Sonnewald and Sonnewald, 2014). Sprout growth is consistent with the change of starch to sugar (Frazier et al., 2004). Natural-occurring compounds are used in potatoes as anti-sprouting agents, based on the belief that natural products are more

harmless to sprout growth (Frazier et al., 2004). Sprouting in certain varieties can be accelerated by high-temperature storage. Fluctuation in storage conditions, atmospheric humidity may encourage sprouting (Claassens and Vreugdenhill, 2000). However, dormancy and physiological aging can be controlled by the timing of warmer stages during storage (Oliveira et al., 2012). Cold storage over an extended period of time slows the emergence of sprouts (Oliveira et al., 2012). Sprout formation is usually affected by the seed tuber's physiological age and storage temperature (Struik and Wiersema, 1999). Sprouting of tubers is affected by the conversion from physiologically immature to mature tubers. Such transitions can be those of vegetative parts, yield, and tuber size (Christiansen et al., 2006). The use of grass by covering the seed tubers allows dormancy breakage, leading to sprouting (Walingo et al., 2001). When the potato seed has sprouted, it can be suitable for planting.

2.3.2 Vegetative stage (stage 2)

The vegetative growth phase starts after emergence and ends at tuber initiation. This growth stage takes place for about 30 to 50 days. However, the period of the vegetative phase depends on planting time, climatic conditions, and other environmental factors. The development of vegetative traits such as root systems and stolons are developed (Saidi and Hajibarat, 2021). Furthermore, photosynthesis starts and supplies sustenance for the plants growth as the plant prepares to store nutrients in tubers (Liu et al., 2020). The temperature during the vegetative phase is significant for the growth and development of tubers (Kumar et al., 2004). However, a high temperature during the vegetative phase, is highly susceptible to the process of photosynthesis occurring (Aien et al., 2011). Soil water stress during this phase restricts root growth, leaf area, plant height, and a limited number of stolons and limits the uptake and responses to nutrients (Shiri-e-Janagard et al., 2009; Abbas et al., 2012; Obidiegwu et al., 2015). Soil water content during this stage is preferred to be at about 70 to 80% field capacity (FC), while lower than that is not preferred (Curwen, 1994). However, soil water saturation during this phase retards the development of vegetative parts, enhances nutrient leaching, and causes soil waterborne diseases (Curwen, 1994). Sandy soil and

nutrient-rich loam soils appear to be absolutely ideal for vegetative growth and root development (Abdulazeez, 2017).

2.3.3 Tuber initiation (stage 3)

The potato seeds are triggered by inflammation of the stolon tips from under-ground shoots, so-called stolons. This cycle takes place in the sub-apical area of the stolon between elongation and cell division (Xu et al., 1998). The tuber initiation stage begins at about 20 to 30 days after emerging from the plant and may be processed for up to two weeks (10 to 14 days) or more than that (45 days under long conditions) (Mihovilovich et al., 2014). Through the tuber initiation stage, tubers develop on stolons, and acclimatization of cell division within the sub-apical part of the stolon converts to build-up arranged growth instead of longitudinal growth (Mihovilovich et al., 2014). Flowering begins at about 40 to 50 days, and tubers start to grow in other root parts of the plant (Leap et al., 2017). The change of stolons to tubers is related to a change from the apoplastic to the symplast way of assimilating unloading (Viola et al., 2001). As reported by Kempen (2012), several aspects affect tuber initiation such as water stress, temperature, light intensity, and soil texture types. This phase is considered the most sensitive to water stress (Sprenger et al., 2016). When soil water decreases to less than 65 % at FC, average yield and quality are adversely affected (Geofrey et al., 2014). Thus, the water content of about 80 to 90% and adequate irrigation should be maintained, but it can vary depending on the cultivar and soil texture type (Curwen, 1994). Sandy soils comprised of

During the pre-stolon initiation stage, temperatures between 14 and 22 °C at night are thought to be best (Gastelo et al., 2014).

2.3.4 Tuber bulking (stage 4)

At this point, the plant has ceased growing, and the tubers are only expanding (Tantowijoyo, 2006). Tuber bulking rate and length assess yield in a potato crop. There is a build-up of sugar, nutrients, and water because of the growth of the tuber cells throughout the tuber bulking period. The accumulation of starch content and water in the cells results in an increase in tuber size of up to about 18 times (Steyn, 1999). Alva (2008) elucidates that during this phase, tuber

sizes and mass rise at a linear rate unless there is no limiting aspect. This phase is the longest period of growth (Patil et al., 2016). These processes are, therefore, best supported by photoperiodism, high luminous intensity, and cool climates, associated with a mean daily temperature of between fifteen and eighteen degrees Celsius ($^{\circ}\text{C}$). Tubers turn out to be the governing site of storage for carbohydrates and moveable inorganic nutrients (Haifa, 2020). Tuber bulking rate and length determine yield on potato crops. Heat and water stress are the most restricting environmental factors for potato production. During the tuber bulking period, the plants have their highest demand for water and are the most sensitive to a deficit. Soil moisture is recommended to be between 80 and 90% or 90-95%FC, depending on the soil type and cultivar (Curwen, 1994). Undersupply of water results in small tuber sizes, irregular shapes, slow growth, and enhanced leaf senescence (Obidiegwu et al., 2015). Water stress experienced at the tuber bulking phase increases the concentration of sugar levels (glucose and sucrose) in the tubers relative to water stress at vegetative phase (Mengistu and Grout, 2017). The high temperature that causes heat stress causes more tiny tubers to grow on each plant and reduces the specific gravity of the tuber with less dry matter content (Haverkort, 1990).

2.3.5 Tuber maturing and harvesting (stage 5)

This stage ends with the senescence of the canopy. The development rate of the tubers increases during maturation. However, photosynthesis ceases, vines die off, and they start turning yellow (Kempen, 2012). Once tubers get to this phase, buds are slowly inactive (Braue et al., 1983). During this phase, the shoot dies, accompanied by physiological aging of the leaf area. The skin becomes thick, tight, and firm (Saidi and Hajibarat, 2021). When the tuber ripens, the buds slowly set off successively dormant, beginning from the stolon end (Burton, 1989; Steyn, 1999). Dormancy is the final stage of the developmental growth of the tuber, and the tubers can be preserved for a while. The length of the time of dormancy depends on the genotype, tuber growing conditions, and storage (Aksenova et al., 2013). At this stage, little irrigation water is required due to the small evapotranspiration demand (Alva, 2008). Few

reports have been reported on the effect of water stress on potato growth, yield and quality aspects. Ojola, (1997) reported that water stress during this growth stage extends the maturation rate. On the other hand, Obidiegwu et al., (2015) stated that water stress at this phase results to a limited tuber sizes, and tuber density. Too much watering during this phase makes the tubers more likely to get diseases that spread through soil water, like water rot, pink rot, and soft rot (Curwen, 1994; Alva, 2008). There are a few reports on water stress effect during this phase.

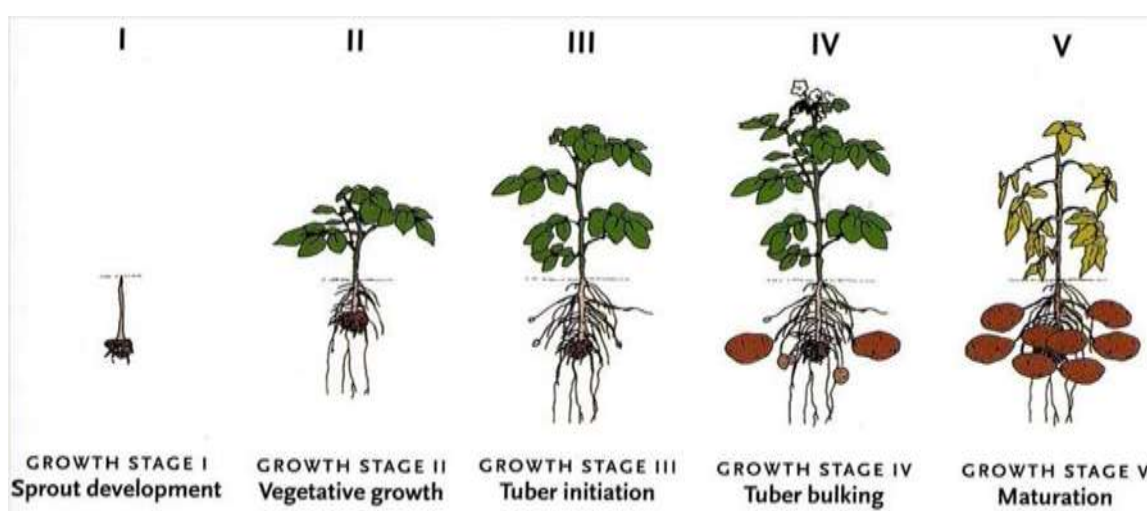


Figure 2.2: Potato growth stages (Haifa, 2020)

2.4 Effect of water stress on potato growth, yield, and quality attributes

A shortage of water negatively affects plant growth, tuber yield, and the quality aspects of potatoes (Aliche et al., 2018). The potato crop is highly susceptible to water stress (Wegener et al., 2017), and that is due to it being comprised of a shallower root system relative to other crops, which results in ineffective water and nutrient absorption in the plant (Joshi et al., 2016; Zarzynska et al., 2017). There's little evidence to support that potato crops have a shallower root system. However, several researchers have reported the root length density (RLD) of potatoes, although there were contrasting depths reported. Ahmadi et al., (2010) reported an RLD ranging from 10 to 16 cm cm⁻³ when using a field grown potato cv. Folva cultivar in a loamy sand, coarse sand and sandy loam. Iwama (2008) reported a range of 12 to 17 cm cm⁻³

³ when using Kunyu cultivar, whilst (Lesczynski and Tanner, 1976) in a field grown Russet Burbank potato grown on a Plainfled loamy sand soil reported a 11 cm cm⁻³ and Parker et al., (1989) reported a range of 8.5 cm to 10 cm cm⁻³ on a potato cv Record cultivar. However, that only supports the fact that the potato crop has shallower root systems, not sensitive to water stress. The differences in RLD may be attributed to the variation in soil texture, water availability, pore size, and nutrient concentration (Vos and Groenwold, 1986).

2.4.1 Effect of water stress on potato growth aspects

Water stress results in a reduction in vegetative growth parameters such as plant height, stem length, diameter, leaf number, size, and area, and those are the first visible signs such (wilting, thin stem diameter, leaves have downward curvature) of water stress (Jefferies et al., 1989; King et al., 2004). The response of the potato vegetative growth traits varies according to different water stress levels or irrigation treatments. Several researchers have reported contradictory results in potato vegetative traits. Zaki et al., (2022) in a field experiment under drought treatments (60%, 40%, and 20% soil moisture content (SMC)) reported that potato leaf area, number of leaves all decreased relative to the control treatment (no drought). Furthermore, the authors reported that drought treatments (60%, 40% and 20% SMC) disrupted the cell expansion and elongation that led to a decrease in leaf area. Li et al., (2016) reported that in severe water stress (50% field capacity (FC), the net photosynthetic rate, leaf area, and aboveground biomass were lower than in well-watered stress (90%FC). On the other hand, Hegazi and Awad (2002) reported that a decrease in water irrigation levels (753 m³ per acre to 565 m³ per acre) led to a substantial reduction in potato leaf area (3.401 cm² to 2.869 cm²) and plant height (72.70 cm to 70.14 cm) in a sandy loam soil. Yuan et al., (2003) observed that potato plants had a bigger biomass by expanding their plant canopy with a larger stem diameter and more leaves because irrigation water encourages plant growth higher and more branches in a silt loam soil. Ghosh et al., (2001) reported a decreasing trend in potato plant height and leaf area with the decrease of soil moisture levels (75% FC, 60% FC, and 45% FC) at all growth phases. Tessema et al., (2019) revealed that plant height under

drought irrigation and well-watered irrigation conditions fell by 26.1 and 22.6 percent (2010 and 2011) and demonstrated a significant ($p < 0.001$) effect. In another study conducted by Sharma et al., (2011) reported that potato plant height decreased significantly with reduced irrigation (I1, normal irrigation (five irrigations); I2, moderate water deficit (three irrigations up to 55 days after planting); and I3, severe water deficit (two irrigations up to 25 days after planting), particularly under severe water deficit from 48.3 cm to 35.4 cm. Hassanpanah, (2010) reported a non-significant ($p < 0.05$) effect on potato plant height under various irrigation water stress levels (normal (50%), mild stress (35%), and severe stress (25%). The drought delayed the time to full canopy development by 2-6 days and decreased the growth of shoots in terms of stem length, stem thickness, number of stems, and fresh weight of the shoots (Chang et al., 2018). Therefore, this implies that regardless of the rate and period of drought affects the growth, yield and quality aspects of potatoes.

2.4.2 Effect of water stress on potato yield

Potato morphological traits (plant height, leaf area, stem height, and diameter) and quality aspects (number of tubers, and tuber sizes) are heavily affected by water stress, and that is largely used to reflect the effect of water stress on potato yield (Tournex et al., 2003). Water stress and irrigation treatments affect yield differently. Several studies have reported that potato yield is affected by water stress. Gultekin et al., (2018) reported a significant ($p < 0.05$) effect of irrigation regimes on tuber yield was due to the quality aspects (tuber sizes and tuber weight). Mahmud et al., (2015) conducted a study under three drought stress treatments (severe (only one irrigation was applied at 30 DAP), moderate (irrigation was applied at 30, and 45 DAP only till harvest) and well-watered (irrigation applied at 30, 45, 60, and 75 DAP). The results of the study showed a significant increase in tuber yield under well-watered conditions. The yield ranged from 386 g/plant to 488.60 g/plant during 2010-2011, while during 2011-2012, the yield ranged from 327.38 g/plant to 357.88 g/plant, respectively. Low yield during the 2011-2012 cropping season was reported to be attributed mainly to the reduction in the number of tubers per plant with small-sized tuber production. Marketable tuber fresh

yield in fully irrigate (100% FC) was 12 and 43% higher than the marketable tuber fresh yield under deficit irrigates treatments TB (irrigate at 100%FC with zero irrigation at the start of tuber bulking phase (75 DAP) for 2 weeks) and TR (irrigate at 100% FC with zero irrigation at tuber maturation and ripening (90 DAP) for 2 weeks (Karam et al., 2014). On the other hand, Sharma et al., (2011) reported that marketable tubers/plant was significantly reduced from 7.2 mm (normal irrigation regime) to 3.9 mm (severe water deficit) and tuber yield was also reduced significantly from 560 g/plant (normal irrigation regime) to 271 g/plant (severe water deficit). Kashyap and Panda (2003) studied the response of potato yield under water stress levels (10, 30, 45, 60, and 75% available water content (AWC)) in sandy loam soil under humid sub-tropical climatic conditions. The study reported that yield significantly declined when irrigated under 60% and 75% AWC, and that stemmed to a least marketable or fresh tuber yield. Therefore, to enhance potato yield several researchers reported that total soil water must not drop to less than 30-50% depletion of soil water content (Reddy et al., 2016; Gultekin et al., 2018; Aldulaimy et al., 2019). Badr et al., (2012) postulated that among the four irrigation treatments of 40 percent, 60 percent, 80 percent, and 100 percent, complete water irrigation (100 percent and 80 percent) produced the highest yield, whereas 40 percent and 60 percent irrigation produced noticeably less when using drip irrigation (drip tubing). A study conducted by Steyn et al., (1998) in SA reported that the highest yield potentials of potatoes were produced under well-water irrigation levels (82 percent and 62 percent) while under water stress irrigation levels (30 percent and 20 percent FC) low yield was noted in a shelter with irrigation nozzles. On the other hand, Akkamis and Caliskan (2021) reported that yield declines if the water level in the soil declines by under 50% AWC. However, water stress on potato crop yield is heavily dependent on the cultivar, soil texture type, growing period, and severity of water stress (Hirut et al., 2017). Lahlou et al., (2003) reported that early potato cultivars were more affected by water stress (well-irrigated, and stressed) than a later maturing cultivar in terms of tuber number, whereas the opposite occurred for LAI and LAD in both field and pot trials. Furthermore, the authors stated that early maturing cultivars resulted in a yield increased compared to late maturing cultivars. Khorshidi Benam and Hassanpanah, (2007) reported that

severe water stress (6 days irrigation) compared to moderate (12 days irrigation) and no water stress (18 days irrigation) decreased tuber weight by 174.7 g and tuber yield (>55 mm) number by 0.79. Mahmud et al., (2015) reported a significant effect of $p < 0.01$ on plant height in sandy loam soil texture under water stress. Ahmadi et al., (2010) reported that loamy sand soil texture produces greater tuber yield, and dry matter content than sandy loam and coarse sandy soil textures, whilst Martins et al., (2018) reported that sandy soils aid the growth of tubers since they are loose, unlike clayey soils which are easily compacted. Therefore, this implies that potato growth, yield and quality aspects are highly dependent on cultivars, severity of water stress, and soil texture.

2.4.3 Effect of water stress on potato quality attributes

A water deficit in the potato crop induces early senescence and deformed tuber shapes such as dumb-bell shapes and knobby and pointed ends (Muthoni and Kabira, 2016). Furthermore, water stress affects other potato quality aspects. Abdelreheem et al., (2018) reported that specific gravity (SG) decreases as water irrigation levels increases from 70%FC, 90%FC, and 100%FC, and the SG means ranged between 1.105 and 1.440. Similar trend was reported by few researchers that the potato SG generally decrease as water applied increases and even water applied in water surface evaporation (E_p) at 0.25, 0.50, 0.75, 1.00, and 1.25 times (Steyn 1997; Yuan et al., 2003). However, Eiasu et al., (2007) reported that both high and low soil moisture levels (25%, 40%, 55%, and 70% maximum allowable depletion (MAD)) decreased specific gravity in an experiment conducted in a sandy clay loam textured soil. SG is used to estimate the dry matter content of potato tubers and it is the fastest index for determining the quality aspects of a potato tuber (Abebe et al., 2013; Mohammed, 2016; Ndungutse et al., 2019). Few researchers reported contrary values of potato tuber SG for processing. Abong et al., (2010) stated that potato tubers with a specific gravity of greater than 1.080 are considered suitable for crisp processing. On the other hand, PSA (2016) reported that SG must be greater than 1.075. However, the SG values are almost equal.

Nonetheless, the variation within the SG of potato cultivars is further explained by climatic variables, potato planting techniques (Wrights et al., 2005; Niederwieser and Raan, 2017).

Fabeiro et al., (2001) conducted an experiment during various potato growth phases in sandy soil in a semi-arid region in Spain. Their results postulated that the smallest tuber sizes (less than 30, 31-40 mm) were obtained under water restricted treatment (318.76 mm), while medium to large tuber sizes (41-50, 51-60, 61-70, and greater than 71 mm) were obtained under treatments that didn't go under water stress during the maturation and ripening phase. According to Karam et al., (2014), under well-drained soil with 40% clay content, medium potato tuber sizes (85-200 g) at tuber bulking (TB) and tuber ripening (TR) treatments were 48% and 56%, compared to the mean of potato tuber production, compared to 46% in control (100%FC throughout the growing season). Large potato tuber sizes (greater than 200 g) were obtained under control (100%FC), which contributed to a 50% mean of the potato tuber production, with 46% and 38% in both tuber bulking (TB) and tuber ripening (TR). Tuber size distribution is used to categorize potatoes and it is a crucial aspect to take into consideration to ensure an optimum economic marketable yield (Raan and Boneschans, 2015). The potato sizes can be graded based on mass, width, and length diameter distribution (Denner et al., 2012), while shapes can be categorized as long, oval, or oblong. Chang et al., (2018) reported a longer tuber shape (i.e. higher L/W ratio) in well-watered treatment than those in drought treatment. Small tuber sizes are less than 55 mm or 85 g, medium size range between 55 mm to 75 mm or 170 to 284.5 g, large sizes comprised of a width of greater than 75 mm or range between 284.5 and 340 g, and extra-large sizes are greater than 340 g (Steyn et al., 2009; Abbas and Ramanathan 2012). Medium to large tuber sizes and oblong, long, and oval tuber shapes are targeted for French fries and for processing potato chips as desired strip sizes are produced as reported by Smith et al., (1997). Elderege et al., (1996) reported that short-term water deficit (32-107 kpa) during tuber bulking phase increases the quantity of reducing sugars in the tubers 2 weeks or long after the stress was reduced. The potato skin colour is an important aspect in consumer acceptance of fresh potatoes from the market (Jemison et al.,

2008). Potato skin differs in colour from yellow to pink or purple (Custer, 2015). The flesh and skin of potato colours vary within cultivar genotypes, extending from white to purple colours (Subía, 2013). Tuber tissue colour is strongly influenced by the anthocyanin and carotenoid pathways and anthocyanins accumulate as water-soluble vacuolar flavonoids (Dhar et al., 2015). Little information is available on the effect of water stress and soil texture on potato skin colour and flesh parameters. Although, a study conducted by Mengistu and Grout, (2017) reported a significant difference in the concentration of reducing sugars (glucose) between the water stress treatments and the colour parameters L^* , a^* and b^* were non-significant on potato colour. The flesh and skin of potato colours vary within cultivar genotypes, extending from white to purple colours (Subía, 2013). Tuber tissue colour is strongly influenced by the anthocyanin and carotenoid pathways and anthocyanins accumulate as water-soluble vacuolar flavonoids (Dhar et al., 2015).

2.6 Effect of soil texture on potato growth, quality, and yield

Potatoes are a flexible crop that can be grown successfully in a variety of soil textures, except for soils with an alkaline soil pH (Koco et al., 2020). The cultivation of potatoes is mostly done on sandy textured soil, which has a lower water retention capacity and high leaching of macronutrients, especially N (Bohman et al., 2019; Stark and Thornto, 2020). Soil reactivity, nutrient availability, water holding capacity, soil porosity, air-water circulation, and soil density are all influenced by the soil texture (Chakraborty and Mistri, 2015). Soil texture determines the available water content for plant growth (Wang and Rosen, 2003). Sandy soils have the lowest plant available water (PAW), whereas silt loam soils have maximum while clay is intermediate. The difference is mainly because of clay content and aggregation exhibited on the soil (Hickey, 1977). Few researchers have reported the effect of soil texture on potato growth, yield, and quality attributes.

2.6.1 Effect of soil texture on potato growth

The shallow and sparse root systems of potato crop result in water stress sensitivity, being unable to absorb water and nutrients ineffectively in deeper soil horizons (Zin El-Abedin et al.,

2019). In a pot experiment, Kisitu (2021) reported that pot plants with about 50% sand to loam soil had the maximum growth vegetative parameters (plant height, highest number of leaves, and vine branches), while pot plants with 0% sand to loam had the lowest vegetative growth parameters (leaf number, vine number, and plant length). This can be explained by the fact that 50% of the soil textures were sand to loam, which contained a greater plant available water content (PAWC) than 0% of the soil textures did. Ayas and Korukcu (2010) reported a significant effect of $p < 0.01$ in potato plant height throughout the growth stages between water stress treatments when using a sandy clay loam soil texture. On the other hand, Mahmud et al., (2015) reported a significant effect of $p < 0.01$ on plant height in sandy loam soil texture under water stress. However, the differences in potato traits (leaf area, plant height, stem height, and diameter) vary during potato growth stages. In a study conducted by Wagg et al., (2021) in a greenhouse, plant height was reported to be significantly different in a sandy loam soil texture during the vegetative and tuber bulking growth stages, when applying three soil moisture levels (deficit, normal and excess) Clay soil is comprised of smaller pore sizes, a large surface area, high water holding capacity, high water retention, high plant available water and better fertility when compared to sandy soils (Reichert et al., 2016).

2.6.2 Effect of soil texture on potato yield and quality attribute

Heavier clay textured soils can produce a great yield of potatoes, the quality is worse since potatoes are more likely to grow to be bigger in size, watery, and tasteless (Schmidt et al., 2014). This is attributed to the ability of clayey textured soil comprised of higher water holding than other soil textures, and poor air permeability which results to watery. According to Asfaw (2016), light, sandy soils produce tubers with the most appealing skin and shape. Heavier soils higher in clay content tend to provide better fertility and water-holding capacity, but there are few researchers reporting potatoes grown on clay soils. Heavier clay soil can cause the deformation of tubers, and dark tuber skins, make tuber washing a problem, and cause distorted tuber shapes (Claridge, 1972; Leap et al., 2017). A study conducted by Martins et al., (2018) reported that the tuber yield of potatoes in clay soil was higher compared to those

planted in sandy soil. Ahmadi et al., (2011) reported a non-significant effect of the irrigation plan on the fresh tuber yield with the soil textures (loamy sandy, sandy loam and coarse sand). However, the author under soil textures (sandy loam, coarse sand) reported that there was a non-significant difference with the irrigation treatments such that loamy sandy soil texture significantly produced the maximum mean (47.86) fresh tuber yield when compared to sandy loam (41.34) and coarse sand (42.34) soils. Furthermore, the results of the study postulated a significant interaction effect between the irrigation treatments and soil textures such that the highest fresh tuber yield was obtained under full irrigation in loamy sand. On the hand Karam et al., (2014) reported that the yield of potato tubers under clay soil was 30 percent lower than on loamy soil, consequently showing the sensitivity of potatoes to soil texture.

2.7 Nutrient requirements

Conducting a soil analysis test is strongly prescribed prior to applying fertilizers to avoid excessive and deficient application. Three key macronutrients, nitrogen (N), phosphorus (P), and potassium (K), are relative inundation plants (Stubbs, 2016). Nevertheless, in potato production, the three key macronutrients are generally regularly utilized during soil fertilization (Davenport et al., 2005). An adequate application of mineral fertilizers fortifies the potato crop in case of unfavourable conditions, is critical for obtaining a greater yield, and is required for producing high-quality potatoes (Koch et al., 2020).

Potato crops essentially require a high measure of fertilizer, not only to avoid deficient application or nutrient stipulation (Hopkins et al., 2008). Also, because of the shallow root arrangement of the potato crop, as referred to insufficient utilization of nutrients like N, and susceptibility to moisture stress (Liu et al., 2015). Plants utilize N from the soil in a variety of forms, either as ammonium (NH_4^+) or nitrate (NO_3^-) ions (Kahsay, 2019). However, Gao et al., (2014) proposed that the impacts of N variety in potato development and improvement might rely upon the growth stage. A review by Qiqige et al., (2017), reported that potato parameters (leaf area and dry matter) in NH_4^+ treatment after measurement during the tuber initiation phase were significantly different compared to treatment with NO_3^- . This can be attributed to

the fact that NO_3^- is mobile, whereas NH_4^+ is immobile in the plant. N facilitates photosynthesis and results in a significant increase in physiological potato parameters (Workineh et al., 2017). In the same sense, N is needed in greater quantity and supplied in a constant linear right just after the start of the tuber bulking stage (Tolessa et al., 2016). To support that, Koch et al., (2020) stated that a quantity of N is required at the tuber bulking phase, roughly 50-70% of which is used at the phase. N deficiency symptoms are slender, upright, and bear smaller, pale green and yellow leaves (Trehan et al., 2001).

Phosphorous (P) is an essential nutrient, that plays a foundational part in crop physiology (Jasim et al., 2020). P is essentially needed by the potato crop in large quantities relatively to other crops (Koch et al., 2020). However, P application varies during the growth phases. Munda et al., (2015) reported that P is essential during tuber initiation phase to obtain optimum tuber numbers and yield. P is pivotal for cell division, and photosynthesis, but insufficient soil P availability limits root growth (Rosen et al., 2014). Additionally, P is pivotal for potato early development, tuber set, skin thickness, and tuber maturity, during the late growth phase (Hopkins et al., 2014; Rosen et al., 2014). To support that, Hopkins et al., (2019) reported that insufficient soil P slows and lowers potato development and maturity. An experiment conducted by Soratto et al., (2019), reported that the yield components (tuber number per plant, tuber mean weight) were directly proportional in P application up to date, only tuber mean weight was significantly affected only up to 50 mg dm^{-3} . Abnormal, undersized development, slender shoots with small, dark green, and lusterless leaves are all signs of P shortage in potato crops (Trehan et al., 2001; Jasim et al., 2020).

Potassium (K) is needed much more in potato crops (Koch et al., 2020). Total K, exchangeable K^+ , and K^+ in the soil solution are the three types of K in the soil (Bista and Bhandari, 2019). In soil and plants, K^+ is vital in exchangeable forms. Therefore, K^+ is highly needed in the potato crop, and is mostly used as a measure of the availability of K^+ in the soil (Bhattarai et al., 2016). K plays an important part in some physiological activities such as photosynthesis,

transpiration, synthesis of proteins, fats, and carbohydrates, and regulation of plant stomata (Bhattarai et al., 2016; Zelelew et al., 2016). An experiment conducted by Zelelew et al., (2016) reported that growth, growth parameters (aerial stem number, leaf number per plant and plant height), yield parameters (tuber diameter, tuber number per plant and tuber weight) and total yield had a significant increase with an increase in K⁺ level. Undersized growth and dark green leaves with a bluish colour are signs of K insufficiency in potato crops (Trehan et al., 2001).

2.9 Water use efficiency

Water use efficiency (WUE) is characterized as the crop yield acquired over the water used by the crop (Reddy et al., 2016). On the other hand, WUE can be further elucidated in various stages, such as leaf WUE, whole plant WUE, and yield WUE (Hong-Xing et al., 2007). Potato WUE strongly depends on the cultivars, cultural practices, irrigation levels, fertilizer application rate, and other environmental aspects (Djaman et al., 2021). Nagaz et al., (2007) postulated that potato WUE showed a variation between growing seasons. It varied from 8-9, 6-8, and 11-14 kg m⁻³ for autumn, winter, and spring, respectively. Another study conducted by Alaa et al., (2012) reported a higher and different irrigation water use efficiency (IWUE) under drip-irrigation compared to furrow-irrigated, and potassium fertilizer application, an enhancement in WUE was observed, while WUE recorded an enhancement from 5.868 to 8.489; 5.129 to 7.379 with furrow irrigation; and an enhancement from 8.121 to 12.212, and 6.907 to 10.257 with drip irrigation were observed. A healthy potato crop uses about 400-800 millilitres of water per day and the use of water differs during growth stages (Reddy et al., 2016). However, when limited irrigation is applied during less critical growth phases such as early vegetative and late tuber bulking, it can help improve crop WUE (Ali and Talukder, 2008). The WUE parameter measures how much water is applied and used during the crop's growing season.

2.10 Agronomic factors

Agronomic aspects that affect potatoes are firmly related to the soil profile utilized in potato production. Plant nutrients are freely available at a soil pH ranging between 6.5 and 7.5 (Soti et al., 2015). That makes the potato plant have significant growth and development. However,

a soil pH greater than 8 results in crop sensitivity to common scabs (Waterer, 2002). Soil compaction due to heavy mechanization from both subsoil and topsoil, especially in wet areas, reduces yield by restricting tuber growth (Johansen et al., 2015). Potato roots and tuber growth require sandy soil comprised of good soil aeration and good drainage for high yield (NPCK, 2019). According to Zheng et al., (2016), potato tuber quantity and tuber weight declined considerably with increased plant density. In the same study, the authors postulated that increasing plant density could improve tuber quantity per unit area while lowering tuber weight. Planting potatoes on the same land year over year could prompt the development of potato-related pests and diseases. Usually, potatoes are mainly rotated with maize and wheat for soil health maintenance. In comparison to solitary potato stands, intercropping potatoes with legumes lima bean (*Phaseolus lunatas* L.) and dolichos (*Lablab purpureous* L.) increased leaf area index (LAI) by 26-57 percent, decreased soil temperature by 7.3 °C at a depth of 0-30 cm and increased potato yield (7.2-38.2 t. ha⁻¹) compared to sole potato treatment (1.3-16.3 t. ha⁻¹) (Nyawande et al., 2019).

2.11 Conclusion

Literature results generally indicate the effect of irrigation water stress levels on potato growth, yield and quality. However, there is no consensus on which water stress level is most detrimental to the performance of potato crop. Similarly, the most economical suitable for potato production. However, the previous research results focused more on sandy soil textures than other soil textures. Therefore, more research on how various water stress levels affect potatoes grown in other soil textures is needed since the potato crop is cultivated in various soil textures in SA. Moreover, interaction of irrigation water stress levels and soil texture have not been reported extensively in other countries and in SA. Furthermore, the effect of water stress on potato growth traits (leaf area, and stem diameter), and quality aspects (tuber skin, flesh colour, and shapes) have not been reported widely. Therefore, this study will attempt to fill the knowledge gap.

Chapter 3

3. Materials and methods

3.1 Study site

The study was conducted during the 2021 (spring) and 2022 (winter) cropping seasons in a plastic tunnel at the University of Venda (UNIVEN) Experimental Farm situated in Thohoyandou (latitude 22°58'S and longitude 30°26' E; altitude 596 m a.m.s.l). Thohoyandou falls within a semi-arid region (Mmarete, 2003). The area receives an annual rainfall of approximately 500 mm with an average minimum and maximum temperature of 18 degree Celsius (°C) and 31 °C, respectively (Mzezewa and Van Rensburg, 2011). Rainfall is highly seasonal, with 95 per cent (%) of the rainfall occurring between October and March (Mmarete, 2003). The mean annual aridity index (AI) is 0.52 (Mzezewa and van Rensburg, 2011).

3.2 Soil collection

Soil samples were collected from a depth of 0-20 cm due to using a clean spade, the depth of 0-20 cm was due to topsoil. Three soil samples with different textural classes were collected (clay, sandy loam, and sandy clay loam) from three sites representing potato growing areas in the Limpopo province as follows:

1. University of Venda (UNIVEN) Experimental Farm (clayey soil). Land use for the site during sampling was a disturbed cropping field.
2. Nzhelele, Tshivhidulu village (latitude of 22°56'16''S and a longitude of 30°40'25''E) (Sandy loam). Land use for the site was a disturbed cropping field (maize) during sampling.
3. Malamulele, Dovheni Commercial Nursery (latitude of 22°56'16''S and a longitude of 30°40'25''E) (Sandy clay loam). Land use for the site was a disturbed cropping field during sampling.

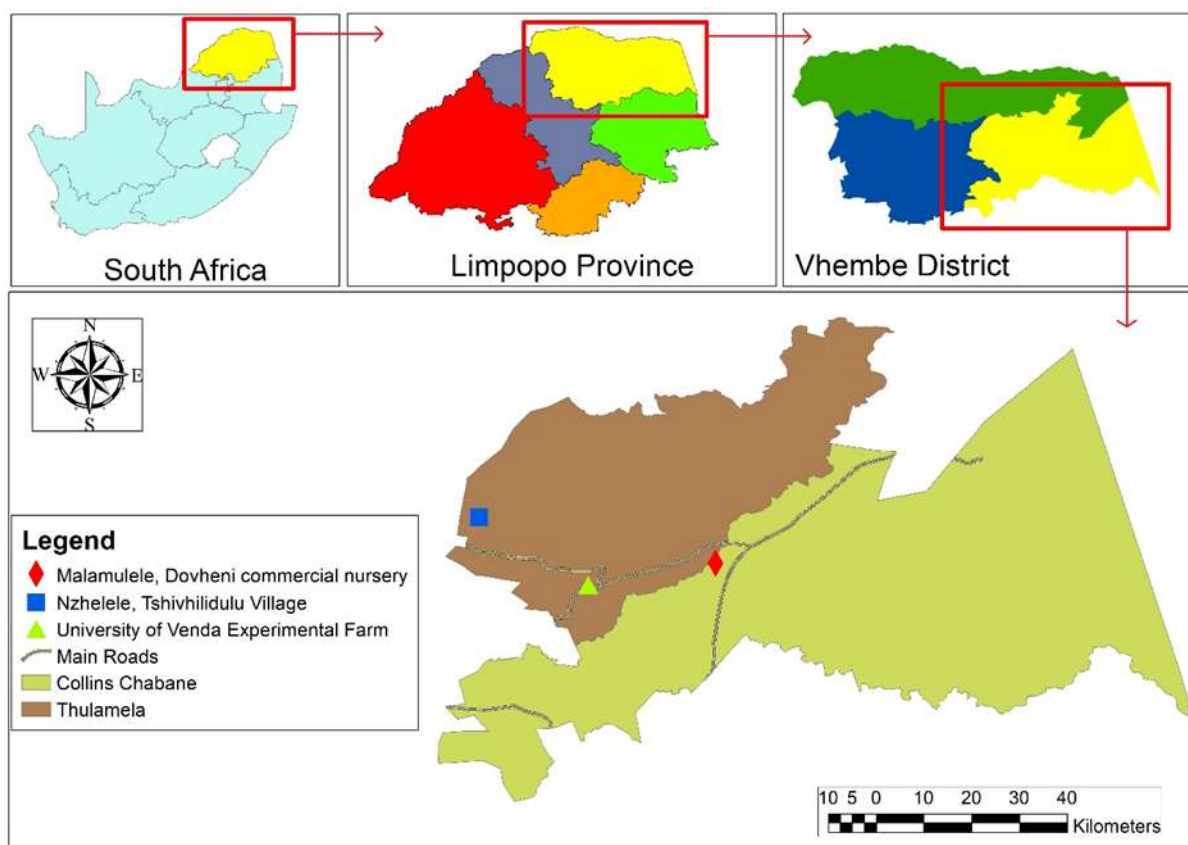


Figure 3.1: Map showing three soil collection sites in Limpopo Province

Five points were randomly selected in the centre of each field for soil collection. Before soil collection, surface litter and organic materials were removed from a space of about 1.5 -2 m² around the selected points. The soil was collected using a clean spade and transferred into a twenty-five- litre bucket and then poured into five sacks of 80 kg from each site and transported to the UNIVEN soil science storeroom. The samples were stored for two days before air drying for another two days. Then they were sieved into twenty-five- litres bucket using a 2-mm aperture sieve to remove debris and organic matter. The sieved soil was poured into sacks for potting preparation later. Two hundred g soil from each field was sub-sampled from the sacks, poured in a sample plastic bag to form a composite sample. The composite sample was used for soil analysis later.

3.3 Soil analysis

Soil pH was determined in both potassium chlorite (KCl) and water (H₂O) (in the supernatant suspension of a 1:2.5 soil: water ratio) using a pH multimeter probe (McLean,1982). Particle size distribution was determined using the hydrometer method by Bouyoucos (1962), were 50 g of soil from the sieved (2-mm) two hundred grams of composite samples of each site was used to determine particle size distribution, using 10 ml of 10% sodium hexametaphosphate (Calgon) solution. Organic carbon (OC) was determined using the Walkely and Black (1934) method. Total nitrogen (N) was determined using the Kjeldahl method by Bremmer and Mulvaney (1982). Available phosphorus (P) was determined by the Bray method (Bray and Kurtz, 1945), and exchangeable cations (Mg²⁺, Ca²⁺, Na⁺, K⁺) were determined using atomic absorption spectrometry after extraction with 1.0 M ammonium acetate (Chapman 1965).

3.4 Determination of field capacity

Field capacity (FC) was determined in duplicates on 20 kg of sieved soil placed in 25 L pots. The bottoms of the pots were covered by a thin perforated plastic film that allowed water to drain freely but trapped soil particles. The soil samples were saturated from the bottom for 48 hours by allowing them in excess water. After saturation, the top of the pots were covered with plastic sheets to avoid evaporation. When the gravitational water ceased (after 48 hrs), the net weight of moist soil was measured. The amount of water held by the soil sample, i.e., 100 % FC, was calculated using the equation below (3.1). Subsequent calculation of water held at 60% and 30 % of FC of each soil in the potato growing area was carried out and used in the experiment.

$$100\%FC = \frac{(\text{Net weight of pot} + \text{net weight of moist soil after 48hrs}) - (\text{Net weight of pot} + \text{net weight of dry air soil})}{(\text{Net weight of pot} + \text{net weight of dry air soil})} \quad (3.1)$$

3.5 Determination of plant available water (PAW)

Soil samples were collected in duplicates from a depth of 0-5 cm using core rings measuring 5 cm (height) by 5 cm (diameter) (98.00 cm³). Excess soil was removed from the core rings by chipping the soil off using a soil knife. Thereafter, core rings were closed on both sides

using caps. The samples were put in plastic sample bags, recorded, and transported to the laboratory. The procedure of the sandbox manual (Eijkelkamp Soil and Water, the Netherlands) was followed. The soil cores were saturated in the sandbox apparatus for 48 hrs before being subjected to a suction head of 100 cm or 10 kPa. Every week, the samples were carefully removed out of the water basin in the sandbox apparatus and wiped off any water drops hanging underneath the sample before weighing using a weighing balance (RADWAG, PS 4500.R2). This was repeated until a constant weight was attained, after which the samples were placed in an oven at 105 degrees °C for drying for 24 hrs. Gravimetric water content was determined by using the below equation (3.2) and bulk density was determined using the equation below (3.3). Volumetric water content at FC was determined using the equation below (3.4).

$$\text{Gravimetric water content in \% (W)} = \frac{(\text{Weight of soil water})(g)}{(\text{Weight of dry soil})(g)} \quad (3.2)$$

$$\text{Bulk density(BD)} = \frac{(\text{Dry soil weight})(\text{excluding ring+cloth+elastic})}{\text{Volume of core ring}} \quad (3.3)$$

$$\text{The volumetric water content of soil at FC } (\Theta_v) = W \times \text{BD} \quad (3.4)$$

3.6 Pressure membrane apparatus

A 200gram (g) composite sample of each site was used for analysis. Three soil samples were placed in retaining rings of 1.6 cm high by 28 cm inside diameter cylinder and then placed on the ceramic plates and saturated in a trough of water for about 48 hrs. Procedure of pressure membrane apparatus was followed (Eijkelkamp Soil and Water, the Netherlands). The ceramic plates were subjected to a pressure of 15 bars or 1500 kPa for the determination of PWP. Equilibrium was observed when water flow from the plates ceased. The samples were weighed immediately, then placed in an oven at 105 °C for drying for 24 hrs. The gravimetric and volumetric water soil water content of the samples was determined as before.

Table 3.1 Water content of the soil textures used in the experiment.

Textural class	FC (cm ³)	PWP (cm ³)	PAWC (cm ³)
Clay	0.45	0.21	0.24
Sandy clay loam	0.37	0.19	0.18
Sandy loam	0.31	0.16	0.15

FC = Field capacity, PWP = Plant wilting point, PAWC = Plant available water content

3.7 Potting soil preparation and agronomic management

The sieved soil in sacks was prepared for potting by weighing 20 kg into each 25 - L pot measuring 36.5 cm in diameter and 34.2 cm in height using a weighing scale (Shekel Merav 2000 model). The pots were transported to the plastic tunnel to prepare for planting. Mondial and Bp1 potato seed cultivars were planted. Bp1 seeds were obtained from Potato Seed Production (PSP Company) and Mondial seeds were sourced from a local farmer at Ha-Mphaila Irrigation Scheme. The sprouted seeds were sown at a depth of 10 cm in each pot. Sowing was done on the 31st of August 2021, and 31st of May 2022 first and second cropping seasons, respectively. Before irrigation, tap water was sampled to determine electrical conductivity (EC) and pH using a conductivity meter and a pH meter, respectively. The EC and pH were 139.1 $\mu\text{s}/\text{dm}$ and 7, respectively. The pots were fully irrigated at 60%FC when irrigation was necessary using tensiometers (Table 3.1). Fertilizer application rates based on 80 kg/ha yield potentials are shown in Table 3.2 and were determined by soil analysis. Urea (46%N), superphosphate (10.5%P), and potassium sulphate (48%K) fertilisers were applied. Fertilisers were split-applied. The first half of the fertiliser amount were applied a week after emergence and the other half was applied at bulking stage. Water stress treatment levels were applied at 100%FC, 60%FC, and 30%FC at 37 DAP. Tensiometers (model 14.04.03 standard) were used to monitor soil water content in the crop root-zone throughout the cropping seasons. The crops were irrigated when the tensiometers readings had reached the values reported in Table 3.1. Plants were sprayed once weekly with fungicide (copper counter N) to control early blight caused by *Phytophthora infestans* at the first site of potato blight. Spraying was stopped when the symptoms of blight eased showing in the plants.

Table 3.2 Tensiometer readings (centibars) for irrigation water stress levels under various soil textures

Soil textures	100%FC	60%FC	30%FC
Clay (UNIVEN Experimental Farm)	70-80	60-70	50
Sandy clay loam (Dovheni Commercial Nursery)	60	50	40
Sandy loam (Tshivhilidulu Irrigation Scheme)	50	40	30

Table 3.3 Fertilizer application rates (g/pot)

Application rates (g/pot)	UNIVEN experimental farm (clayey)	Tshivhilidulu Irrigation Scheme (sandy loam)	Dovheni Commercial Nursery (sandy clay loam)
Urea	1.35	2.40	2.80
Superphosphate	1.56	0.74	1.30
Potassium sulphate	0.29	4.30	3.14

3.8 Experimental design and treatments

The pot experiment was a $2 \times 3 \times 3$ factorial experiment laid out in a Completely Randomized Design (CRD). The treatments comprised the following factors: two potato cultivars, three soil textures, and three water stress levels with three replicates making a total of 54 experimental units (polyethylene pots).

Table 3.4 Treatments combinations used during the 2021/2022 cropping season

Cultivars	Soil textures	Water stress levels		
		M ₁ (100%FC)	M ₂ (60%FC)	M ₃ (30%FC)
Mondial	T ₁ (Clayey)	T ₁ M ₁	T ₁ M ₂	T ₁ M ₃
	T ₂ (Sandy loam)	T ₂ M ₁	T ₂ M ₂	T ₂ M ₃
	T ₃ (Sandy clay loam)	T ₃ M ₁	T ₃ M ₂	T ₃ M ₃
Bp1	T ₁ (Clayey)	T ₁ M ₁	T ₁ M ₂	T ₁ M ₃
	T ₂ (Sandy loam)	T ₂ M ₁	T ₂ M ₂	T ₂ M ₃
	T ₃ (Sandy clay loam)	T ₃ M ₁	T ₃ M ₂	T ₃ M ₃

100% FC = 5 litres in clayey textured soil, 3.6 litres in sandy clay loam textured soil, 2.7 litres in sandy loam textured soil.

60% FC = 3.0 litres in clayey textured soil, 2.16 litres in sandy clay loam textured soil, and 1.62 litres in sandy loam textured soil.

30% FC = 1.5 litres in clayey textured soil, 1.08 litres in sandy clay loam textured soil, and 0.81 litres in sandy loam textured soil.



Figure 3.2: Potato plants in a tunnel at UNIVEN Experimental Farm during the 2021 cropping season.



Figure 3.3: Potato plants in a tunnel at UNIVEN Experimental Farm during the 2022 cropping season.

3.9 Growth parameters

Planting, crop emergence dates, and the dates to reach various growth stages were recorded in the field notebook for each pot.

3.9.1 Plant height and stem diameter measurements

Plant height and stem diameter were measured approximately after four weeks of emergence (38 DAP). Measurements were taken during the growth stages (vegetative, tuber initiation, tuber bulking, and maturation phases) in each treatment every after seven days. Plant height was measured using a measuring stick from the base of the main shoot of the plant to the apex of the topmost leaf. Stem diameter was measured using a Vernier caliper, main stem was selected in each pot and measured.

3.9.2 Leaf area determination

Leaf area (LA) was measured using a ruler, by randomly selecting leaves at the uppermost of the potato plants to measure in every plant. The length (L) and width (W) of the selected potato plant leaves were measured during the growth phases (vegetative, tuber initiation, tuber bulking and maturation) in each treatment. A factor (f) (0.74) was used to calibrate the L and W, then the equation below was used to calculate LA (Widaryanto et al., 2019).

$$LA = f \times L \times W \text{ (cm}^2\text{)} \quad (3.5)$$

3.10 Yield of potatoes

The yield of potato tubers was calculated in marketable yield (g/pot plant) were potato tubers in each pot plant were weighed and recorded. Marketable tuber yield was determined by weighing all the potato tubers that were defects-free (diseases, cracks, small in sizes ($\leq 55\text{mm}$) and other various physiological disorders) according to (Lung'aho et al., 2007).

$$\text{Yield} = \frac{\text{Mass of potatoes per pot (g)}}{\text{pot plant}} \quad (3.6)$$

3.11 Quality attributes

3.11.1 Specific gravity determination

Specific gravity (SG) was determined by the weight of tuber in air and weight of tuber in water method (Edgar, 1951). Three tuber samples were randomly sampled for SG determination. The samples were weighed in air (weight in air), immersed in a known volume of tap water, and then weighed again (weight in water) using a weighing balance. Specific gravity was calculated using the below equation.

$$SG = \frac{M_a}{M_a - M_w} \quad (3.7)$$

Where

M_a is the mass in the air

M_w is the mass in water

3.11.2 Sizes, shapes, and colour determination

3.11.2.1 Sizes

Potato tuber sizes were determined by taking measures along the diameter of the principal axes using a Vernier caliper having an accuracy of 0.02 mm. Twelve potato tubers were randomly sampled and measured using the Vernier caliper. The size grading of Ekin, (2013) was used scale the potato tuber sizes, larger size was greater than or equal to 75 mm, a medium size between 55 to 75 mm, and for small size less than or equal to 55 mm.

3.11.2.2 Shape

The potato tuber shape was determined using the tuber form index (TFI). Potato tuber length and width were measured using a Vernier caliper. Two potato tubers were randomly sampled in each treatment for shape determination. Calculations were done using the TFI index formula below (3.5). The TFI is used to classify tuber shape index as follows, round (less than 1.09), short-oval (between 1.10 and 1.29), oval (between 1.30 and 1.49), and long-oval (between 1.50 and 1.69), or long (greater than 1.70) (Ekin, 2013).

$$TFI = \frac{\text{Length of the potato tuber}(cm)}{\text{Width of potato tuber}(cm)} \quad (3.8)$$

3.11.2.3 Colour

Potato tuber skin and flesh colour were analysed using a Hunter Lab colorimeter (MiniScan XE Plus, Model CM-3500d, Hunter Associate laboratory, Reston, VA, USA), which comprised of a D65 light source, 8 observer, diffuse/O mode, 8 mm aperture of the instrument for illumination, and 8 mm for measurement. The equipment was calibrated with black and white tiles. Two potato tubers were randomly sampled by cultivar (BP1 and Mondial) in each treatment. The potato tuber skin was determined by inserting the potato tuber of each potato cultivar (BP1 and Mondial) into the hunter colorimeter, and after determining the potato tuber skin (BP1 and Mondial) samples were peeled off the skin to determine the colour of the flesh by inserting the tuber flesh into the hunter's colorimeter. Chroma, and hue angle were

determined using the equations below (3.10 and 3.11). Higher numbers of chromaticity indicate a more vivid colour, whereas lower numbers correspond to dull colours.

Where:

L* value is the lightness parameter indicating the degree of lightness of the sample; it varies from 0 = black (dark) to 100 = white (light).

a* is the chromatic redness parameter, whose value means tending to red colour when positive (+) and green colour when negative (-).

b* is a yellowness chromatic parameter corresponding to yellow colour when it is positive (+) and blue colour when it is negative (-).

$$\text{Chroma} = \sqrt{(a^*)^2 + (b^*)^2} \quad (3.9)$$

$$\text{Hue angle } (H^{\circ}) = \tan^{-1} \left(\frac{b^*}{a^*} \right) \quad (3.10)$$

3.10 Statistical analysis

Data collected was arranged using excel and analysed by a two-way analysis of variance (ANOVA) using Minitab 21. Difference between the treatment means was compared using Tukey's honestly significant difference (HSD). Probability (p) level of less than 0.05 was designated as significant. If there was a statistically significant interaction between the main effect of water stress and soil texture, then the interaction was presented. Otherwise only the main effects of water stress and soil texture were reported. However, when the main effect interaction of varieties were found to be not-significant, data were pooled and reanalysed, except for skin and colour determination.

Chapter 4

4. Results

4.1 Initial soil characterization

Physio-chemical composition of the soils used in the experiment are represented in Table 4.1a. The soil pH_(H₂O) of the soils used were slightly acidic, ranging from 4.5 - 5.9, whilst the soil pH (KCl) ranged from 5.56 - 6.08. The Dovheni Commercial Nursery sandy clay loam (SacL) had a higher electrical conductivity (EC) value of 93.4 than the UNIVEN clay (C) and Tshivhiludulu sandy loam soils (SaL). Total nitrogen (N) and potassium (K⁺) were lower in SaL with values of 19.56 mg/kg, and 43 mg/kg, respectively. UNIVEN C soil had a low phosphorus (P) of 2 mg/kg, whilst the Dovheni Commercial Nursery SacL soil was comprised of a higher P value of 23 mg/kg.

Table 4.1a Pre - cropping soil properties (chemical, soil particle size distribution and texture)

Parameters	Sample sites		
	UNIVEN Experimental farm (C)	Dovheni Commercial Nursery (SaCL)	Tshivhilidulu Irrigation Scheme (SaL)
pH (KCl)	5.92	5.95	4.47
pH (H ₂ O)	6.06	5.81	5.56
Total N (mg/kg)	22.54	44.24	19.56
P (mg/kg)	2	23	10
Exchangeable cations (mg/kg)			
Ca ²⁺	797	1195	361
Mg ²⁺	290	461	30
K ⁺	92	295	43
Na ⁺	13	10	13
CEC (cmolc kg ⁻¹)	7.25	7.48	3.02
EC (µs/cm)	47.4	93.4	38.02
OC (%)	1.60	1.10	0.53
Particle size distribution (%) and texture			
Sand	37	51	79
Clay	43	25	9
Silt	20	24	12
Textural class	Clay	Sandy clay loam	Sandy loam

N = Nitrogen, P = Phosphorus, K = Potassium, CEC = cation exchange capacity, EC = electrical conductivity, OC = organic carbon, Exchangeable cations (Ca= calcium, Mg= magnesium, K= potassium, Na= sodium), C = clay, SaCL= sandy clay loam, SaL = sandy loam.

Table 4.1b Experimental details and dates of phenological stages during the 2021/22 cropping seasons

Phenological phases	2021	2022
Planting	31 Aug	04 May
Emergence	14 Sep	18 May
Water stress applied	7 Sep (37 DAP)	7 Jul (37 DAP)
Vegetative	14 Sep (44 DAP)	14 Jun (44 DAP)
Tuber initiation	28 Sep (58 DAP)	28 Jul (58 DAP)
Tuber bulking	12 Oct (72 DAP)	12 Aug (72 DAP)
Maturation	26 Oct (86 DAP)	26 Aug (86 DAP)
Harvesting	09 Nov (100 DAP)	09 Sep (100 DAP)

Jun = June, Jul = July, Aug = August, Sep = September, Oct = October, Nov = November,

DAP = Days after planting

4.2 Effect of water stress and soil texture on growth parameters

4.2.1 Plant height

There was a significant ($p < 0.05$) interaction between water stress \times soil texture on potato plant height at 51 days after planting (DAP) (vegetative stage) to 72 DAP (tuber bulking stage) during the 2021 cropping season (Table 4.2a; Figure 4.1). Maximum potato plant height (89.66 cm) was observed at 72 days after planting (DAP) at 100%FC \times sandy loam soil, whilst least potato plant height of 52.5 cm was reported at 30%FC \times sandy clay loam at 51 DAP. There was a non-significant increase on potato plant height at all water stress levels under sandy clay loam soil during 51DAP, 65 DAP and 72 DAP (Figure 4.1). An increase of 49%, 46% and 30% under clayey soil at 30%FC, 60%FC and 100%FC during 51 DAP was observed on potato plant height relative to the other studied soil textures (sandy clay loam and sandy loam), although they were statistically similar. Water stress treatment was significant only at 44 DAP (Table 4.2a), whilst soil texture treatment was significant almost the entire growth period except at 58 DAP and 79 DAP (Table 4.2a). Water stress treatment at 72 DAP had an increase in plant height with an increase in water stress level (Table 4.2a).

There was a significant ($p < 0.05$) interaction between water stress \times soil texture on potato plant height was observed at 44 DAP to 86 DAP, during the 2022 cropping season (Table 4.2; Figure 4.2). The highest plant height mean value of 67.33 cm was observed at 79 DAP under 60% water stress level \times sandy clay loam soil, whereas the lowest plant height of 26.00 cm was observed at 86 DAP under 60% water stress level \times clay soil (Figure 4.2). Significant variation on potato plant height decreased with an increase of irrigation water stress levels in sandy clay loam at 44 DAP to 58 DAP (Figure 4.2). However, in sandy loam soil and clayey soil there was no trend observed, although significant variations were observed at 44 DAP to 58 DAP. During the 72 DAP and 79 DAP at 30%FC, 60%FC, and 100%FC water stress levels in sandy clay loam soil an increase of 37.74%, 25%, 21.57%, and 22.65%, 33.33%, 17.24% respectively of potato plant height was observed relative to the studied soil texture (sandy loam and clay soil), respectively. Soil texture significantly influenced potato plant height

throughout the growing period. Sandy clay loam revealed a greater increase in potato plant height from 36.89 cm to 62.78 cm than the other studied soil textures (clay and sandy loam), whilst at 86 DAP and 93 DAP from 39.50 to 25.06 cm, respectively (Table 4.2b).

Table 4.2a Effect of water stress and soil texture on plant height (cm) during the 2021 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (FC%)								
30 (Severe water stress)	51.17 ^b	57.11 ^a	61.17 ^a	66.11 ^a	65.78 ^b	69.22 ^a	76.94 ^a	46.22 ^a
60 (Moderate water stress)	60.11 ^a	60.61 ^a	64.94 ^a	69.67 ^{ab}	76.67 ^{ab}	81.17 ^a	90.00 ^a	51.33 ^a
100 (Well-watered)	54.17 ^{ab}	62.83 ^a	68.50 ^a	75.83 ^a	78.06 ^a	86.67 ^a	86.61 ^a	48.83 ^a
ST								
Clay	58.22 ^a	61.39 ^{ab}	65.56 ^a	67.56 ^b	74.06 ^{ab}	78.56 ^a	89.61 ^a	52.06 ^a
Sandy clay loam	57.44 ^a	63.89 ^a	68.39 ^a	79.61 ^a	82.17 ^a	87.56 ^a	92.28 ^a	51.28 ^a
Sandy loam	49.78 ^b	55.28 ^b	60.67 ^a	64.44 ^b	64.28 ^b	70.94 ^a	73.67 ^b	43.06 ^b
SEM	1.60	1.68	2.14	2.13	2.83	4.17	3.77	1.60
WS	*	ns	ns	ns	*	ns	ns	ns
ST	*	*	ns	*	*	ns	*	*
WS x ST	ns	*	*	*	*	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant $p < 0.01$, WS = Water stress, ST = Soil texture, DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

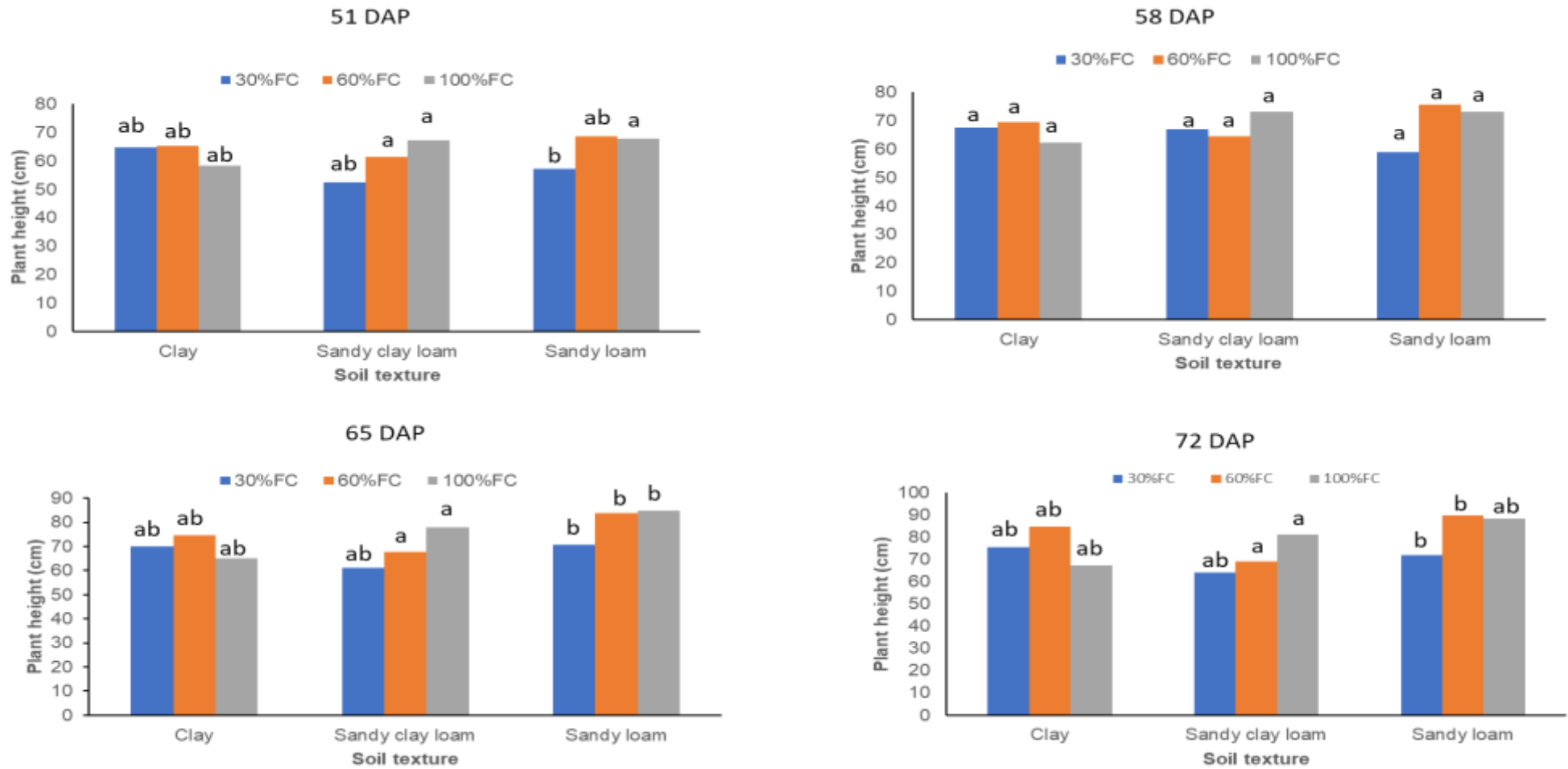
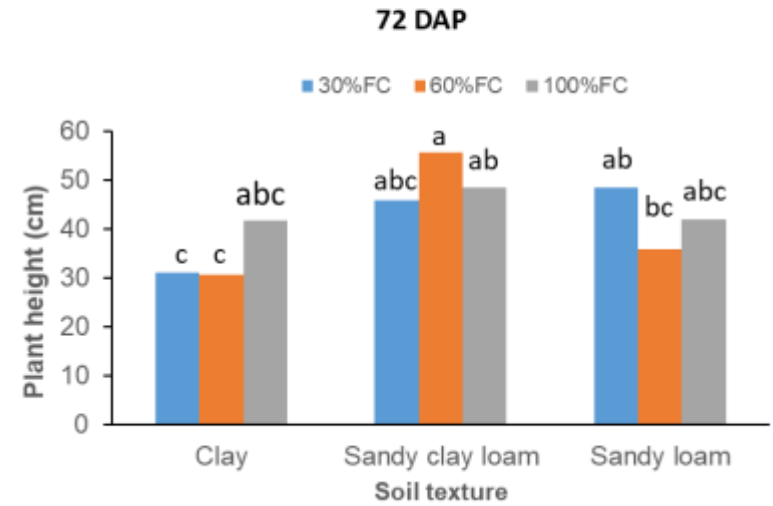
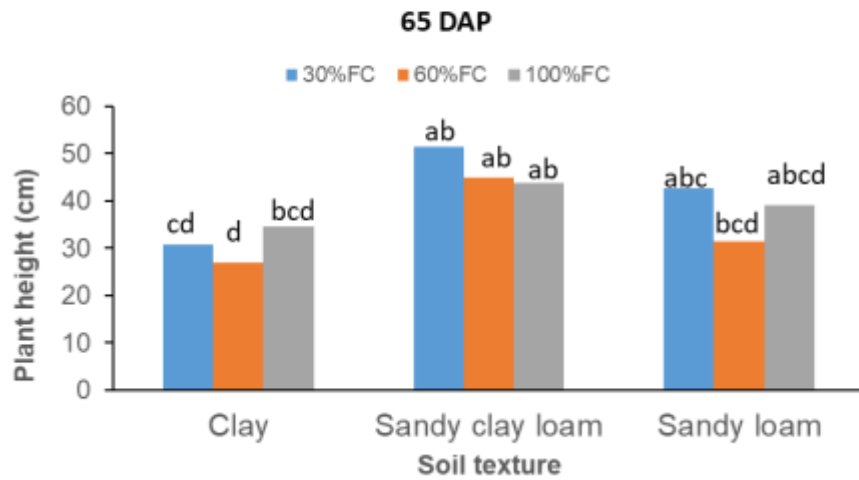
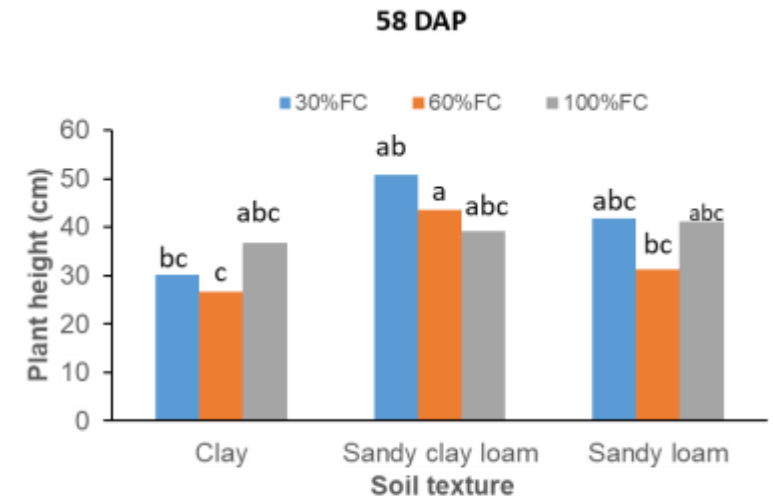
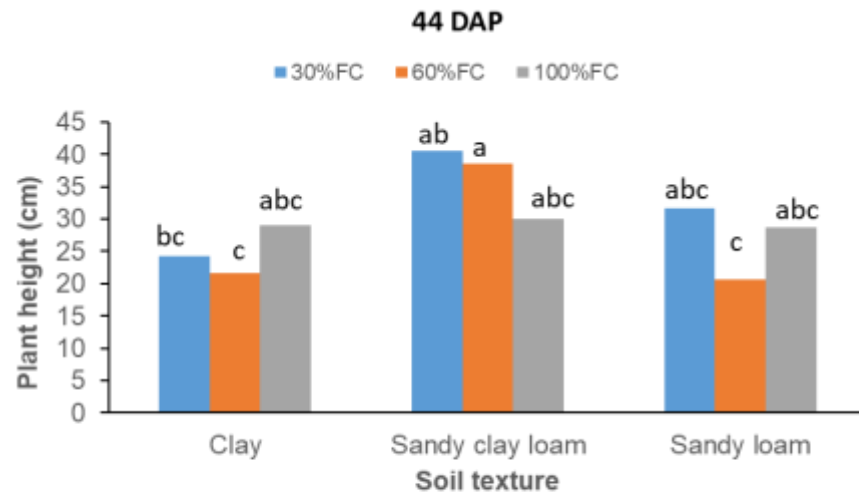


Figure 4.1: The interaction of water stress and soil texture on potato plant height during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.2b Effect of water stress and soil texture on plant height (cm) during the 2022 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (FC%)								
30 (Severe water stress)	31.67 ^a	38.50 ^a	39.22 ^a	41.83 ^a	47.17 ^a	54.17 ^a	35.56 ^a	21.94 ^a
60 (Moderate water stress)	27.61 ^a	36.06 ^a	36.67 ^a	40.72 ^a	47.22 ^a	53.39 ^a	31.39 ^a	22.44 ^a
100 (Well-watered)	29.41 ^a	39.00 ^a	39.22 ^a	43.78 ^a	51.94 ^a	59.00 ^a	36.39 ^a	23.33 ^a
ST								
Clay	24.97 ^b	31.17 ^b	30.61 ^c	34.56 ^c	39.00 ^c	51.39 ^b	32.00 ^b	19.89 ^b
Sandy clay loam	36.89 ^a	44.28 ^a	46.72 ^c	49.94 ^a	58.33 ^a	62.78 ^a	39.50 ^a	25.06 ^a
Sandy loam	26.83 ^b	38.11 ^a	37.78 ^b	41.83 ^b	49.00 ^b	52.39 ^b	31.83 ^b	22.78 ^{ab}
SEM	1.59	1.58	1.37	1.57	1.48	1.43	1.47	1.20
WS	ns	ns	ns	ns	ns	ns	ns	ns
ST	*	*	*	*	*	*	*	*
WS x ST	*	*	*	*	*	*	*	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.



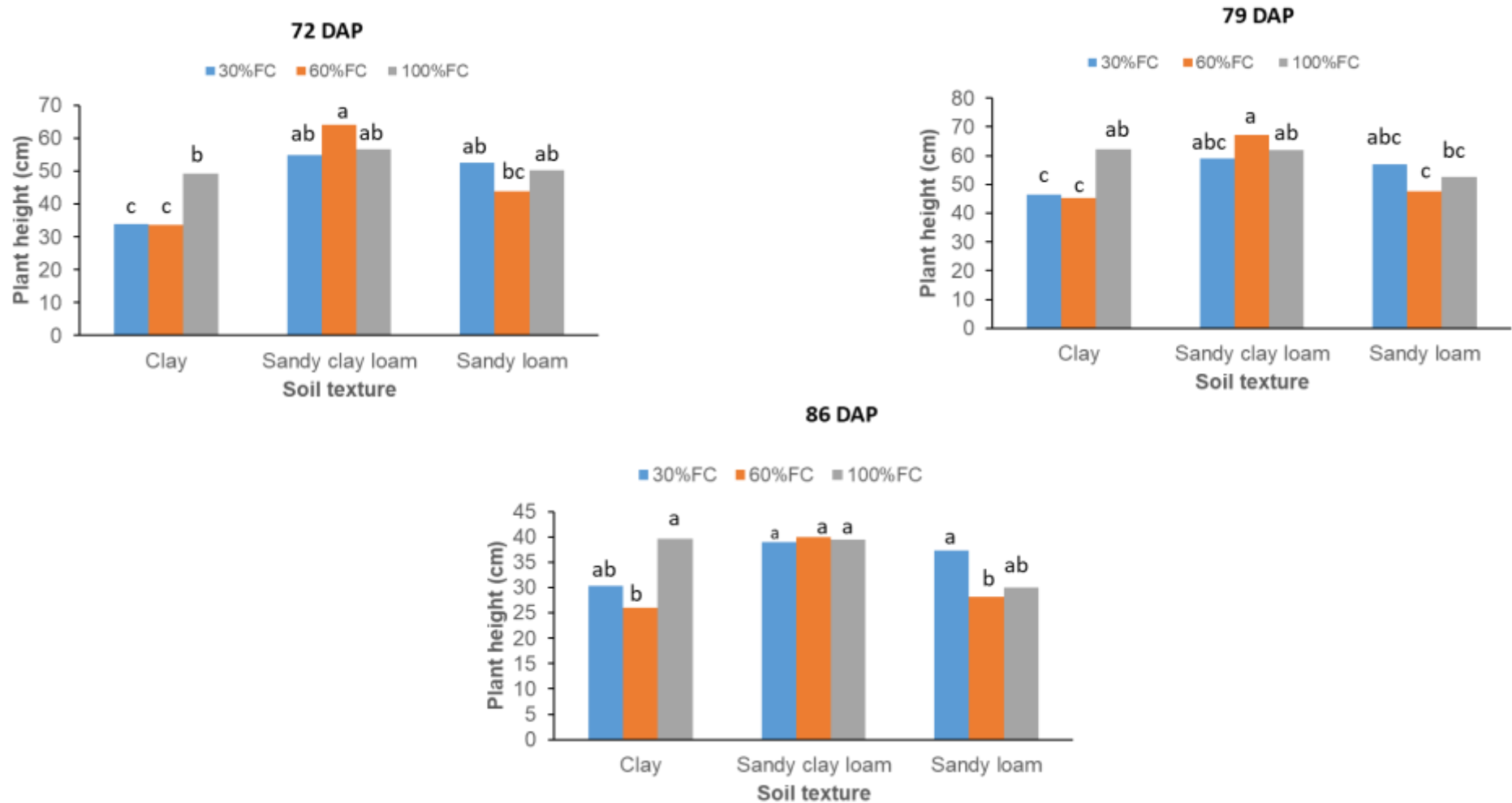


Figure 4.2: The interaction of water stress and soil texture on potato plant height during the 2022 cropping season. Means that do not share the same letters in a column are significantly different.

4.2.2 Leaf area

There was no significant ($p>0.05$) interaction effect between water stress \times soil texture treatments on leaf area (LA) during the 2021 cropping season (Table 4.3a). Water stress treatment had no significant ($p>0.05$) effect on LA over the entire growing period. A decrease on LA with an increase on irrigation water stress levels was observed at 44 DAP, 51 DAP, and 65 DAP, recording the maximum LA (27.05 cm^2) at 44 DAP at 30%FC, while the least recorded (15.38 cm^2) at 86 DAP, although there was no significant difference. Soil texture treatment had a significant ($p<0.05$) effect during 44 DAP and 58 DAP. Sandy loam showed a variation compared to the other studied soil textures (sandy clay loam and clay) at 44 DAP. However, at 51 DAP a highly significant variation on the soil textures (clay and sandy loam), while sandy clay loam was similar to both soil textures (clay and sandy loam). The highest LA mean was recorded in clayey soil (31.91 cm^2) at 44 DAP, whilst the lowest LA mean was recorded in sandy loam soil (14.85 cm^2).

Water stress \times soil texture interaction had no-significant ($p>0.05$) effect on LA throughout the growing period during the 2022 cropping season (Table 4.3b). Soil texture treatment had a significant variation on LA at 79 DAP and 93 DAP. Sandy loam soil had a variation on LA compared to the other studied soil textures (sandy clay loam and clayey soils) at 79 DAP. Variation on soil textures at 93 DAP was observed, however sandy clay loam was similar to both clayey soil and sandy loam. A maximum LA (47.91 cm^2) was recorded under clay soil (93 DAP), whilst the minimum LA (19.15 cm^2) was recorded under sandy loam soil (79 DAP). However, water stress treatment had no significant ($p>0.05$) effect throughout the growth period, similarly during the 2021 cropping season. LA due to water stress treatment had an increase with an increase in irrigation water stress levels at 51 DAP, 58 DAP, 65 DAP, 72 DAP and 79 DAP, although no significant variation on water stress were observed.

Table 4.3a Effect of water stress and soil texture on leaf area (cm²) during the 2021 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (%FC)								
30 (Severe water stress)	27.05 ^a	19.65 ^a	18.50 ^a	16.71 ^a	16.25 ^a	15.77 ^a	15.38 ^a	15.60 ^a
60 (Moderate water stress)	23.70 ^a	16.34 ^a	18.92 ^a	16.68 ^a	17.79 ^a	17.38 ^a	18.17 ^a	17.02 ^a
100 (Well-watered)	21.94 ^a	16.21 ^a	20.45 ^a	16.49 ^a	17.61 ^a	16.36 ^a	16.86 ^a	17.05 ^a
ST								
Clay	31.94 ^a	18.45 ^a	21.96 ^a	18.50 ^a	21.31 ^a	19.25 ^a	18.36 ^a	18.35 ^a
Sandy clay loam	25.88 ^a	16.88 ^a	19.67 ^{ab}	15.63 ^a	16.43 ^a	15.69 ^a	15.82 ^a	16.31 ^a
Sandy loam	14.85 ^b	16.87 ^a	15.89 ^b	15.74 ^a	13.91 ^a	14.57 ^a	16.22 ^a	15.02 ^a
SEM	2.02	1.62	1.20	0.71	1.74	1.40	1.72	1.23
WS	ns	ns	ns	ns	ns	ns	ns	ns
ST	*	ns	*	ns	ns	ns	ns	ns
WS x ST	ns	ns	ns	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

Table 4.3b Effect of water stress and soil texture on leaf area (cm²) during the 2022 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (%)								
30 (Severe water stress)	19.36 ^a	16.90 ^a	24.89 ^a	26.84 ^a	24.90 ^a	23.38 ^a	35.43 ^a	39.43 ^a
60 (Moderate water stress)	19.07 ^a	20.77 ^a	28.90 ^a	29.06 ^a	25.36 ^a	25.21 ^a	37.92 ^a	39.25 ^a
100 (Well-watered)	20.46 ^a	23.86 ^a	33.16 ^a	29.19 ^a	29.85 ^a	31.41 ^a	34.45 ^a	42.63 ^a
ST								
Clay	17.53 ^a	22.13 ^a	31.84 ^a	32.20 ^a	28.92 ^a	32.09 ^a	41.02 ^a	47.91 ^a
Sandy clay loam	23.65 ^a	21.58 ^a	28.74 ^a	30.50 ^a	29.40 ^a	28.75 ^a	35.27 ^a	41.66 ^{ab}
Sandy loam	17.71 ^a	17.82 ^a	26.38 ^a	22.39 ^a	21.89 ^a	19.15 ^b	31.51 ^a	31.74 ^b
SEM	1.60	1.48	2.02	2.12	2.26	1.83	3.31	2.36
WS	ns	ns	ns	ns	ns	ns	ns	ns
ST	ns	ns	ns	ns	ns	*	ns	*
WS x ST	ns	ns	ns	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

4.2.3 Stem diameter

Water stress \times soil texture interaction had a significant ($p < 0.05$) effect on stem diameter at 93 DAP during the 2021 cropping season (Table 4.4a; Figure 4.3). There were no significant ($p > 0.05$) differences in stem diameter amongst the three water stress levels sandy loam textured soils. Maximum stem diameter (0.77 cm) was observed under sandy loam textured soil \times 60%FC whereas, the least stem diameter (0.43 cm) was recorded under clayey soil \times 30%FC. Stem diameter significantly increased with water stress levels under clayey soil (0.43 cm, 0.47 cm and 0.60 cm), sandy clay loam soil (0.62 cm, 0.67 cm, and 0.68 cm) (Figure 4.3). However, in sandy loam soil a higher stem diameter (0.77 cm) was observed at 60%FC and the least were at 100%FC and 30%FC. The water stress treatment had significant ($p < 0.05$) effect on stem diameter at 86 DAP and 93 DAP (Table 4.4a). Stem diameter by water stress treatment increased with water stress levels at 44 DAP, 51 DAP, 79 DAP and 86 DAP, although there was no-significant ($p > 0.05$) difference. However, at 93 DAP 60%FC water stress level and 100%FC recorded the same mean stem diameter (0.62 cm). Soil texture treatment had a significant ($p < 0.05$) effect over the entire growing period except at 51 DAP, 65 DAP, and 72 DAP (Table 4.4a). The highest stem diameter (0.94 cm) was recorded under sandy clay loam soil (79 DAP), whilst the lowest stem diameters 0.62 cm, and 0.50 cm were recorded under sandy clay loam soil (44 DAP), and sandy loam soil (93 DAP), respectively.

During the 2022 cropping season, there was a significant ($p < 0.05$) effect between water stress \times soil texture interaction on stem diameter at 65 DAP (Table 4.4b; Figure 4.4). Highest stem diameter (1.10 cm) was recorded on sandy clay loam soil \times 30%FC, while the least stem diameter (0.78 cm) was recorded on clayey soil \times 30%FC (Figure 4.4). The stem diameter had significantly increased (0.78 cm $<$ 0.83 cm $<$ 0.88 cm) variation with irrigation water stress levels under clayey soil, although 30%FC and 60%FC were observed to be similar (Figure 4.4). Water stress treatment had a significant ($p < 0.05$) effect on stem diameter at 51 DAP and 58 DAP (Table 4.4b). A decrease in stem diameter with an increase in water stress levels at 58 DAP, although during 65 DAP and 93 DAP there was no significant different observed.

Maximum stem diameter (0.98 cm) by water stress treatment was observed at 30%FC during the 51 DAP, whereas the least stem diameter (0.84 cm) was observed at 100%FC during 58 DAP. Soil texture treatment had a significant ($p<0.05$) effect on stem diameter over the growing period except at 86 DAP and 93 DAP (Table 4.4b). Maximum stem diameter (1.02 cm) by soil texture treatment was observed in sandy clay loam soil (1.02 cm) at 51 DAP and 72 DAP, while the least stem diameter (0.50 cm) was observed in clayey soil (0.45 cm) at 93 DAP, although soil texture had no significant different.

Table 4.4a Effect of water stress and soil texture on stem diameter (cm) during the 2021 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (%FC)								
30 (Severe water stress)	0.67 ^a	0.78 ^a	0.78 ^a	0.84 ^a	0.83 ^a	0.83 ^a	0.81 ^b	0.51 ^b
60 (Moderate water stress)	0.69 ^a	0.84 ^a	0.86 ^a	0.83 ^a	0.89 ^a	0.88 ^a	0.89 ^{ab}	0.63 ^a
100 (Well- watered)	0.80 ^a	0.90 ^a	0.85 ^a	0.87 ^a	0.89 ^a	0.90 ^a	0.93 ^a	0.63 ^b
ST								
Clay	0.83 ^a	0.85 ^a	0.86 ^{ab}	0.86 ^a	0.88 ^a	0.89 ^{ab}	0.94 ^b	0.50 ^b
Sandy clay loam	0.62 ^b	0.88 ^a	0.88 ^a	0.89 ^a	0.90 ^a	0.94 ^a	0.87 ^{ab}	0.66 ^a
Sandy loam	0.71 ^{ab}	0.79 ^a	0.75 ^b	0.89 ^a	0.83 ^a	0.78 ^b	0.82 ^a	0.62 ^a
SEM	0.04	0.03	0.03	0.03	0.02	0.03	0.02	0.02
WS	ns	ns	ns	ns	ns	ns	*	*
ST	*	ns	*	ns	ns	*	*	*
WS x ST	ns	ns	ns	ns	ns	ns	ns	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

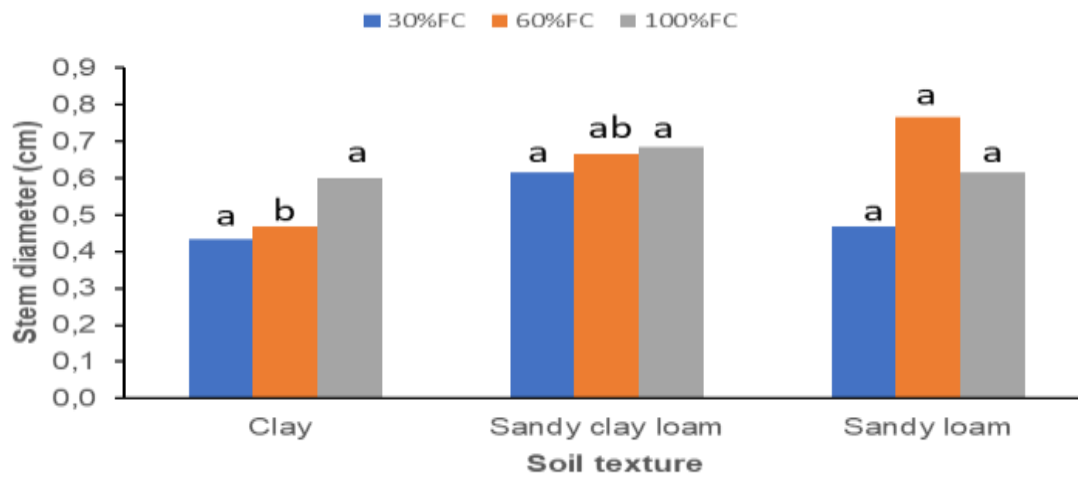


Figure 4.3: The interaction effect of water stress and soil texture on stem diameter at 93 DAP during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.4b Effect of water stress and soil texture on stem diameter (cm) during the 2022 cropping season

Treatments	44(DAP)	51(DAP)	58(DAP)	65(DAP)	72(DAP)	79(DAP)	86(DAP)	93(DAP)
WS (%FC)								
30 (Severe water stress)	0.87 ^a	0.98 ^a	0.97 ^a	0.94 ^a	0.92 ^a	0.92 ^a	0.65 ^a	0.50 ^a
60 (Moderate water stress)	0.81 ^a	0.88 ^b	0.87 ^{ab}	0.92 ^a	0.89 ^a	0.95 ^a	0.61 ^a	0.47 ^a
100 (Well-watered)	0.83 ^a	0.90 ^b	0.84 ^b	0.88 ^a	0.89 ^a	0.92 ^a	0.61 ^a	0.49 ^a
ST								
Clay	0.83 ^{ab}	0.81 ^c	0.83 ^b	0.83 ^b	0.84 ^b	0.89 ^b	0.58 ^a	0.45 ^a
Sandy clay loam	0.92 ^a	1.02 ^a	1.00 ^a	1.00 ^a	1.02 ^a	1.01 ^a	0.69 ^a	0.51 ^a
Sandy loam	0.76 ^b	0.93 ^b	0.86 ^b	0.91 ^{ab}	0.84 ^b	0.88 ^b	0.60 ^a	0.50 ^a
SEM	0.04	0.02	0.03	0.02	0.03	0.02	0.03	0.03
WS	ns	*	*	ns	ns	ns	ns	ns
ST	*	*	*	*	*	*	ns	ns
WS x ST	ns	ns	ns	*	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, DAP = Days after planting, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

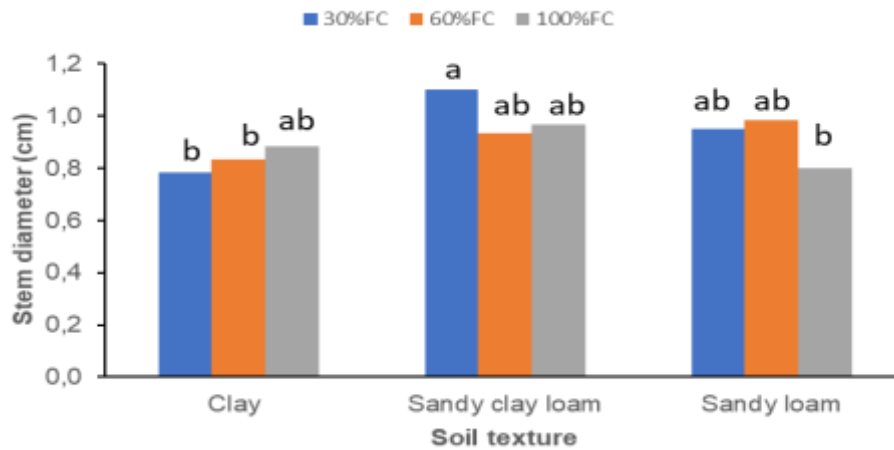


Figure 4.4: The interaction effect of water stress and soil texture on stem diameter at 65 DAP during the 2022 cropping season. Means that do not share the same letters in a column are significantly different.

4.3 Effect of water stress and soil texture on marketable potato yield.

The interaction between water stress × soil texture had no significant ($p>0.05$) effect on marketable potato yield during the 2021 cropping season (Table 4.5a). Water stress treatment also had no significant ($p>0.05$) effects on marketable potato yield. However, the soil texture treatment was only significant ($p<0.05$) on potato marketable yield. Clayey soil produced the highest marketable tuber yield (30.92 g/pot), but statistically similar to the marketable potato yield produced in sandy clay loam soil. Sandy loam soil produced the least marketable tuber yield (18.72 g/pot).

A significant ($p<0.05$) interaction effect between water stress and soil texture on marketable potato yield was observed during the 2022 cropping season (Table 4.5b; Figure 4.5). Marketable potato yield in sandy clay loam soil significantly decreased with irrigation water stress levels and recording the highest potato marketable yield (411.39 g/pot) under sandy clay loam × 30%FC, whilst the least potato marketable yield (185.01 g/pot) was recorded under sandy clay loam × 100%FC (Figure 4.5). In sandy loam × irrigation water stress levels had no significant differences on marketable potato yield. However, in clayey soil a significant difference across the irrigation water stress levels was observed. Furthermore, in clayey soil at 30%FC irrigation water stress level recorded the highest marketable potato yield, followed by 100%FC and lastly by 60%FC irrigation water stress levels.

Table 4.5a Effect of water stress and soil texture on marketable potato yield (g/pot) during the 2021 cropping season

Treatments	Marketable potato yield (g/pot)
WS (%FC)	
30 (Severe water stress)	23.51 ^a
60 (Moderate water stress)	25.70 ^a
100 (Well-watered)	25.87 ^a
ST	
Clay	30.92 ^a
Sandy clay loam	25.43 ^a
Sandy loam	18.72 ^b
SEM	1.46
WS	ns
ST	*
WS × ST	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means.

Means that do not share the same letters in a column are significantly different within the treatment factors.

Table 4.5b Effect of water stress and soil texture on potato marketable yield (g/pot) during the 2022 cropping season

Treatments	Marketable potato yield (g/pot)
WS (%FC)	
30 (Severe water stress)	373.04 ^a
60 (Moderate water stress)	265.07 ^b
100 (Well-watered)	295.52 ^b
ST	
Clay	301.22 ^a
Sandy clay loam	310.24 ^a
Sandy loam	322.17 ^a
SEM	17.2
WS	*
ST	ns
WS x ST	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means.

Means that do not share the same letters in a column are significantly different within the treatment factors.

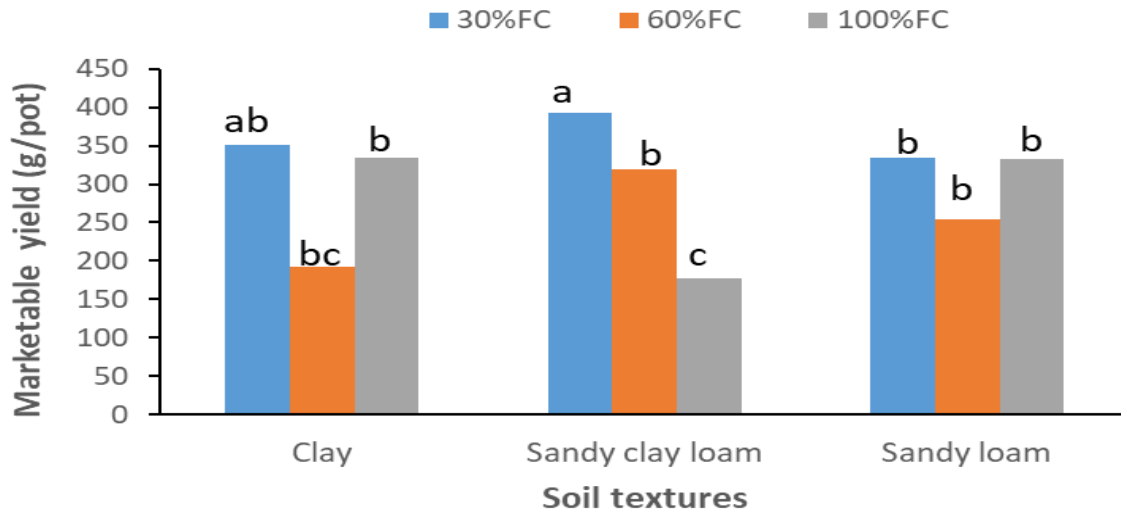


Figure 4.5: The interaction effect of water stress and soil texture marketable potato yield during the 2022 cropping season. Means that do not share the same letters in a column are significantly different.

4.4 Effect of water stress and soil texture on potato quality attributes

4.4.1 Sizes

Water stress × soil texture interaction had a significant ($p < 0.05$) effect on potato tuber size during the 2021 cropping season (Table 4.6; Figure 4.6). There was a significant increase (44.93 mm, 49 mm, 53.92 mm) on potato tuber sizes with irrigation water stress levels in sandy loam soil (Figure 4.6). Clayey soil at 100%FC and 30%FC were similar on potato tuber sizes, except at 60%FC which was the same to sandy loam soil at 60%FC (Figure 4.6). However, in sandy clay loam soil a maximum mean tuber size of 59.42 mm was observed at 100%FC, whilst the least mean tuber size of 39.50 mm was recorded in sandy clay loam soil at 60%FC, and there was significant variation (Figure 4.6). In all the studied soil textures at 30%FC the potato tuber sizes were statistically similar.

In the 2022 cropping season, there was no significant ($p > 0.05$) interaction between water stress and soil texture on potato tuber sizes (Table 4.6). Both the treatments of water stress and soil texture did not have significant ($p > 0.05$) effect on the potato tuber sizes. However, irrigation water stress treatment at 30%FC produced slightly higher tuber sizes compared to the other studied irrigation water stress levels (60%FC and 100%FC), although there was no significant variation. Soil texture treatment, under clayey soil slightly produced higher tuber sizes compared to the studied soil textures (sandy clay loam and sandy loam soil), although there was no significant variation. Although the treatments and the interactions had no significant effect on potato tuber sizes obtained during the 2022 cropping season, the potato tuber sizes were categorized as larger tuber sizes (≥ 75 mm).

4.4.2 Shapes

There was no significant ($p > 0.05$) interaction between water stress × soil texture on potato tuber shapes during both seasons (Table 4.6). During the cropping season of 2021, the potato tuber shape determined by water stress treatment recorded a higher average of 1.42 at 60%FC and the lowest average of 1.24 at 30%FC. But water stress treatment had no significant ($p > 0.05$) effect on potato tuber shape. Soil texture treatment recorded a maximum

average in clay soil (1.37), while sandy clay loam and sandy loam recorded the least similar averages of 1.34, although the soil texture treatment had no significant ($p>0.05$) effect. The soil texture and water stress treatments both did not have a significant ($p>0.05$) effect on potato tuber shapes during the cropping season of 2022 (Table 4.6). Tuber form index (TFI) of the potato shapes obtained on the 2021 cropping season were ranging on short-oval (1.10 to 1.29) and oval (between 1.30 and 1.49), whilst the potato tuber shapes during the 2022 cropping season were ranging on long oval (between 1.50 and 1.69) to long (≥ 1.70).

4.4.3 Specific gravity

There was no significant ($p>0.05$) interaction between water stress and soil texture on specific gravity (SG) during both 2021/2022 cropping seasons (Table 4.6). Similarly, both water stress and soil texture had no significant ($p>0.05$) effect on SG during both 2021/2022 cropping seasons. Maximum SG (1.07) by water stress treatment was recorded at 30%FC, whereas 60%FC and 100%FC recorded similar least value (1.06) during the 2021 cropping season, although there was no significant difference. In the 2022 cropping season, SG by water stress treatment increased with irrigation water stress levels, but there was no significant variation. The potato specific gravity recorded in this study was suitable for processing mean values were ranging at 1.05 to 1.21.

Table 4.6 Effect of water stress and soil texture on potato quality attributes during the 2021/2022 cropping seasons

Treatments	2021 cropping season			2022 cropping season		
	Sizes (mm)	Shapes	SG	Sizes (mm)	Shapes	SG
WS (%FC)						
30 (Severe water stress)	45.03 ^b	1.24 ^a	1.07 ^a	83.83 ^a	1.69 ^a	1.09 ^a
60 (Moderate water stress)	46.56 ^b	1.42 ^a	1.06 ^a	77.98 ^a	1.71 ^a	1.14 ^a
100 (Well-watered)	52.51 ^a	1.39 ^a	1.06 ^a	81.24 ^a	1.80 ^a	1.19 ^a
ST						
Clay	47.43 ^a	1.37 ^a	1.06 ^a	85.76 ^a	1.80 ^a	1.21 ^a
Sandy clay loam	47.39 ^a	1.34 ^a	1.07 ^a	78.18 ^a	1.65 ^a	1.11 ^a
Sandy loam	49.28 ^a	1.34 ^a	1.05 ^a	79.10 ^b	1.76 ^a	1.09 ^a
SEM	1.30	0.05	0.01	2.02	0.04	0.03
WS	*	ns	ns	ns	ns	ns
ST	ns	ns	ns	ns	ns	ns
WS x ST	*	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SG = Specific gravity, SEM = Standard error means. Means that do not share the same letters in a column are significantly different within the treatment factors.

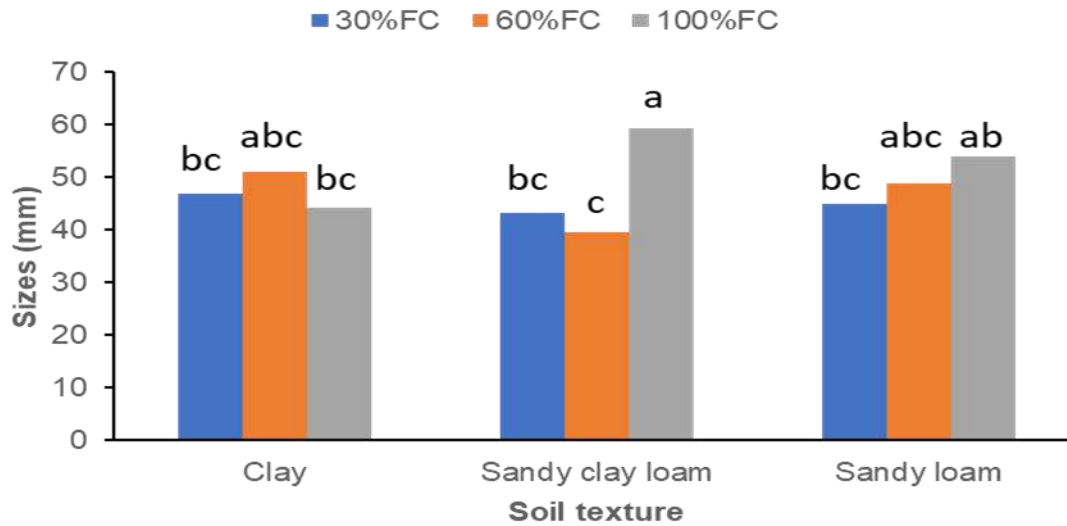


Figure 4.6: The interaction effect of water stress and soil texture on potato tuber sizes during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

4.3.4 Potato Bp1 skin colour

There was a significant ($p < 0.05$) effect on water stress \times soil texture interaction on potato Bp1 skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season (Table 4.7a; Figure 4.7). Chroma mean values in sandy loam soil significantly increased ($0.35 < 27.51 < 35.07$) with irrigation water stress level, and recorded the highest Chroma mean value (35.07) in sandy loam soil \times 100%FC, whereas the least Chroma value (0.045) was recorded in sandy clay loam soil \times 60%FC. Clayey soil had no significant differences on Chroma mean values across water stress treatments, unlike in sandy clay loam soil a significant difference was observed at 30%FC, whilst at 60%FC and 100%FC were statistically similar. Hue angle in sandy loam soil significantly increased (26.57° , 58.67° and 70.13°) with an increase in water stress levels (Figure 4.7). A higher hue angle (82.60°) was observed in clayey soil \times 60%FC, while the least hue angle (26.57°) was observed in sandy loam soil \times 30%FC. Hue angle in clayey soil had no significant difference at 30%FC and 60%FC, but at 100%FC was observed to be significantly different, unlike in sandy clay loam soil a significant difference was observed only at 60%FC. However, at 30%FC and 100%FC \times sandy clay loam there was no significant difference (Figure 4.7). Potato Bp1 skin lightness parameter (L^*) in sandy loam soil had a significant increase with water stress levels. On the other hand, in clayey soil a non-significant difference was observed, and recorded the maximum L^* at 60%FC, followed by 100%FC and 30%FC, respectively. Unlike in sandy clay loam soil a significant difference was observed, and recording the highest L^* at 30%FC, while 60%FC and 100%FC were similar. The L^* had a light-coloured skin colour (>50) at all the treatments, except at 100%FC \times clay and 100%FC \times sandy loam. A significant difference was observed amongst the soil textures on Chromatic redness parameter (a^*). Chromatic redness parameter (a^*) of potato Bp1 skin colour recorded a high mean value (12.47) in sandy loam \times 60%FC, whereas the least a^* (0.015) was recorded in sandy clay loam \times 60%FC. The a^* tended towards the red colour as positive (+) average values of a^* were observed. Yellowness chromatic parameter (b^*) of potato Bp1 skin colour showed an increase (0.16, 20.48, and 32.97) with water stress levels in sandy loam soil and recorded the maximum b^* value (32.97) in sandy

loam soil × 100%FC, comparatively to the other studied soil textures (sandy clay loam and clay). Sandy clay loam soil × 30%FC was observed to be significantly different, compared to sandy clay loam soil × 60%FC and 100%FC, although were similar. Least b^* was observed in sandy clay loam soil × 60%FC, compared to the other soil textures (sandy loam and clay). The potato Bp1 skin gravitated towards yellow as shown by the positive (+) mean values of yellowness (b^*) parameter (Table 4.7a; Figure 4.7)

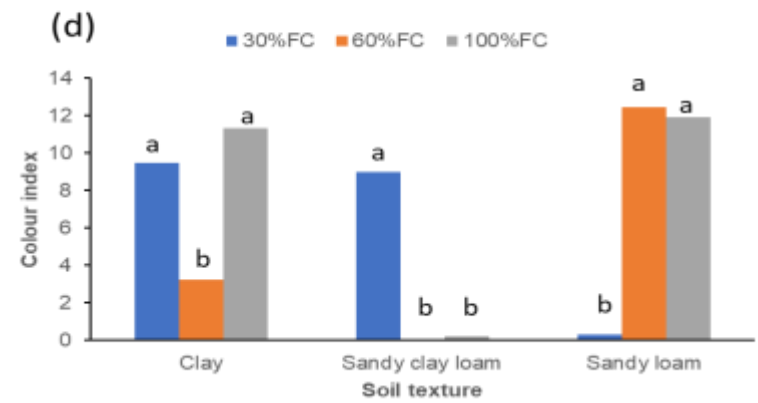
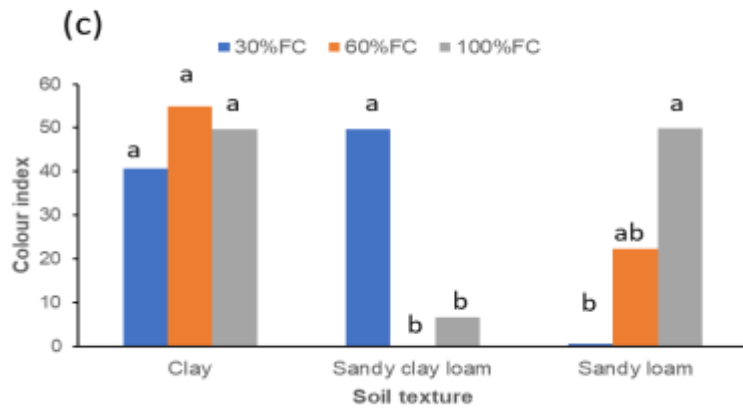
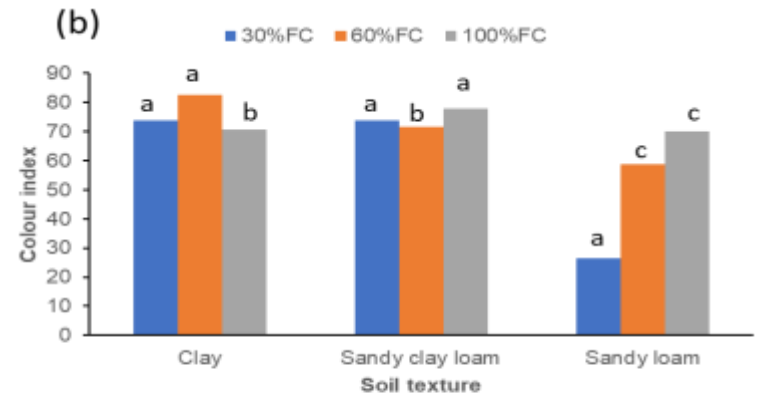
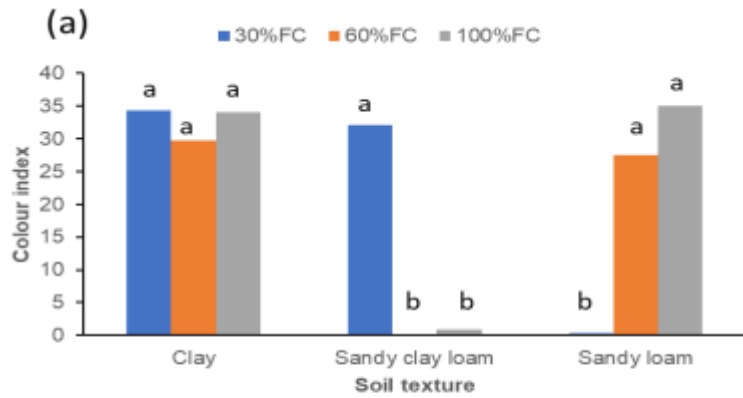
water stress and soil texture interaction had no significant ($p>0.05$) effect on potato Bp1 skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2022 cropping season (Table 4.7b). However, a significant difference was observed on Chroma by water stress treatment, and on a^* by soil texture treatment. Maximum Chroma mean value by water stress treatment was observed at 60%FC and least Chroma mean value was observed at 100%FC. Hue angle increases with water stress levels.

Table 4.7a Effect of water stress and soil texture on potato Bp1 skin colour during the 2021 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	22.25 ^a	58.03 ^b	30.28 ^a	6.26 ^b	21.30 ^a
60 (Moderate water stress)	19.11 ^a	70.96 ^a	25.74 ^a	5.25 ^b	15.25 ^b
100 (Well-watered)	23.34 ^a	72.88 ^a	35.30 ^a	7.82 ^a	21.99 ^a
ST					
Clay	32.72 ^a	75.65 ^a	48.36 ^a	8.03 ^a	30.09 ^a
Sandy clay loam	11.01 ^c	74.43 ^a	18.74 ^b	3.06 ^b	10.58 ^c
Sandy loam	20.97 ^b	51.79 ^b	24.22 ^b	8.24 ^a	17.87 ^b
SEM	0.94	0.55	2.05	0.29	0.52
WS	ns	*	ns	*	*
ST	*	*	*	*	*
WS x ST	*	*	*	*	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means,

L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.



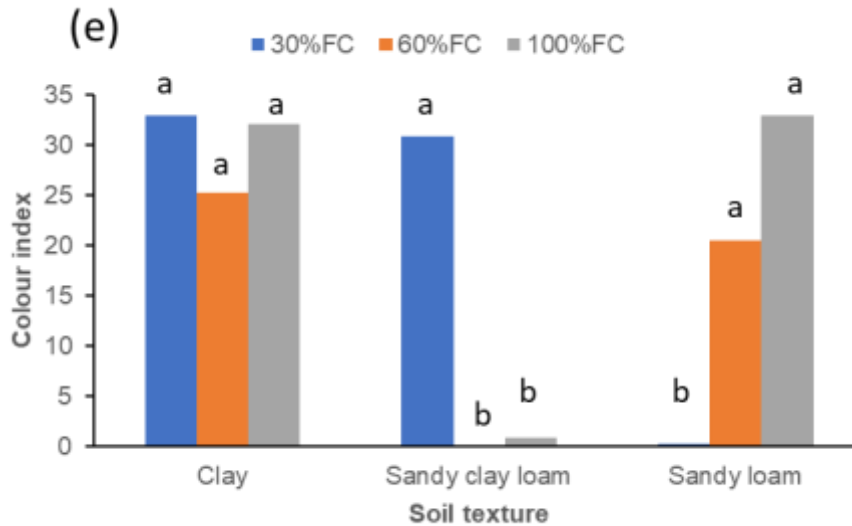


Figure 4.7: The interaction of water stress and soil texture on Potato Bp1 skin colour parameters (a) Chroma, (b) Hue angle, (c) L* = lightness parameter, (d) a* = chromatic redness parameter and (e) b* = yellowness chromatic parameter during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.7b Effect of water stress and soil texture on potato Bp1 skin colour during the 2022 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	34.01 ^{ab}	76.73 ^a	58.19 ^a	7.77 ^a	33.08 ^a
60 (Moderate water stress)	35.44 ^a	76.36 ^a	57.96 ^a	8.34 ^a	34.21 ^a
100 (Well-watered)	31.96 ^b	74.04 ^a	53.65 ^a	8.65 ^a	30.63 ^a
ST					
Clay	34.96 ^a	74.00 ^a	55.59 ^a	9.46 ^a	33.58 ^a
Sandy clay loam	32.04 ^a	78.91 ^a	58.88 ^a	6.05 ^b	31.24 ^a
Sandy loam	32.04 ^a	74.22 ^a	55.33 ^a	9.25 ^a	33.10 ^a
SEM	0.71	1.87	1.63	0.65	0.80
WS	*	ns	ns	ns	ns
ST	ns	ns	ns	*	ns
WS x ST	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness parameter, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.

4.3.5 Potato Bp1 flesh colour

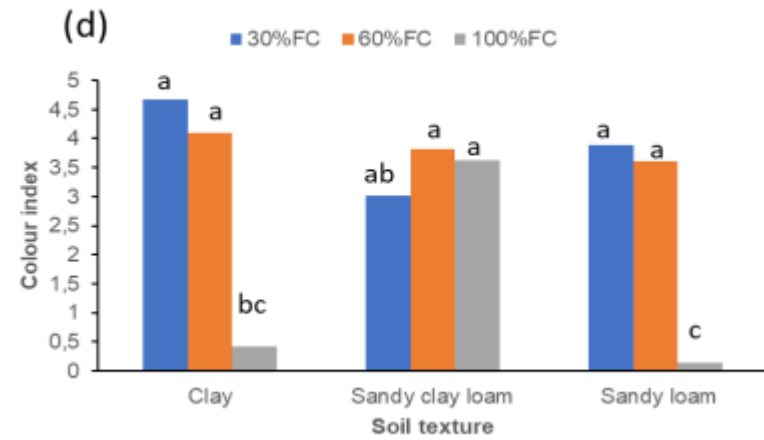
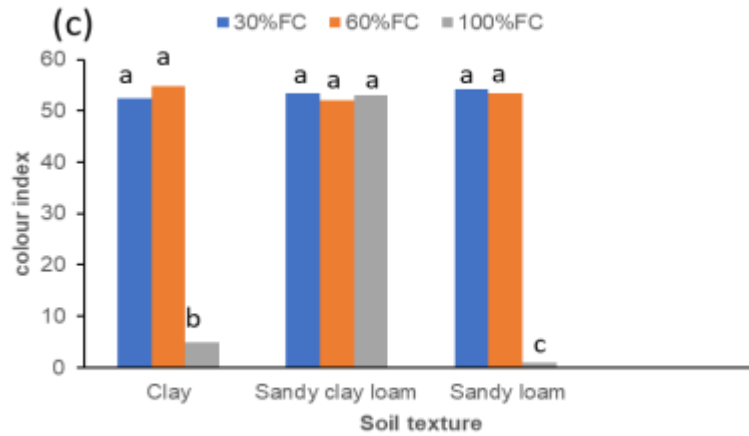
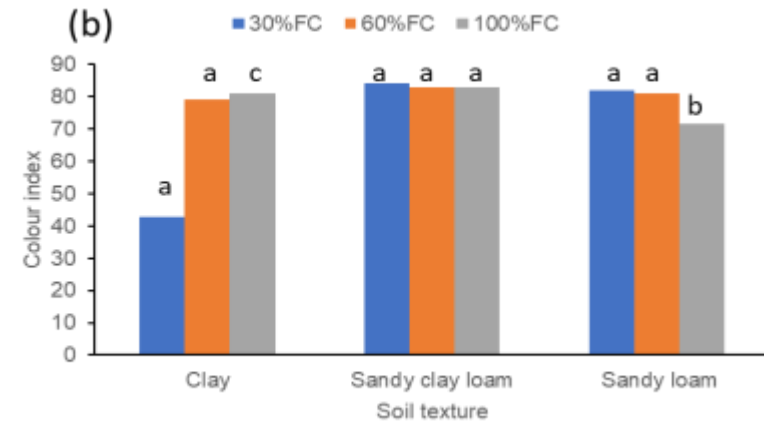
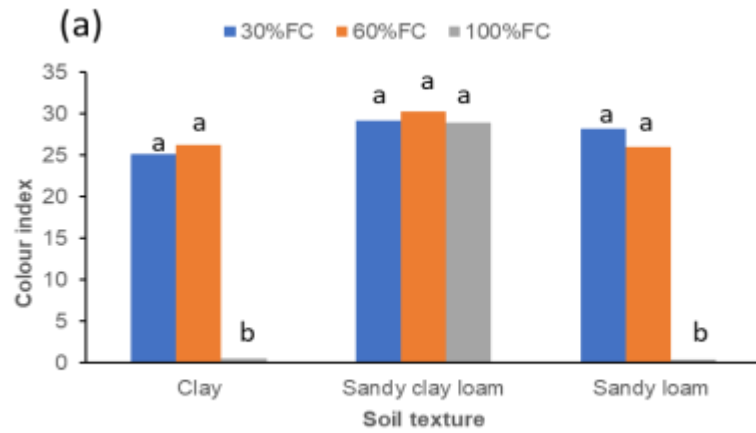
Water stress \times soil texture interaction had a significant ($p < 0.05$) effect on potato Bp1 flesh colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season (Table 4.7c, Figure 4.8). Chroma mean value varied significantly in sandy loam and clay soil compared to sandy clay loam. Chroma average values in sandy loam soil decreased (28.18, 26.06, 0.44) with an increase in irrigation water stress levels (30%FC, 60%FC and 100%FC) (Figure 4.8). Maximum Chroma average value was observed in sandy clay loam soil \times 60%FC, while the least was recorded at 100%FC \times sandy loam soil, although there was no significant difference. Less intense (Chroma) colour was reported on the Bp1 flesh to be < 30 . Hue angle in clayey soil increased ($42.81^\circ > 79.09^\circ > 81.03^\circ$) as irrigation water stress levels increase (30%FC $<$ 60%FC $<$ 100%FC), while in sandy loam soil the hue angle decreased ($87.07^\circ < 81.03^\circ < 71.55^\circ$) as the irrigation water stress levels increase (30%FC $<$ 60%FC $<$ 100%FC) (Figure 4.8). The potato Bp1 hue angle showed yellowness at clayey \times 60%FC and clayey \times 100%FC (hue angle $> 75^\circ$), while at clayey \times 30%FC showed redness (hue angle $< 75^\circ$). A highly significant difference in clayey \times 100%FC was observed compared to clayey \times 60%FC and clayey \times 30%FC. Similarly, a highly significant difference was observed in sandy loam \times 100%FC, compared to sandy loam \times 60%FC, and sandy loam \times 30%FC. Lightness (L^*) in sandy loam soil had a decrease as irrigation water stress levels increase. A highly significant difference was observed on L^* at sandy loam \times 100%FC, and in clayey soil \times 100%FC. In clayey (4.67, 4.1 and 0.41), and sandy loam (3.89, 3.6 and 0.4) soils a^* decreased with an increase in irrigation water stress levels. A highly significant difference was observed on a^* at clayey \times 100%FC relatively to clayey \times 60%FC and clayey soil \times 30%FC, whilst clayey \times 30%FC and clay \times 100%FC were the same. Similarly, a highly significant difference was observed on a^* in sandy loam soil \times 100%FC compared to sandy \times 60%FC, and sandy \times 30%FC. However, in sandy loam soil b^* decreased (27.91, 25.81 and 0.41) with an increase in irrigation water stress levels. Sandy loam \times 100%FC and clay \times 100%FC had a highly significant difference on b^* .

Water stress \times soil texture interaction had no significant ($p>0.05$) effect on potato Bp1 flesh colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2022 cropping season (Table 4.7d). Both water stress and soil texture treatments were also observed not to be significant ($p>0.05$) on the potato Bp1 flesh colour parameters. Therefore, in general the potato Bp1 flesh colour parameters were the same throughout the cropping season.

Table 4.7c Effect of water stress and soil texture on potato Bp1 flesh colour during the 2021 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	27.50 ^a	81.74 ^a	53.34 ^a	3.86 ^a	27.20 ^a
60 (Moderate water stress)	27.53 ^a	81.96 ^a	53.43 ^a	3.84 ^a	27.26 ^a
100 (Well-watered)	9.98 ^b	65.72 ^b	19.62 ^b	1.39 ^b	9.83 ^b
ST					
Clay	17.31 ^b	67.64 ^c	37.39 ^b	3.06 ^a	16.98 ^b
Sandy clay loam	29.47 ^a	82.22 ^a	52.80 ^a	3.49 ^a	29.26 ^a
Sandy loam	18.23 ^b	78.57 ^b	36.20 ^b	2.54 ^a	18.04 ^b
SEM	0.50	0.58	0.28	0.22	0.51
WS	*	*	*	*	*
ST	*	*	*	ns	*
WS x ST	*	*	*	*	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.



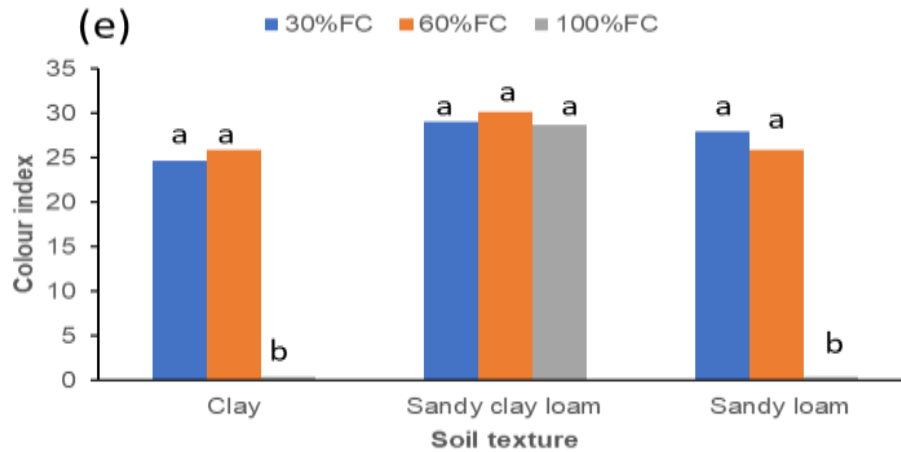


Figure 4.8: The interaction of water stress and soil texture on Potato Bp1 flesh colour parameters (a) Chroma, (b) Hue angle, (c) L* = Lightness (d) a* = Chromatic redness parameter and (e) b* = Yellowness chromatic parameter during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.7d Effect of water stress and soil texture on potato Bp1 flesh colour during the 2022 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	33.76 ^a	87.36 ^a	71.41 ^a	1.57 ^a	33.72 ^a
60 (Mild water stress)	34.68 ^a	87.77 ^a	73.55 ^a	1.38 ^a	34.49 ^a
100 (Well-watered)	33.97 ^a	87.55 ^a	71.85 ^a	1.48 ^a	33.94 ^a
ST					
Clay	34.44 ^a	87.37 ^a	69.90 ^a	1.59 ^a	34.23 ^a
Sandy clay loam	32.08 ^a	87.88 ^a	73.94 ^a	1.21 ^a	32.06 ^a
Sandy loam	35.90 ^a	87.88 ^a	72.97 ^a	1.63 ^a	35.86 ^a
SEM	1.37	0.28	0.89	0.20	1.32
WS	ns	ns	ns	ns	ns
ST	ns	ns	ns	ns	ns
WS x ST	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.

4.3.6 Potato Mondial skin colour

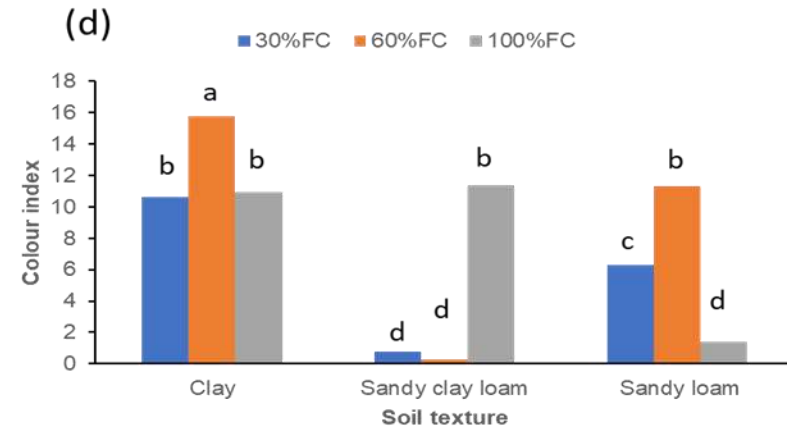
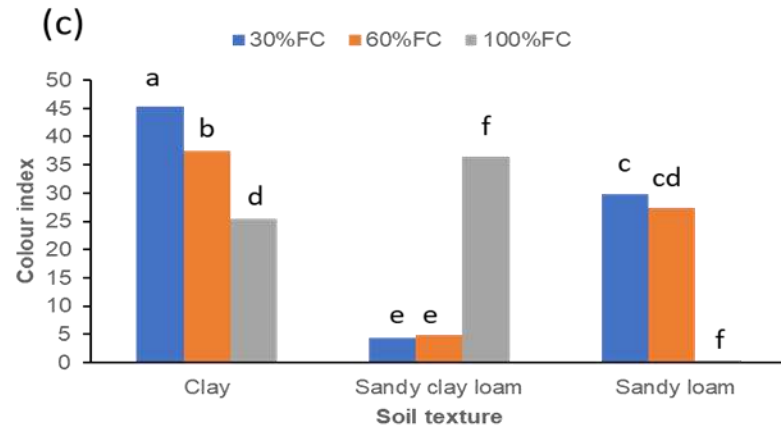
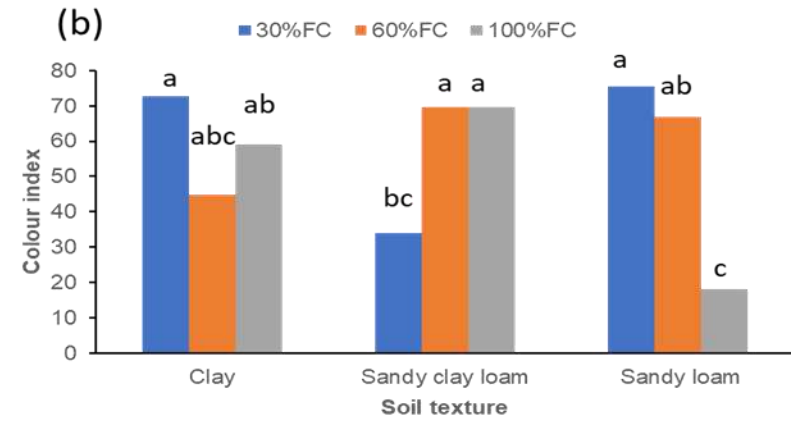
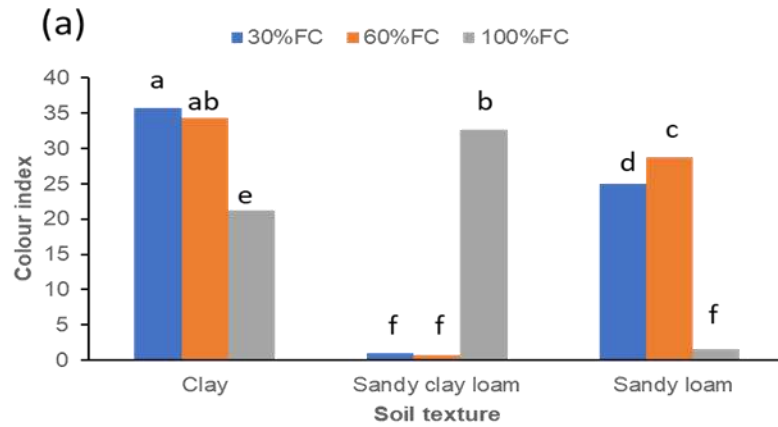
There was a significant ($p < 0.05$) effect on water stress \times soil texture interaction on potato Mondial skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season (Table 4.8a; Figure 4.9). Highly significant differences on Chroma mean values were observed among the soil textures. The mean values for Chroma in clayey soil significantly decreased with an increase in irrigation water stress level (Figure 4.9) Thus, recording the maximum Chroma mean value (35.72) in clayey \times 30%FC, whilst the lowest Chroma value was observed in sandy clay loam \times 60%FC (0.65). Significant variations were observed at 30%FC \times sandy clay loam and at 100%FC \times sandy loam on hue angle (Figure 4.9). Unlike at 60%FC \times soil textures, 30%FC \times clay and 30%FC \times sandy loam had no significant difference. The hue angle in sandy loam soil decreased with an increase in irrigation water stress levels, whilst the opposite was observed for sandy clay loam soil. L^* in clayey soil and sandy loam decreased with an increase on irrigation water stress levels, although there was no significant difference. However, at 100%FC \times sandy loam sharply decreased. The L^* of the potato Mondial skin colour tended towards the whiteness or light due to that it was greater than 50, except at 100%FC \times soil textures it was less than 50. Highly significant variation on a^* at the soil textures, except in clay \times 100%FC and sandy clay loam \times 100%FC which were also similar. Maximum a^* (15.75) was observed in clay \times 60%FC, whereas the least a^* (0.24) was observed in sandy clay loam \times 60%FC. The a^* tended towards the red colour as it was positive (+). Significant variation was observed on mean values of b^* amongst the soil textures There was a significant decrease in b^* mean values (34.1 < 30.51 < 18.21) with an increase on irrigation water stress levels under clayey soil. Unlike in sandy clay loam soil at 30%FC and 60%FC there was no significant difference on b^* , while at 100%FC a significance difference was observed on b^* and there was a sharp increase. In sandy loam soil at 30%FC and 60%FC there was no significant variation on b^* , a significant difference was observed at 100%FC which had a sharp decrease on b^* Maximum b^* (34.10) was recorded at 30%FC \times clay, whereas the lowest (0.47) was recorded at 100%FC \times sandy loam. The potato Mondial b^* was corresponding to yellow colour as it was positive (+) on the interactions of the treatments.

A non-significant ($p>0.05$) effect on water stress \times soil texture interaction was observed on potato Mondial skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2022 cropping season (Table 4.8b). However, the soil texture treatment had a significant ($p<0.05$) effect throughout the potato Mondial skin colour parameters. Chroma mean value in clayey soil recorded the highest value (38.70), whilst the least Chroma mean value (32.46) was recorded in sandy clay loam. Highest hue angle (79.09°) was recorded in sandy clay loam and the lowest was recorded in clay soil (70.83°). The hue angle reported on the soil texture treatments intended towards yellowness. Maximum L^* (60.22) was reported in clay soil, while least (54.24) was reported in sandy loam. Sandy clay loam and sandy loam were significantly different, relatively to clay soil in L^* . The a^* was highly significant between the soil texture treatments. Maximum b^* value (36.50) was recorded in clay soil which was significantly different from sandy clay loam and sandy loam soil. The b^* in sandy clay loam (31.84) and sandy loam (32.39) were similar.

Table 4.8a Effect of water stress and soil texture on potato Mondial skin colour during the 2021 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	20.55 ^a	60.73 ^a	26.49 ^a	5.88 ^c	19.61 ^a
60 (Mild water stress)	21.25 ^a	60.55 ^a	23.31 ^b	9.09 ^a	19.21 ^a
100 (Well-watered)	18.46 ^b	48.96 ^a	20.70 ^c	7.91 ^b	16.43 ^b
ST					
Clay	30.44 ^a	58.91 ^a	36.07 ^a	12.42 ^a	27.61 ^a
Sandy clay loam	11.41 ^c	57.83 ^a	15.26 ^c	4.13 ^c	10.60 ^c
Sandy loam	18.42 ^b	53.50 ^a	19.17 ^b	6.33 ^b	17.04 ^b
SEM	0.20	2.92	0.23	0.20	0.20
WS	*	ns	*	*	*
ST	*	ns	*	*	*
WS x ST	*	*	*	*	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.



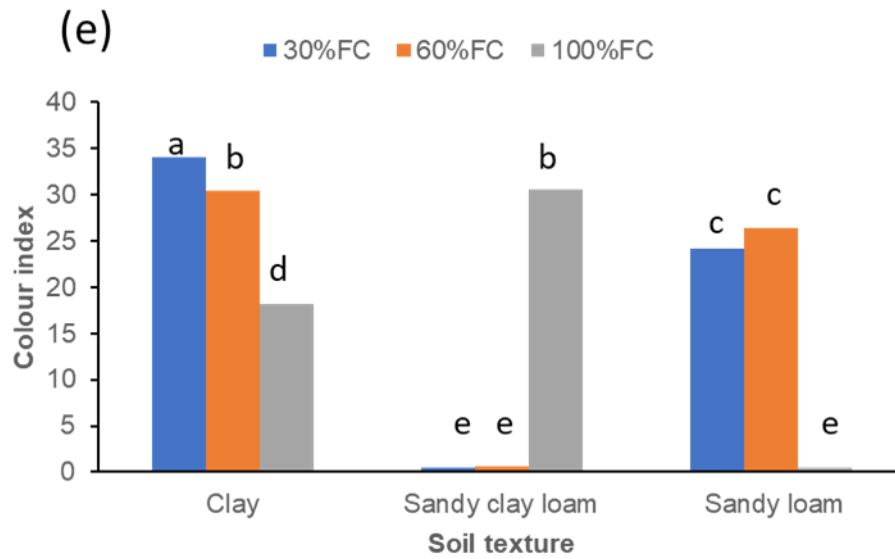


Figure 4.9: The interaction of water stress and soil texture on potato Mondial skin colour parameters (a) Chroma, (b) Hue angle, (c) L* = Lightness (d) a* = Chromatic redness parameter and (e) b* = Yellowness chromatic parameter during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.8b Effect of water stress and soil texture on potato Mondial skin colour during the 2022 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	36.11 ^a	73.45 ^a	56.98 ^a	10.40 ^a	34.48 ^a
60 (Mild water stress)	33.17 ^a	75.20 ^a	57.48 ^a	8.50 ^a	31.97 ^a
100 (well-watered)	36.11 ^a	75.32 ^a	58.68 ^a	9.07 ^a	34.28 ^a
ST					
Clay	38.70 ^a	70.83 ^b	58.68 ^{ab}	12.70 ^a	36.50 ^a
Sandy clay loam	32.46 ^a	79.09 ^a	60.22 ^a	6.06 ^c	31.84 ^b
Sandy loam	33.69 ^b	74.05 ^b	54.24 ^b	9.12 ^b	32.39 ^b
SEM	0.80	0.86	1.05	0.52	0.82
WS	ns	ns	ns	ns	ns
ST	*	*	*	*	*
WS x ST	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means that do not share the same letters in a column are significantly different within the treatment factors.

4.3.7 Potato Mondial flesh colour

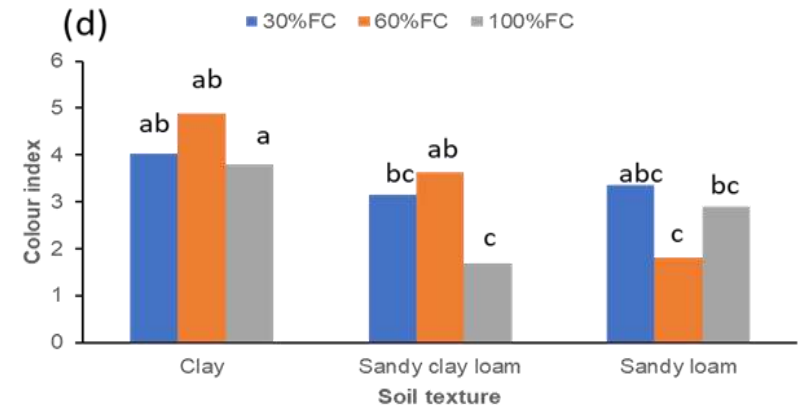
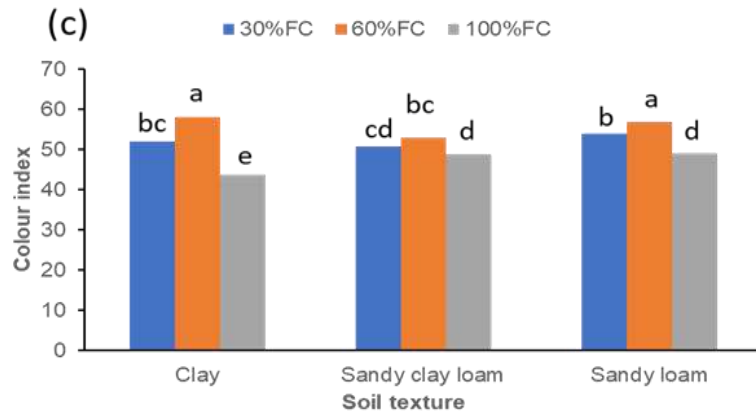
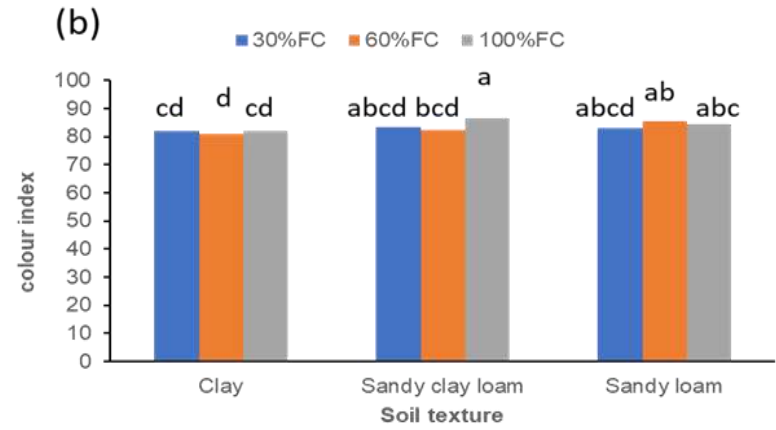
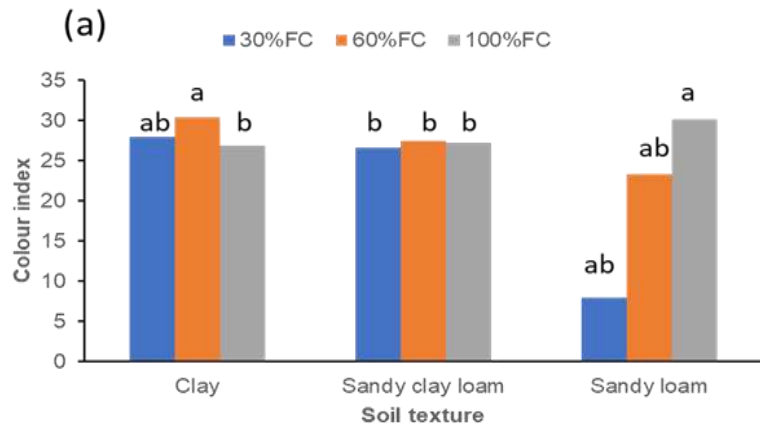
There was a significant ($p < 0.05$) interaction effect between water stress \times soil texture on the potato Mondial flesh colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season (Table 4.8c; Figure 4.10). Chroma in sandy loam \times irrigation water stress increased with an increase on irrigation water stress levels (Figure 4.10). Maximum Chroma mean value (58.13) was observed in clay \times 60%FC, whereas the least (7.92) was observed in sandy loam \times 30%FC. A greater hue angle (86.46°) was recorded in sandy clay loam \times 100%FC, lowest (80.75°) was recorded in clay \times 30%FC. The hue angle was intended for yellowness as it was $>75^\circ$ in all the soil textures. A highly significant difference in L^* was observed in clay soil. Clay \times 60%FC recorded a maximum L^* mean value (58.13), whereas the least L^* (43.73) was observed in clay \times 100%FC. There was no significant difference in clayey soil across the irrigation water stress, and the maximum a^* (4.89) was observed in clay \times 60%FC. The lowest a^* (1.68) was observed in sandy clay loam \times 100%FC. The b^* in sandy loam \times 60%FC was highly significantly different to all the treatments. A higher b^* (30.01) was recorded in sandy loam \times 100%FC, lowest (23.23) was recorded in sandy loam \times 60%FC. The b^* was intended towards yellowness as it was positive (+).

Water stress \times soil texture interaction had a non-significant ($p > 0.05$) effect on potato Mondial flesh colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2022 cropping season. (Table 4.8d). In contrast, both water stress and soil texture treatments were non-significant. Therefore, the potato Mondial flesh colour parameters were observed to be similar throughout the cropping season and were non-responded on the treatments.

Table 4.8c Effect of water stress and soil texture on potato Mondial flesh colour during the 2021 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (severe water stress)	27.84 ^a	82.80 ^b	52.25 ^b	3.50 ^a	27.61 ^{ab}
60 (Moderate water stress)	27.05 ^a	82.91 ^{ab}	55.96 ^a	3.44 ^{ab}	26.82 ^b
100 (well-watered)	28.06 ^a	84.28 ^a	47.11 ^c	2.79 ^b	27.90 ^a
ST					
Clay	28.74 ^a	81.55 ^b	51.30 ^b	4.23 ^a	28.43 ^a
Sandy clay loam	27.08 ^b	84.04 ^a	50.80 ^b	2.82 ^b	26.92 ^b
Sandy loam	27.12 ^b	84.39 ^a	53.23 ^a	2.68 ^b	26.98 ^b
SEM	0.22	0.29	0.23	0.15	0.22
WS	ns	*	*	*	*
ST	*	*	*	*	*
WS x ST	*	*	*	*	*

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means. L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Mean separation that do not share the same letters in a column are significantly different within the treatments.



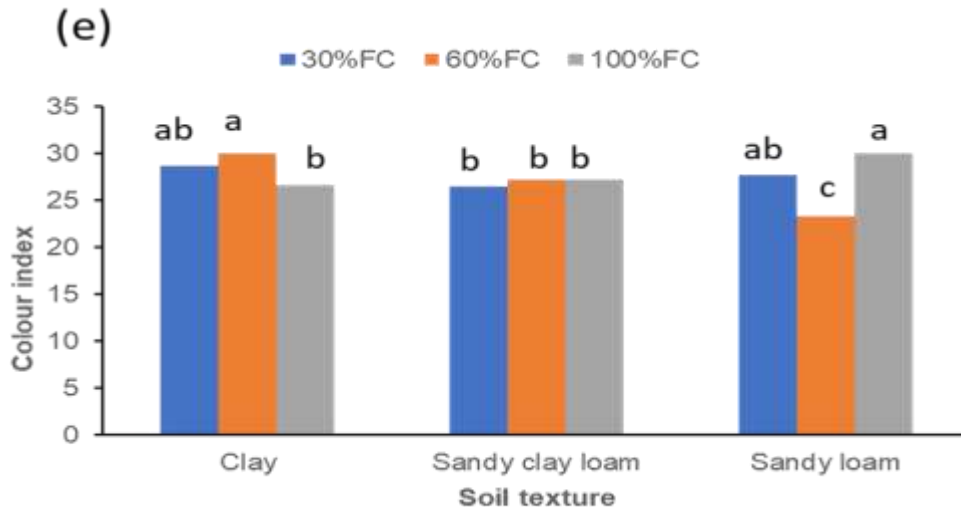


Figure 4.10: The interaction of water stress and soil texture on potato Mondial flesh colour parameters (a) Chroma, (b) hue angle, (c) L* = Lightness, (d) a* = Chromatic redness parameter and (e) b* = Yellowness chromatic parameter during the 2021 cropping season. Means that do not share the same letters in a column are significantly different.

Table 4.8d Effect of water stress and soil texture on potato Mondial flesh colour during the 2022 cropping season

Treatments	Chroma	Hue angle (Degrees)	L*	a*	b*
WS (%FC)					
30 (Severe water stress)	36.23 ^a	87.33 ^a	72.92 ^a	1.73 ^a	36.18 ^a
60 (Moderate water stress)	36.78 ^a	87.74 ^a	73.00 ^a	1.48 ^a	36.75 ^a
100 (Well-watered)	33.39 ^a	87.76 ^a	73.52 ^a	1.24 ^a	33.36 ^a
ST					
Clay	34.44 ^a	87.36 ^a	72.39 ^a	1.59 ^a	34.40 ^a
Sandy clay loam	34.40 ^a	87.82 ^a	74.32 ^a	1.25 ^a	34.37 ^a
Sandy loam	37.57 ^a	87.65 ^a	72.73 ^a	1.62 ^a	37.53 ^a
SEM	1.48	0.31	0.75	0.26	1.47
WS	ns	ns	ns	ns	ns
ST	ns	ns	ns	ns	ns
WS x ST	ns	ns	ns	ns	ns

ns = non-significant, * = Significant at $p < 0.05$, ** = Significant at $p < 0.01$, WS = Water stress, ST = Soil texture, SEM = Standard error means, L* = Lightness, a* = Chromatic redness parameter, b* = Yellowness chromatic parameter. Means separation that do not share the same letters in a column are significantly different within the treatments

Chapter 5

5. Discussion

5.1 Effect of water stress and soil texture on potato growth parameters

5.1.1 Plant height

The potato plant height plays a pivotal role in determining the quality aspects, the yield of potatoes, and economic returns to potato growers, mostly choosing good soil brings an ecological benefit (Pervez et al., 2013; Koco et al., 2020). The significant interaction effect of water stress \times soil texture during the cropping seasons was because of the variation in the temperatures during the cropping seasons (winter and spring). In sandy clay loam soil, there was a significant difference on potato plant height increasing with an increase in irrigation water stress levels at 51 DAP, 65 DAP, and 72 DAP during the 2021 cropping season. This was because of the observation made that on sandy clay loam moderate water drainage, and PAW compared to the other studied soils (clay, and sandy loam). This led to an increase on potato plant height especially at these developmental growth stages (51 DAP, 65 DAP and 72 DAP), soil water must be maintained at above 70%FC. The increase on potato plant height trend with an increase in irrigation water levels is in harmony with a study by Zaki et al., (2022). Nonsignificant variation at 58 DAP in all the soil textures \times water stress, this was because of the observation made that the potato crop adapted to water stress levels, compared to 51 DAP the crop began tuber initiation much variation was observed. However, during the 2022 cropping season (winter) potato plant height had a significant decrease with an increase in irrigation water stress levels from 44 DAP (vegetative) to 58 DAP (tuber initiation) in sandy clay loam soil. This was because the sandy clay loam soil was draining slow, and saturated at 60%FC and 100%FC, thus this leads to loss of nutrients for plant growth. Furthermore, the temperatures were low during the 2022 cropping did not antagonize the soil water, as irrigation frequency was lower compared to the 2021 cropping season. The decreasing potato plant height trend is in harmony with the one reported by Sharma et al.,

(2011) in a field experiment using sandy clay loam. They stated that decrease in potato plant height with water stress is because of decrease in cell enlargements, synthesis (wall and protein), and photosynthesis due to low turgor pressure resulting in smaller potato plant heights (Taize and Zeiger, 2006; Kumar et al., 2007; Sharma et al., 2011). The non-significant variation at 58 DAP (tuber initiation) in all the soil textures \times irrigation water stress levels during the 2021 cropping season was because of the observation that when the potato plant starts another growth developmental stage delays to adapt. At 72 DAP (tuber bulking) and 79 DAP (tuber bulking) in sandy clay loam soil during the 2022 cropping season an increase of 37.74%, 25%, 21.57% and 22.65%, 33.33%, 17.24%, with irrigation water stress levels on potato plant height, respectively. This was because the sandy clay loam soil comprised of moderate PAW, drainage and water holding capacity, this results to available plant water for growth and nutrients as during the tuber bulking phase (72 DAP and 79 DAP) the plant uses more water and nutrients for tuber growth. The non-significant variation in soil textures \times water stress interaction at 86 DAP during the 2022 cropping season, is attributed to the observation that not much irrigation was required during this phase and the soils were mostly wet. Furthermore, as the temperature were low during the winter (2022 cropping season) did not antagonize the irrigation water stress levels in the soil textures. Maximum potato plant heights (89.66 cm and 67.33 cm) were observed at 72 DAP 100%FC \times sandy loam soil, and at 79 DAP 60%FC \times sandy clay loam soil, during the 2021/2022 cropping season, respectively. However, the least potato plant heights of 52.5 cm, and 26.00 cm were reported at 30%FC \times sandy clay loam during 51 DAP, and at 86 DAP under 60%FC \times clay soil, during the 2021/2022, respectively. A possible reason for the maximum potato plant height in sandy clay loam at any water stress levels could be that well-drained, moderately fertile sandy loam to sandy clay soils are preferred for most vegetative growth of various plants (Abdulazeez, 2017). However, a possible reason for the least potato plant heights in clay soils (sandy clay loam and clay) is due to poor aeration, and drainage, also nutrients and water are withheld from plants (Lekgoathi et al., 2022).

5.1.2 Leaf area

The primary causes of yield loss under water stress circumstances are reductions in leaf area (Legay et al., 2011). Leaves are the primary organs that facilitates processes like light radiation, transpiration, and photosynthesis in plants. Consequently, water stress has an impact on photosynthesis by limiting CO₂ transport to chloroplast and metabolic constraints (Pinheiro et al., 2011; Widaryanto et al., 2019). The study investigated the effect of water stress and soil texture on potato leaf area (LA). A significant ($p < 0.05$) effect on LA was reported on soil texture treatment at 44 DAP (vegetative), and 58 DAP (tuber initiation) in the 2021 cropping season, whilst during the 2022 cropping season a significant ($p < 0.05$) effect was at 79 DAP, and 93 DAP. Sandy loam soil had a significant difference, and recording the least LA compared to the other studied soil textures (clay and sandy clay loam) at both cropping seasons. This could be attributed to the low water holding capacity and PAW of sandy loam which forces the potato crop to close its stomata, and suppressed leaf expansion, thus reducing transpiration and photosynthesis resulting in a decrease in LA (de Wit, 2021, Shakeel et al., 2011). Therefore, in 2022 cropping season at 79 DAP and 93 DAP water stress did not have much effect on LA as these stages are not that sensitive to water. Nonetheless, at 44 DAP and 58 DAP at the 2021 cropping season are highly susceptible to water stress which leads to a high yield loss. The maximum LA was reported in clay soil in both cropping seasons 2021/2022. This was expected, as clay soil comprised a high plant available water (PAW) than sandy soils (Reichert et al., 2016). Thus, a high plant available water increases the uptake of nutrients (nitrogen (N), phosphorus (P), potassium (K)) from the soil, translocate photosynthesis assimilates, and starts showing on a high and increasing LA (Leilah, 2009). The lack of significant difference on the sampling days is attributed to the variation of

5.1.3 Stem diameter

Stem diameter had significant ($p < 0.05$) at 60%FC × soil textures, and 30%FC soil textures at 93 DAP, and 65 DAP during the 2021/2022 cropping seasons, respectively. The significant ($p < 0.05$) effect of water stress and soil texture interaction on stem diameter at 93 DAP and 65

DAP is attributed to the variation of the cropping seasons (spring/winter). Increase in stem diameter with an increase in irrigation water stress levels in clayey soils at 93 DAP and 65 DAP, during the 2021/2022 cropping seasons. This is because of the observation that clayey soil comprised of smaller pore size, high water holding capacity and PAW. Comparatively to sandy clay loam soil the stem diameter increased with an increase in irrigation water stress at 65 DAP during the 2021 cropping season. A possible reason is that during the 65 DAP the potato plant requires more water for tuber growth, and stem growth unlike at 93 DAP (maturation stage) the potato crop does not require much water for tuber and stem growth. The results obtained in this study are in line with the study of Zheng et al., (2016), who reported that stem diameter is directly proportionally to water stress levels using rice as test crop. Din et al., (2011) reported that water plays a significant role in which small decrease in water availability affects the stem diameter growth. Aliche et al., (2018) reported that stem growth reduction during water stress may serve as an advantageous purpose for the plants in order to reduce transportation distance to facilitate efficient water, nutrients, and assimilate transports in plants. Therefore, this suggests that stem growth reduction under severe water availability can facilitated efficient water, nutrients and assimilate transports in plants. On the other hand, in this study stem diameter was the highest (0.77 cm, and 1.10 cm) at sandy loam \times 60%FC, and sandy clay loam \times 30%FC, respectively during the 2021/2022 cropping season. Therefore, this is in line that stem diameter during water stress level (30%FC and 60%FC) serves as an advantageous purpose for the plants in order to reduce transportation distance to facilitate efficient water, nutrients, assimilate transports in plants, and increasing the yield (Aliche et al., 2018).

5.2 Effect of water stress and soil texture on yield

5.2.1 Marketable yield

The potato marketable tuber yield is the most pivotal aspect for most farmers (Nouri et al., 2016). Interaction of water stress and soil texture had no significant ($p>0.05$) effect on marketable potato yield during the 2021 cropping season. However, soil texture treatment had

a significant ($p < 0.05$) effect on potato marketable yield. This was because the soil textures used had different field capacities, plant available water, drainage, aeration and pore size distribution. Clayey soil comprised of a higher water holding capacity, PAW, smaller pore size distribution, comparatively to sandy clay loam and sandy loam soils. The adverse effect of water stress is stronger on sandy loam and sandy clay loam soils than in clay soil (Sharafzadeh et al., 2011). Similar observation to our study was observed as clayey soil recorded the maximum (30.92 g/pot) potato marketable yield, and least recorded in sandy loam (18.72 g/plant), although the yield was very low (18.72 g/plant to 30.92 g/plant) during the 2021 cropping season. Therefore, this supports that clayey soils have less effect on water stress and can produce a higher yield. Similarly, Martins et al., (2018) reported a maximum potato yield in clayey soil and the least in sandy soil. Furthermore, in this study during 2021 cropping season (spring) the marketable potato yield was very low, compared to the 2022 cropping season (winter) in clay, sandy clay loam, and sandy loam at 30.92 g/plant, 25.43 g/plant, and 18.72 g/plant, respectively. The low marketable potato yield could be ascribed to various aspects. Firstly, it could be due to the observation of higher potato plant height and thinness. Similarly, Li et al., 2020 stated that the quantity of tubers per plant is not favoured when the plant height is too high and thin. Secondly, the spring cropping season accompanied by high temperature and heat could be attributed to the low marketable yield. This was supported by Steyn et al., (1998) in a rain shelter experiment in both spring and autumn under water stress. Their results postulated that the effect of water stress on yield was lower in spring cropping season than in autumn. However, water stress had no significant effect on marketable potato yield, this was attributed to the observation that during the 2021 cropping more irrigation was required, high temperatures were experienced for which antagonized water stress treatment compared to the 2022 cropping season. This was supported by Steyn et al., (1998) who reported that higher temperatures during the spring experiment antagonized the effect of water stress. Therefore, the climatic conditions experienced during the spring cropping season could have attributed to the lower yield.

Water stress \times soil texture interaction had a significant effect on potato marketable yield during the 2022 cropping season. The marketable potato yield significantly showed the highest marketable yield at 30%FC \times sandy clay loam, and the least at 100%FC \times sandy clay loam, compared to the studied water stress levels and soil textures during the 2022 cropping season. This was in-contrast with the results reported by Mahmud et al., (2015) who reported that potato yield significantly increases in well-watered ranging from 385 g/pot to 488.60 g/pot than in severe water stress in sandy soils. Conversely, the results of the study are different from those reported by Mahmud et al., (2014), who observed that potato yield was significantly increased from 386.90 g/plant to 488.60 g/plant in 2010/2011 and 327.38 g/plant to 357.88 g/plant in 2011/2012 in well-watered conditions even using various varieties. The high marketable potato yield could be attributed due to the large ≥ 75 mm tuber sizes and long oval (1.50-1.69), or long (1.70) tuber shapes. Moreover, it could be attributed to the higher increase of potato plant height at tuber bulking phase (72 DAP and 79 DAP) and the highest stem diameter (1.10 cm) at 65 DAP might increase the total amount of assimilates to be synthesized in the leaves, stem diameter and transported to the tubers for a greater yield. Mihovilovich et al., (2014) stated that a greater increase on potato growth traits (plant height, stem diameter, leaf area) duration determines the final yield. Thirdly, the high marketable potato yield is due to that during the 2022 cropping season (winter) severe water stress treatment (30%FC) could be the appropriate water level required to maintained in other to achieve a higher yield in this study. However, this contrasted to the studies reported by several researchers (Reddy et al., 2016; Gultekin et al., 2018; Aldulaimy et al., 2019). They stated that in-order to enhance the potato yield the total soil water must not drop to less than 30-50% depletion of soil water content regardless of the soil texture. We observed that during the 2022 cropping season temperatures were lower compared to the 2021 cropping season. This further postulated that during the 2022 cropping season we were not irrigating much, soil was not drying rapidly, and desiccating like 2021 cropping season. This further shows that water stress was not antagonized by temperature in the soil textures on the marketable potato yield as it was reported on a study conducted by Steyn et al., (1998) that high temperatures aggravate water

stress, as winter cropping seasons are not accompanied by high temperatures in the study area. Nonetheless, the interaction effect is clear that sandy clay loam \times water stress had a decrease in marketable potato yield as irrigation water stress levels increased and recorded the highest marketable potato yield. This clearly implies a huge prospective of managing soil texture, and irrigation in order to utilise the little water resources, especially in semi-arid region. For instances, when there's deficit water (30%FC) under sandy clay loam soil texture, potatoes can be produced with the deficit water and produce a greater potato marketable yield.

5.3 Effect of water stress and soil texture on potato quality attributes

5.3.1 Sizes

There was a significant ($p < 0.05$) effect on water stress \times soil texture interaction on potato tuber sizes during the 2021 cropping season. However, a significant difference on potato tuber sizes was observed at 100%FC \times soil textures. Similar results were reported by Shiri-e-Janagard et al., (2009), who reported a significant difference on potato tuber sizes and grades at well-watered irrigation level (80%) in a field experiment using a medium textured soil. This was because well-watered irrigation provided sufficient water in all the soil textures studied to the potato crop and this leads to enough turgor pressure to full development of potato tuber sizes. Surprisingly, sandy clay loam \times 100%FC recorded the highest potato tuber sizes, while the sandy clay loam \times 60%FC recorded the least potato tuber sizes, and there was a significant difference. This was surprising, because literature states that sandy clay loam soils at 100%FC are poorly drained, and nutrients are often held from the plants and the least potato tuber size was expected. To support that Lekgoathi et al., (2022) stated that sandy clay loam and clayey soils are poorly drained, nutrients, and water often withheld from plants sown in sandy clay loam soil. A significant increasing trend in potato tuber sizes with an increase in irrigation water stress levels in sandy loam soil was observed. An analogous increasing trend on potato tuber sizes was reported in literature by several researchers (Fabeiro et al., 2001; Karim et al., 2014; Gultekin and Erket, 2018). The researchers stated that potato tuber sizes increased with irrigation water levels in sandy soils. However, in this study the potato tuber sizes obtain during

2021 planting seasons were small or baby potatoes ranging below 55 mm, according to the potato size grading reported by Ekin (2013), which cannot be used by the processing (chips, French fries and scrips). We observed that the higher potato plant height (89.66 cm) and thin stem diameter during the cropping season, compared to the 2022 cropping season. Therefore, the higher plant height and thin stem diameter results to low photosynthesis by products (glucose, and energy), and other nutrients (K, P, and iron) might not had been assimilated and transported to the tuber and expand the tuber sizes. In 2022 cropping season, there was no significant ($p>0.05$) effect between the interaction of water stress and soil texture. This is attributed to the low temperatures experienced at the study area during the winter cropping season, there was less soil water exacerbated by evaporation and what we have noticed is that we irrigated lesser compared to the 2021 cropping season. Furthermore, we observed that the soil textures (sandy loam, sandy clay loam and clay) used retained more moisture for an extended period even at 30%FC and this reduced the accuracy of some irrigation water stress levels 60%FC and 100%FC, for which were observed not to have a significant effect on potato tuber sizes.

5.3.2 Shapes

The results of the current study had a non-significant ($p>0.05$) effect on the interaction of water stress levels \times soil textures on potato tuber shapes during both 2021/2022 cropping seasons. However, during both cropping seasons severe water stress had a lower tuber shape (L/W) index of 1.24, and 1.69 while in moderate water stress (1.39) and well-watered (1.80) were higher, although there was no significant ($p>0.05$). Similar results were reported by Chang et al., (2018), who reported longer tuber shape (i.e. higher L/W ratio) in well-watered treatment than those in drought treatment. A possible reason could be the decrease on tuber growth traits (plant height, leaf area and stem growth) (Chang et al., 2018). Comparatively, to the results of the present study longer tuber shapes (high L/W ratio) in well-watered and moderate, than in severe water stress were observed. Nonetheless, the water stress and soil texture interaction had no significant ($p>0.05$) effect on shapes during both cropping seasons. This

was due to the observation made that maintaining soil water at the irrigation water stress levels interacted with the soil textures studied had no significant effect on potato leaf area and stem diameter especially at the vegetative and tuber initiation phases. These further states that assimilates (water, N, K, and P) that are transported to the tubers might not have been fully stored at the tubers and expanded the tuber shape.

5.3.3 Specific gravity

Interaction effect of water stress and soil texture had no significant ($p>0.05$) effect on potato specific gravity (SG) during the 2021/2022 cropping season (Table 4.6). Furthermore, water stress and soil texture had no-significant variation during both cropping seasons. Thus, our findings are like those documented by Abbas et al., (2015), who reported a non-significant difference on potato SG under water stress (overhead irrigation system and no supplemental irrigation) using coarse-textured loamy sand soil. The non-response of the potato specific gravity to water stress, soil texture and their interaction in the current study was mainly due to the variation in climatic conditions (winter and spring), soil texture, and in water stress intensity as reported by several researchers (Bowen, 2003; Akkamis et al., 2021). Potato SG during the 2021 cropping season had a decrease with an increase in water stress levels, whereas during the 2022 cropping season showed an increase with water stress, although all the treatments had no significant effect. This is in line to the results documented by Abdelreheem et al., (2018) who conducted a field experiment in Egypt using clayey soil reported that SG decreases as water irrigation levels increase from 70%FC, 90%FC, and 100%FC, and the means of SG varied between 1.105 and 1.440. Moreover, their results were different from those documented by Eiasu et al., (2007), who reported that both high and low soil moisture levels (25%, 40%, 55%, and 70% maximum allowable depletion (MAD)) decreased specific gravity in an experiment conducted in a sandy clay loam textured soil in a pot experiment. Nonetheless, as observed in this study that the interaction of water stress and soil texture on potato SG had no-significant ($p>0.05$) effect during both 2021/2022 cropping seasons. This was attributed to that both cultivars used in this study had no significant effect on the

treatments and the interactions of the treatments. This might have led to the SG not to have a significant effect on SG, as the potato SG is strongly influenced potato varieties.

5.3.4 Potato Bp1 skin colour

The statistical analysis showed that there was a significant ($p < 0.05$) effect on water stress \times soil texture interaction on potato Bp1 skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season, however there was no significant ($p > 0.05$) effect during the 2022 cropping season. The significant increase on Chroma parameter and hue angle with water stress level on sandy loam soil could be attributed to the water stress effect at tuber bulking phase (72 DAP) on potato plant height which increases the concentration of sugar (glucose and sucrose) in the tubers as reported by Mengistu and Grout, (2017). Surprisingly, the highest lightness (L^*) of potato Bp1 was produced at 60%FC \times clay. This was surprising because clayey textured soils are reported to produce dark potato tuber skins making tubers difficult to wash (Leap et al., 2017). Thus, clayey soil showed that there was no excessive darkness regardless irrigated at 60%FC. Surprisingly, the chromatic redness parameter (a^*) of potato Bp1 skin colour recorded a high mean value (12.47) in sandy loam \times 60%FC, whereas the least a^* (0.015) was recorded in sandy clay loam \times 60%FC. Therefore, this was because of the observation that the sandy loam soil was lighter in colour, having a higher sand percentage (79%), and low clay percentage (9%), compared to the sandy clay loam soils which was darker in colour, high in clay percentage (25%), low sand percentage (51%). During the 2021 spring cropping season (spring), we observed that it was extremely hot in the study area and the sandy loam textured soil was having a high soil temperature, drying very quickly, and experiencing soil desiccation, therefore this might have attributed that this attributed to that sandy loam textured soil has a high soil temperature as it warms up rapidly, compared to soils with a high clay content (Aketer et al., 2015). Hence, at 60%FC \times sandy loam resulted to a high anthocyanin, carotenoid pathways and anthocyanins accumulate as water-soluble vacuolar flavonoids which influences the redness in potato tissue colour (Dhar et al., 2015). Yellowness chromatic parameter (b^*) of potato Bp1 skin colour showed an increase (0.16,

20.48, and 32.97) with irrigation water stress levels in sandy loam soil and recorded the maximum b^* value (32.97) in sandy loam \times 100%FC, however the least b^* (0.05) was recorded in sandy clay loam \times 60%FC. This was attributed to the observation that sandy loam textured soil has a high soil temperature, and absorb sunlight rapidly, hence sandy loam \times 100%FC might have a low temperature than the other treatments (sandy loam \times 30FC and sandy loam \times 60%FC) and the studied soil textures. Consequently, the low temperature in sandy loam \times 100%FC resulted to a low soil temperature and enhance the anthocyanin, glucose concentration in the tuber skin. According to Lewis et al (1999) anthocyanin is high when the soil temperature is low less than 10. Therefore, yellowness is affected by the concentration of anthocyanin. The potato Bp1 skin corresponded to yellow colour due to the positive (+) mean values of yellowness (b^*) parameter during the 2021 cropping season. In 2022 cropping season, the interactions of water stress and soil texture had no significant ($p>0.05$) effect on potato Bp1 skin colour. This attributed to the cropping season as irrigation was not required that much compared during the 2021 cropping season, and soil textures had moisture. The significant difference in Chroma mean values by water stress treatment is attributed to the amount of irrigation water stress levels (30%FC, 60%FC and 100%FC) transporting nutrients concentration (glucose, sucrose, N, P, K) differently to the potato Bp1 skin colour and tuber and the highest Chroma mean value (35.44) at 60%FC. The significant variation by soil texture treatment in potato Bp1 a^* skin colour parameter is attributed to the nutrient, water holding capacity of the soil textures, as the highest a^* was observed in clayey soil which had the maximum plant available water content (0.24 cm^3) and field capacity (0.45 cm^3) amongst the other studied soil textures. Furthermore, the highest a^* mean value by soil texture treatment in clayey soil could be attributed to that the University of Venda (UNIVEN) clayey soil was highly red in colour and stick when wet attached to the tubers and making it hard to wash. Thus, resulting to the a^* to tend towards red colour as it was positive (+). The results of this study corroborate with the ones reported by Mengistu and Grout (2017), who reported a non-significant difference on colour measurements L^* , a^* and b^* on water stress treatments. Furthermore, Mengistu and Grout (2017) reported that the non-significant response on waters

stress treatment potato colour measurements L^* , a^* and b^* might be due to the low concentration of glucose in the tubers resulting from water stress. The potato Bp1 skin colour produced at this study during both cropping seasons was more appealing to be accepted at the market and by consumers.

5.3.5 Potato Bp1 flesh colour

In 2021 cropping season, a non-significant ($p>0.05$) effect on water stress \times soil texture interaction was observed on potato Bp1 flesh colour parameters (Chroma, hue angle, L^* , a^* and b^*). This was expected as potato Bp1 skin colour had a non-significant ($p>0.05$) effect on interaction of water stress \times soil texture. However, during the 2022 cropping season, maximum Chroma mean value was reported in sandy clay loam \times 60%FC, while the least was recorded at 100%FC \times sandy loam although there was a non-significant variation. This could be attributed to the potato flesh colour not protected by the skin, resulting to the lesser dense Chroma. Hue angle in clayey soil increased ($42.81^\circ > 79.09^\circ > 81.03^\circ$) with irrigation water stress level (30%FC > 60%FC > 100%FC), while in sandy loam soil the hue angle decreased ($87.07^\circ < 81.03^\circ < 71.55^\circ$) with an increase in irrigation water stress levels (30%FC < 60%FC < 100%FC). This might be due to observation that sandy loam textures soils irrigated at 100%FC drains water rapidly, this might have drained the nutrients and less water stored into the tuber flesh at 100%FC resulting to the potato Bp1 flesh colour intended from yellowness towards redness. Nevertheless, in clayey soil high nutrients and water could be absorbed at 100%FC and leading the potato Bp1 flesh colour to intend from redness to yellowness. Lightness (L^*) in sandy loam soil decreased with an increase in irrigation water stress levels and at 100%FC there was a sharp decrease observed. This was expected, as the sandy loam textured soil at 100%FC, it was observed that water was draining rapidly, unlike at 30%FC and 60%FC. Therefore, this could have been attributed to less water and nutrients absorbed through the soil at 100%FC. Comparatively to clayey soil a significant variation was observed at 100%FC. This was due to that in clayey soil \times 100%FC it was observed that the was always available soil water this resulted to less L^* mean value and to

be different relatively to the other studied water levels which had no significant variation. In clay (4.67, 4.1 and 0.41), and sandy loam (3.89, 3.6 and 0.4) soils there was decrease on a^* with an increase in irrigation water stress levels, this was not expected as irrigation water stress levels increases the lesser nutrients and water are accumulated on the potato tuber flesh. The more a^* intensity on the potato flesh colour the high Chroma. Similarly, Luis and Ronald, 1997 observed that less a^* intensity, less Chroma. There was decrease in b^* mean values in sandy loam soil with an increase in irrigation water stress levels. This was attributed to that sandy loam soil retains lesser water as irrigation water increases and subsequently nutrients are more likely to be less absorbed in the tubers. Sandy loam \times 100%FC and clay \times 100%FC responded the same to the interaction of water stress and soil texture, unlike the other treatments. In the present study, this was not expected as sandy loam soil was much more lighter compared to the clayey soil which was red darker in colour as this two soils were different.

5.3.6 Potato Mondial skin colour

There was a significant ($p < 0.05$) effect of water stress \times soil texture interaction on potato Mondial skin colour parameters (Chroma, hue angle, L^* , a^* and b^*) during the 2021 cropping season. A possible reason could be the effect of environmental conditions, planting season, and cultivar as during the 2021 cropping season (spring) potato Bp1 skin colour had a significant ($p < 0.05$) effect on water stress \times soil texture interaction. Chroma mean values in clayey soil decreased (less colour intensity) with an increase in irrigation water stress level and the was less colour intensity. Clayey soil was dark red in colour, and attached to the tubers making it difficult to wash this could have been the decrease in the intensity of the Chroma averages intending towards redness when water levels increase and darkens the Chroma. The significantly difference on hue angle in sandy loam soil decreased with an increase on irrigation water stress level and resulted to intending towards redness, this might be due to that water was draining rapidly in sandy loam textured soil, unlike at 30%FC and 60%FC. Therefore, this could have been attributed to less water and nutrients absorbed for the building

up of the potato skin through the soil at 100%FC. The intending of hue angle towards redness, might be due to the presence of antioxidants. According to Witbooi et al., (2020), the presence of antioxidants increases redness in potato skin colour. The significant difference on L* in clayey and sandy loam soils decreased with an increase in irrigation water stress levels. This was due to that as irrigation water stress increases in the soils. Maximum a* (15.75) was observed in clay × 60%FC, whereas the least a* (0.24) was observed in sandy clay loam × 60%FC. In the present study, we observed that b* mean values were corresponding to yellow colour as it was positive (+) on the interactions of the treatments.

In the 2022 cropping season, water stress and soil texture interaction had no significant ($p>0.05$) effect on potato Mondial skin colour parameters. The non-response of the skin colour parameter could be attributed to the environmental conditions, planting season (winter) and cultivar. Similarly, the potato Bp1 skin colour in the same season had a non-significant ($p>0.05$) effect. However, the significant effect of the soil texture treatment on potato Mondial skin colour might be due to the observation that the soil textures studied have varies water holding capacity, and nutrients accumulation, this could have resulted in have a significant effect. Nevertheless, the potato Mondial skin colour was the same throughout the treatment's combination. Hue angle on the soil texture treatments intended towards yellowness. The lightness (>50) of the cultivar could attribute to the yellowness of the skin. Maximum L* (60.22) was observed in clay soil, while the least (54.24) was observed in sandy loam soil. This could be attributed to that clayey soil has ability to absorb water and nutrient resulting in the least quantity of reduced sugar displayed (Rahman et al., 2016). Moreover, the significant difference in sandy clay loam and sandy loam in L* might be due to the high soil temperature of the soils as they warm up rapidly, compared to soils with clay content affecting L* (Aketer et al., 2015). The soil textures showed a highly significant difference on a*. This was expected as the soil colours of the textures were different, showing more redness intensity on clay soil as it was dark red. The b* intended towards yellowness of the potato skin colour as it was positive (+).

5.3.7 Potato Mondial flesh colour

The potato Mondial flesh Chroma mean values in sandy loam soil increased with water stress levels. A possible reason could be to that sandy loam soil is light-medium textured, as water increases more nutrients are stored in the tuber flesh, thus increasing Chroma (colour intensity). Potato flesh colour was less intense in colour (Chroma), this was expected as the lightness and hue angle were higher ($>40^\circ$ and $>80^\circ$), respectively. The hue angle was intended for yellowness as the mean values were $>75^\circ$ in all the soil textures. Clay \times 60%FC recorded a maximum L^* mean value (58.13), whereas a least L^* value (43.73) was observed in clay \times 100%FC. This was not expected as the clayey soil was dark red in colour, the tubers were attached to the soil and hard to wash. The L^* in sandy loam soil decreased with an increase in irrigation water stress levels, although at 30%FC and 60%FC there was no significant variation. This was because, in sandy loam at 100%FC it was observed that more water was drained, low water holding capacity and low pore sizes. Maximum a^* (4.89) was observed in clay \times 60%FC whilst the least a^* value (1.68) observed in sandy clay loam \times 60%FC. A possible reason could be the colour of the soil, as clayey soil was dark red which could have increased the a^* , while sandy clay loam soil was darker in colour which could have attributed to the low a^* . It was observed that the soil was attached to the tuber skin, and it required thoroughly wash. The highest b^* (30.01) was recorded in sandy loam \times 100%FC, least (23.23) was recorded in sandy loam \times 60%FC. As expected, the sandy loam soil was very light-textured soil, thus it is believed that 100%FC leaches the nutrients and water in the sandy loam intending the maximum b^* mean value towards yellowness. In the 2022 cropping season, a non-significant ($p>0.05$) effect between water stress and soil texture interaction on Mondial potato flesh colour parameters could be attributed to the environmental conditions, cultivar and planting season. Other possible reason is that all the skin and flesh colour parameters during the 2022 cropping seasons had no significant ($p>0.05$) effect on water stress and soil texture interaction. The potato Mondial flesh colour was intense in colour (Chroma). Hue angle increased with water stress levels, thus the flesh colour tended towards yellowness. Witbooi et al., (2020) reported that the presence of antioxidant increases redness in skin colour, thus

we can state that the Mondial flesh was less in antioxidants as water stress levels increased. The flesh colour produced in this study would be accepted in the market and by consumers. However, in this study the potato Mondial flesh parameters were not significant ($p>0.05$) even on the treatments.

Chapter 6

6. Conclusion and Recommendation

6.1 Conclusion

The present study investigated the effect of water stress and soil texture on potato growth, yield and quality attributes of potatoes (*Solanum tuberosum* L) in two consecutive cropping seasons of 2021/2022. Results showed that water stress and soil texture significantly affect growth traits (plant height, and stem diameter), quality attribute (sizes) which affects marketable potato yield, especially shape and sizes. However, the responses depended on water stress levels and soil textures. The findings of the present study reports that the tall and thinner the potato growth traits (plant height and stem diameter) results to smaller potato tuber sizes, and lower yield. Comparatively, when short plant height and thicker stem diameter medium to larger tuber sizes are expected and a greater yield. Low marketable potato yield (18.72 g/pot to 30.82 g/pot) obtained during the 2021 cropping season clearly indicated that it was attributed to the tall plant height and thin stem diameter. Moreover, the low yield was due to the smaller potato tuber sizes and round shape obtained. Thus, making it difficult to decide which soil texture and irrigation water stress level is suitable for marketable potato yield. Comparatively, during the 2022 cropping season potato plant height was short, with thick stem diameter, and the medium to larger potato tuber sizes and long-oval shapes. In conclusion, based on the marketable potato yield obtained during the 2022 cropping season, it is evident that irrigating at 30%FC water stress level can be adopted for potato cultivation. Although, planting season or time must be highly considered as in this study the greater yield (350-430 g/pot) was obtained during the (winter) 2022 cropping season. Sandy clay loam soil subjected to 30%FC water stress levels produced the highest marketable potato yield (430 g/pot), followed by clayey soil (350 g/pot) and sandy loam soil (330 g/pot). This further explains that watering at 30%FC irrigation water stress level in the other studied soil textures (sandy clay loam and clayey soils) greater marketable potato yield can still be achieved and save the little water resources in semi-arid regions as the regions are associated with unreliable rainfall,

heat and water stress. Therefore, sandy loam soil at 30%FC was the suitable treatment for potato cultivation in this study. The potato tuber sizes obtained during the 2021 planting season were categorised as small/ baby potatoes (<55 mm), unlike the potato tuber sizes obtained on the 2022 cropping season were categorized as oval to long-oval sizes. Tuber form index (TFI) of the potato shapes obtained on the 2021 cropping season were ranging on short-oval (1.10 to 1.29) and oval (between 1.30 and 1.49), whilst the potato tuber shapes during the 2022 cropping season were ranging on long oval (between 1.50 and 1.69) to long (≥ 1.70). Potato specific gravity results show that the tubers can be used for processing. In this study the Bp1 and Mondial skin and flesh colour parameters were significantly affected by water stress \times soil texture interaction during the 2021 cropping season only. However, during the 2022 cropping season had no significant effect on the treatment's interaction. This could state that the skin colour influences the potato flesh colour, when there's no effect on skin colour there's no effect on flesh colour, as skin acts a barrier to permits the nutrients and compositions which affects the potato skin colour and flesh.

6.2 Recommendation

A limitation to this recent study was using less cultivars (two cultivars), for which the cultivars response to water stress and soil texture interaction had no significant ($p > 0.05$) effect and the cultivar factor was pooled and reanalysed. It is recommended that plethora studies be conducted under field conditions to validate the findings from this study. Furthermore, investigations on potato chemical composition traits (starch content, antioxidant, ascorbic acid, phenolic acid, sugar content, anthocyanin and carotenoid) studies are needed to be conducted, as it is known that the potato chemical composition aspects affect potato skin colour and flesh. Further research is required to be done especially on the new cultivars (Innovators, Larnoma, Mnandi, Savanna, Sifra, and Panamera). There is little literature on the effect of water stress on stem diameter, leaf area, tuber sizes, shapes and tuber skin and flesh. Therefore, further research is needed more on the traits (stem diameter, leaf area, tuber sizes, shapes, tuber skin and flesh) to be studied on the effect of water stress and soil texture.

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