POSTHARVEST QUALITY CHARACTERISTICS AND SENSORY EVALUATION OF INTRA AND INTERSPECIFIC GRAFTED TOMATO (*SOLANUM LYCOPERSICUM*) FRUITS

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Postharvest Quality Characteristics and Sensory Evaluation of Intra and Interspecific Grafted Tomato (*Solanum lycopersicum*) Fruits

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DECLARATION

This thesis my original work and has not been presented for a degree in any other university

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This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

This thesis is dedicated to my parents, Julius Walubengo Silisisi and Jescah Mutenyo King'or,o and my twin sister Damaris Mulongo Walubengo. Your unwavering emotional and financial support has propelled me to this higher education level. I also dedicate it in a special way to my late uncle Erastus Kingóro.

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ABBREVIATIONS AND ACRONYMS

AFA Agriculture and Food Authority

CO_2 Carbon dioxide

FAO Food and Agricultural Organization of the United Nations

FAOSTAT Food and Agriculture Organization Corporate Statistical Database

GC Gas chromatography

HCD Horticultural Crops Development

HCDA Horticultural Crops Development Authority

HPLC Higher Performance Liquid Chromatography

JKUAT Jomo Kenyatta University of Agriculture and Technology

KALRO Kenya Agricultural Livestock Research Organization

MOA Ministry of Agriculture

MOALF Ministry of Agriculture Livestock and Fisheries

ABSTRACT

Tomato (*Solanum lycopersicum L.*) is the second most important exotic vegetable widely consumed in Kenya. Its production constitutes one of the fastest growing markets in Kenya, edging towards a vital cash crop. Despite this, tomato production in the country has been declining in the past decade. This decline is attributed to a number of constraints in the value chain, including bacterial wilt disease complex caused by *Ralstonia solanacearum* that can devastate production, causing yield losses of up to 100%. More studies on solving tomato diseases by grafting tend to focus on production quantity but overlook the quality aspect of these grafted tomatoes. Numerous studies have reported the positive impact of grafting on tomato yields. However, grafting on different rootstocks has reported varying results on tomato quality. A clear understanding of the effect of grafting on tomato fruit quality can provide a guide in adopting grafting as an effective farming practice to solve the bacterial wilt problem in tomatoes, thus maximizing profits with minimal resource input that directly contributes to food and nutritional security. This study aimed to evaluate the postharvest quality and the sensory characteristics of intra- and interspecific grafted tomato fruit. Anna F1 and Cal-J, Kenyan commercial tomato varieties were interspecifically grafted on three African eggplant rootstocks; Manyire, AB2, and Sangawiri from World Veg. Centre, Arusha. The two varieties were also intraspecifically grafted on two wilt resistant hybrid tomato rootstocks; B.B and Armada from Takii Seed Company, Japan. The tomatoes were grown in a greenhouse and harvested at the mature green, turning, and ripe stages. The tomatoes were analyzed for size, weight, cumulative weight loss, texture, color changes, lycopene content, vitamin C, total soluble solids, total titratable acidity, respiration and ethylene gas production rates, and sensory evaluation. Interspecific grafting on Manyire green, AB2, and intraspecific grafting on Armada and B.B rootstocks significantly improved the physical and physiological attributes of the tomato fruit. There was a significant difference ($p < 0.05$) in the fruit size and weight of grafted tomatoes and control at all the three maturity stages. Intraspecific grafted tomato fruits on Armada rootstocks had the best quality characteristics in terms of firmness, low cumulative weight loss, respiration, and ethylene production rates associated with extended postharvest shelf-life. Intraspecific grafting reduced respiration and ethylene gas production rates with tomatoes from Anna F1 grafted onto Armada rootstocks attaining the least climacteric peaks of 20.20 ml CO_2 $Kg^{-1}h^{-1}$ and 0.34 µL C_2H_4 $Kg^{-1}h^{-1}$ at the mature green stage, thus extending the postharvest life of these tomatoes. On the other hand, fruits from Cal-J grafted on Sangawiri rootstock had the highest ethylene production rate at 6.7 µl/kg/h in the ripe stage. Anna F1 tomatoes grafted onto B.B rootstock had the highest vitamin C content (28.11 mg/100g). Fruits from Cal-J grafted on Sangawiri reported the least sensory attributes in terms all the attributes assessed. Fruits from Anna F1 grafted on Armada reported the highest score in all sensory attributes evaluated; firmness (9.2), sweetness (9.1), juiciness (6.6), saltiness (9.3), overall look (9.4), and overall acceptability (9.3). On the other hand, the sensory attributes of tomato grafted on Sangawiri; are firmness (5.7), sweetness (5.1), saltiness (6.2), juiciness (6.4), overall look (5.5), and overall acceptability (5.3) had no significant difference ($p< 0.05$) from the nongrafted control. From this study, it is evident that the effect of grafting on tomato quality is dependent on hormonal and biochemical scion/rootstock interactions and a combination of both. Intra- and interspecific grafting on Manyire and AB2 rootstocks improved the physical, physiological, and sensory attributes compared to nongrafted control. However, biochemical quality was not affected upon grafting except Vitamin C and total soluble solids which were significantly improved and reduced respectively through intraspecific grafting. In general, grafted Anna F1 variety reported better quality traits than the Cal-J variety but were not significantly different. Intraspecific grafting had the best quality traits over interspecific grafting, with Armada rootstock reporting the best tomato quality. However, interspecific grafting on Manyire and AB2 rootstocks had comparable fruit quality to intraspecific grafting. Therefore, they could be adopted to complement the existing wilt management chemical methods.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tomato (*Solanum lycopersicum* L.) is the second most crucial exotic vegetable widely consumed in Kenya. Tomato production constitutes one of Kenya's fastest-growing markets edging towards a vital cash crop (Arah et al., 2015). Nutritionally, tomatoes are rich sources of antioxidant compounds such as β carotene, lycopene, ascorbic acid, and phenolic compounds (Georgé et al., 2011). Tomatoes are part of the daily diet of millions of Kenyans. Tomato production in the country has been declining from 570,000 metric tons in 2007 to 410,000 metric tons in 2016 (MoALF, 2017). This decline is attributed to several constraints in the value chain, including bacterial wilt disease complex caused by *Ralstonia solanacearum* that can devastate production, causing yield losses of up to 100% (Kariko et al., 2016). Though disease-tolerant tomato varieties have been developed through breeding and biotechnological strategies, the cost of the resistant hybrid tomato seeds tends to be beyond the reach of a majority of small holder farmers (Djidonuo et al., 2016). Grafting remains one of the alternative cost effective and high yielding strategies that control soil-borne diseases such as bacterial wilt (King et al., 2008).

Grafted tomatoes typically consist of a traditional cultivar of scion and a rootstock that may be resistant to one or more soil-borne pathogens and/or "vigorous"—meaning that it drives vegetative and fruit growth at a higher-than-normal rate (Masterson et al., 2016). This technique allows the cultivation of susceptible tomato varieties in areas infested with pathogens using resistant rootstocks (Lee, 1994). Vegetable grafting dominates the high-tech hydroponic greenhouse industry in European countries. It is a ubiquitous tool in boosting the production of fruiting vegetables of Solanaceae and Cucurbitaceae families in many countries, especially in Asia countries (Lee et al., 2010a). For example, grafted tomatoes accounted for about 40% of Spain's total tomato production, translating to 50 to 70 million grafted plants per year (Raymond, 2013).

There are also reports of grafting in Kenya; Anna F1 scion was grafted onto Cheong gang, Shin cheong gang rootstocks from Korea, and a local wild tomato variety rootstock in several sites, including Ruiru, Kiambu, Isinya, and Karen (Onduso et al., 2018). The study reported that grafting reduced bacterial wilt disease severity and incidence by 92%, 95%, and 64% for the Cheong gang, Shin cheong gang, and the wild tomato rootstocks variety, respectively. Grafted tomatoes onto Cheong gang and Shin cheong gang rootstocks had the lowest wilt disease incidence and produced a high yield of tomatoes with improved quality compared to non-grafted Anna F1. There is another report of grafting of Anna F1 and Cal J scions onto eggplant, Sodom apple, and tomato cultivar Mt56 rootstocks (Waiganjo et al., 2011). Grafting Anna F1 on Mt56, *S. melongena*, and *S. incarnum* rootstocks showed varying compatibility rates of 93.30%, 96.7%, and 73.3%, respectively. On the other hand, Grafting Cal-J on Mt56, *S. melongena*, and *S. incarnum* showed varying compatibility rates of 76.7%, 83.3%, and 100%, respectively. All the grafted plants had successful graft unions except those on the Sodom apple, whose rootstock stem expanded at a varying rate from the scion stem.

In solanaceous crops, the use of both intraspecific (i.e., grafting of stock and scions which belong to the same species) and interspecific (closely related species) grafting is well documented (Chaudhari et al., 2016; Grieneisen et al., 2018). There is a wide range of hybrid tomato rootstocks with the ability to increase yield that has been confirmed in multiple studies (Barrett et al., 2012; Djidonou et al., 2013; Rysin and Louws., 2015). These studies describe profound, and often economically significant, increases in the marketable yield of tomatoes from grafted plants when compared to the non-grafted scion cultivar (Rysin and Louws., 2015). Interspecific grafting of tomato scions onto eggplant (*Solanum melongena*) rootstock has a history of successful use in conferring environmental tolerances to fruit-producing scions and is recommended for flooded or water-logged soils (Black et al., 2003). The World Vegetable Research Center (WorldVeg) found that the rootstocks of EG195 and EG 203 (*Solanum melongena*) eggplant accessions were compatible with most tomato scions and conferred resistance to bacterial wilt, fusarium wilt, and root-knot nematode (Keatinge et al., 2014). African eggplant (*Solanum aethiopicum* L.) is one of the African indigenous vegetables that play a significant role in subsistence production and income generation in Africa (Chadha & Olouch, 2007). Even though the leaves are similar to the conventional eggplant (*Solanum melongena*), they have bright scarlet fruits resembling oval-shaped capsicum peppers. In contrast, some have scarlet rounded fruits with a ridged pattern similar to some heirloom tomato varieties. Our previous unpublished data screened and identified compatible African eggplant rootstock that conferred bacterial wilt resistance to tomato scions. The success of interspecific grafting of tomato scions to eggplant rootstocks suggested the possibility of using this scion-rootstock combination to curb bacterial wilt however, the information on comparative studies on the postharvest quality of interspecific and intraspecific grafted tomato fruits are lacking.

1.2 Problem statement

Food security is among Kenya's government's big four agenda (Food and Agriculture Organization of the United Nations (FAO), 2018). Among the significant causes of food insecurity is preharvest and postharvest losses of fruits and vegetables. Postharvest quality is crucial in determining the consumer's acceptability. Diminished quality characteristics such as small-sized, uneven ripening, less juicy, and soft texture fruits, among others are reasons why consumers reject tomatoes at the market. Tomato production is emerging as a significant source of income in Kenya, particularly for small-scale farmers (KALRO, 2016). Despite its economic importance, tomato production in Kenya faces significant challenges such as pests and diseases, and of significance is bacterial wilt disease (HCD, 2019). Due to a lack of knowledge and training in disease management techniques such as grafting, Kenyan farmers rely heavily on pesticides and use of the disease tolerant tomato varieties which are not consumer and environmental friendly and cost-effective respectively (Kanyua, 2018). Also, the lack of effective bacterial wilt management options has resulted in the destruction of ecosystems as farmers shift to new cultivation lands presumed to be bacteria-free.

For this reason, the grafting technique has been used to solve bacterial wilt with the intention of increasing tomato production (Davis et al., 2008). There has been several reports on the effect of grafting on tomato quality (Passam et al., 2005; Flores et al., 2010; Nkansah et al., 2013; Vieira & Hanada, 2019). However, most of these studies focus on the aspect of tomato yields but not postharvest quality. Elsewhere, studies that have focused on both yield and quality have reported positive impacts on yields but inconsistent results on tomato quality. Some studies have shown that grafting improves quality (Vieira & Hanada, 2019; Kumar et al., 2015), while others have reported that grafting reduces tomato quality (Velasco-Alvarado et al., 2017; Turhan et al., 2011) hence posing uncertainty whether grafting is advantageous or detrimental. Rouphael et al., (2010) attributed these results' differences to different production environments and methods, rootstock/scion combinations used, and harvest date. Inadequate information on suitable rootstocks and their compatibility with preferred tomato varieties has hampered efforts to implement grafting technology as an alternative disease management strategy. This study therefore sought to evaluate the impact of grafting on postharvest quality characteristics and the sensory attributes of a tomato fruit.

1.3 Justificación

Locally available rootstocks can be cost-effective in addressing the challenge of bacterial wilt in tomato production, provided that the postharvest quality attributes conferred to the scion are comparable and similar to the commercial hybrid tomato rootstocks. Explicit knowledge of the effect of grafting on the quality of tomato fruit would give direction on adopting the grafting technique as an effective farming practice to solve the bacterial wilt problem in tomatoes. Implementation of this technique would therefore enable farmers to achieve maximum profits with minimal resource input and provide a product that would contribute directly to food and nutritional security. The implementation will also benefit manufacturing industries that greatly depend on ultimate tomato quality from small and large-scale farmers, thus increasing tomato commercialization. This would therefore contribute to meeting the zero hunger and no poverty sustainable goals respectively. No Poverty SDG can be achieved through producing quality tomatoes, smallholder farmers can increase their income and reduce poverty. The Zero Hunger SDG can be achieved through quality nutritious crop that can help to address malnutrition in Kenya. By producing quality tomatoes, farmers can help to ensure that people have access to healthy food.

In addition, tomato fruit has numerous health benefits, such as reducing cancer risks (Dorais et al., 2008), so ensuring quality and maximum production is critical. This study would also help with key-decision making bodies at the national level in policy making and the implementation of grafting technique for wilt management. There can be changes in agricultural policies whereby stakeholders may work together to influence agricultural policies that promote and advocate for the adoption of this technology.

1.4 Objectives

1.4.1 Main objective

To evaluate the postharvest quality characteristics and sensory attributes of intra- and interspecific grafted tomato fruit

1.4.2 Specific objectives

1. To determine the physical (weight, weight loss, colour, texture, size) and physiological characteristics (respiration rate and ethylene gas production rate) of the intra- and interspecific grafted tomato fruit at specific maturity stages (mature green, turning, and red).
2. To determine the biochemical (total titratable acidity, total soluble solids, vitamin C and lycopene content) characteristics of the intra- and interspecific grafted tomato fruit at specific maturity stages (mature green, turning, and red).
3. To evaluate sensory acceptability attributes of intra- and interspecific grafted tomato at ripe stage.

1.5 Null hypothesis

1 H_0 -There is no difference in the physical and physiological quality of intra- and interspecific grafted tomato fruit and the control at specific maturity stages.

2 H_0 -There is no difference in the biochemical characteristics of intra- and interspecific grafted tomato fruit and the control at specific maturity stages.

3 H_0 -There is no difference in the sensory acceptability attributes of the intra- and interspecific grafted tomato fruit and the control at the ripe stage.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, taxonomy, and botany

Tomato (*Solanum lycopersicum*) originated from the Western part of South America in the coastal highlands (Genova et al., 2013). This fruit migrated through some unknown means to the Central part of South America, where it was domesticated and first used as a vegetable in cooking during the 500 B.C period (Genova et al., 2013). Tomato belongs to the Solanaceae family and other plants like eggplant, potato, pepper, and tobacco (Brewer et al., 2007). This species is botanically classified as berries. It is dicotyledonous growing in branching stems. Tomato stem growth can either be erect or prostrate or grow to two to four meters in height. These stems are glandular, coarse, solid, and hairy. They have compound leaves with distributed leaflets on the rachis. These fruits vary in size and shape. For instance, they are round and spherical, and their sizes range from small to large (Brewer et al., 2007).

There are six stages of ripening in tomatoes. These include mature green, breaker, turning, pink, light red, and red. Most studies focus on three stages of maturity (Mature green, turning, and red) because there is no difference in the characteristics of the intermediate stages (Agromisa, 2005). According to Vieira & Hanada, (2019) good quality tomato is one that has attained the desired post-harvest physical, physiological, and biochemical characteristics. These can be generalized into, maturity indices and physiological and nutritional postharvest characteristics. Some of these quality characteristics increase while others decrease with ripening.

Maturity indices attributes are; size, weight, colour, texture, sugar content (°Brix), and titratable acidity (Vieira & Hanada, 2019). For example, tomatoes gradually change colour from green in the mature green stage to red ripe stage. Hunter colour values usually determine colour, and there is a change from greenness, a negative value of 'a', to redness, a positive value. A quality tomato is firm in texture. A firm tomato prolongs shelf-life, thus, minimizing losses. According to (Rodica et al., 2018), puncture resistance decreased from 10.5 to 2.3 Newtons as ripening progressed. Total sugars were reported as 1.67 g/100 g at the mature green stage and 5.52 g/100 g at the last ripening stage. Besides, total soluble solids were seen to have increased from 4.15 to 6.62 g/100 g as it ripens. Tomato acidity was reported as 0.36 g/100 g at the mature green state while 0.54 g/100 g at the last stage of ripening.

Physiological attributes include ethylene production during ripening and carbon dioxide (CO_2) production during respiration. The ripening stages of tomatoes can be ascertained through respiration rate and ethylene production measurement. Nutritional attributes include vitamin C, pro-vitamin A, lycopene, folate, vitamin K, and potassium content (Vieira & Hanada, 2019). Lycopene in the skin increased from 0.07 to 14.28 mg/100 g, while tomato pulp increased from 0.04 to 6.73 mg/ 100 g in the last red ripe stage (Rodica et al., 2018). There are different ranges of biochemical traits in tomatoes. For instance, approximately up to 2,573 μg lycopene content, up to 14 mg vitamin C content, up to 7.9 μg vitamin K, up to 449 μg β-carotene, and high soluble solids (°Brix) of up to 2.6 g/100g. Starch is broken down into sugars as the fruit ripens (Rodica et al., 2018).

2.2 Tomato Production in Kenya

Tomato is Kenya's second most important vegetable, surpassed only by Brassicas, mostly kales and cabbage (Rodolfi et al., 2018). It is ranked third most important vegetable after kale and cabbage, accounting for 18% to 20% of vegetable value and area under production (HCDA, 2015). This fruit is broadly grown for home consumption and largescale sales. It is cooked as vegetables, used as salads, processed as tomato sauce, and tomato pastes (puree) (Henriques et al., 2019). Tomato is an income-generating horticulture crop in Kenya for both small and largescale farmers. The most common tomato varieties grown in Kenya include; Cal J, Anna F1, Rio Grande, Nema 1400, Parmamech, M82, Picardor, Rubino, Spectrum, Roma VF, Nema 1401, and Parma VF (Anastacia et al., 2011). Tomatoes are mainly grown in areas with low rainfall and irrigation facilitated in semi-arid areas. Too much rainfall is discouraged since it supports the thriving of pathogens. Temperatures of 15° C and 25° C give optimal production. Similarly, well-drained soils with high organic content and pH ranging from 5 -7.5 favour high yields (Semiz

& Suarez, 2015). Tomatoes are primarily grown in Kiambu, Maragwa, Nyeri, Kajiado, Laikipia, Mitunguu, and Kirinyaga counties in Kenya (Waiganjo et al., 2011). Most grow in open fields and, recently, in greenhouses with controlled growth conditions. For example, Anna F1, Corazzon F1, and Prostar F1 tomato varieties do well in greenhouses. On the other hand, Cal-J and Rio Grande varieties do well in open fields (KARI, 2005).

During a national agriculture product value chain exercise in 2010, seventy eight stakeholders ranked tomatoes among the Kenya's most essential exotic vegetables (KALRO, 2016). According to the Economic Review of Agriculture, (2012), tomato production increased from 354,356 metric tons in 2009, 378,756 metric tons in 2010, and 407,374 metric tons in 2011. There was also an increase in value for this consecutive years with 8,549,178,482, 10,441,561,004, and 12,353,653,058 Kenyan shillings in 2009, 2010, and 2011 respectively (Ministry of Agriculture, 2013). Tomato production covered 18,613 ha in 2012, with a total production of 397,007 metric tons valued at 12.8 billion Kenyan shillings, with Kirinyaga, Kajiado, and Taita Taveta leading with 13.7, 9.1, and 6.9, respectively which was a rise from the previous year (HCDA, 2013). In 2014, vegetables contributed 31.8% to domestic horticulture and were planted on an area of 280,541 ha, representing a 9% increase from 2013, producing 3.6 million tons valued at 64.1 billion Kenyan shillings as shown in (Table 2.1) (HCDA, 2015). AFA-HCDA, (2016) reported an increase in tomato production from the previous year, with 20,111 hectares accounting for 20% of the domestic value obtained from tomato production.

However, it has been reported that production in specific counties has been declining since 2016. In 2016, production was 410,033 tonnes, but it dropped to 283,000 tonnes in 2017, as shown in (Table 2.2) (FAOSTAT, 2018). HCD, (2019) reported tomato as the leading vegetable accounting for 37.63 of all exotic vegetables in 2017 and 2018. There was a 14.5 percent increase in tomato value from 17.38billion Kenyan shillings in 2017 to 19.90 billion Kenyan shillings in 2018, as shown in (Table 2.3). There was a steady increase in value and areas under production in Machakos, Kajiado, and Narok with the Kirinyaga, Trans Nzoia, Bungoma, Laikipia, Kwale, and Meru counties reporting a decrease in area under production, volume, and value. The decrease in production in these counties was attributed to a build-up pests and diseases. Pests and diseases remain the main challenges in tomato production in Kenya (Ochilo et al., 2019). . The decline in tomato production is generally linked to poor preharvest and postharvest practices. Preharvest causes of tomato losses include diseases, pest infestation, inappropriate irrigation fertilizers, and poor cultural practices; of significant concern is bacterial wilt disease which can cause up to 100 percent loss in tomato production (Deribe et al., 2016; Tatlidil et al., 2005). Postharvest tomato losses are caused by poor harvesting methods, transportation, inappropriate sorting and grading, and improper packaging and storage. Also, factors such as temperature, gases in storage, relative humidity, and postharvest calcium chloride application influence tomato quality after harvest (Arah et al., 2015).

Table 2.1: Tomato production in the top ten counties in Kenya from 2012 to 2014

County	**2012**			**2013**			**2014**		
	Area (Ha)	**Volume (MT)**	**Value (Million KES)**	**Area (Ha)**	**Volume (MT)**	**Value (Million KES)**	**Area (Ha)**	**Volume (MT)**	**Value (Million KES)**
Kirinyaga	1,903	59,464	1,159	1,796	30,774	750	1,648	48,560	1,156
Kajiado	1,603	35,937	921	1,668	50,884	962	1,680	47,368	1,624
Bungoma	1,344	39,232	1,221	1,474	41,568	1,228	1,700	50,399	1,611
Kisumu	822	12,219	347	1,537	14,307	444	1,477	16,720	328
Kisii	876	15,590	331	951	16,985	364	937	16,664	351
Kiambu	964	18,029	811	691	9,169	419	964	18,029	812
Trans Nzoia	480	9,270	129	623	17,395	302	628	14,848	416
Machakos	547	10,335	222	724	11,548	323	447	6,189	356
Nakuru	509	6,745	602	495	8,668	516	633	17,511	347
Makueni	431	17,582	651	486	22,560	991	558	21,096	857
Others	9,706	139,702	3,992	10,540	160,010	5,353	13,402	142,820	3,945
Total	**19,185**	**364,105**	**10,386**	**20,985**	**383,868**	**11,652**	**24,074**	**400,204**	**11,803**

Source: Horticultural Crops Directorate (HCD) validated report 2015; Mi- million, MT- metric tons, Ha- hectare. Note that the total is for all the tomatoes produced in Kenya.

Table 2.2: Tomato production in the top ten counties in Kenya in 2015 and 2016

County	2015			2016		
	Area (Ha)	**Volume (MT)**	**Value (Million KES)**	**Area (Ha)**	**Volume (MT)**	**Value (Million KES)**
Kirinyaga	2,015	42,780	2,100	3,128	54,185	2,323
Kajiado	1,360	27,440	1,388	1,452	32,789	1,613
Taita Taveta	579	13,745	557	830	18,026	1,158
Laikipia	536	12,674	650	583	14,070	986
Bungoma	1,055	25,429	1,211	811	21,305	951
Trans Nzoia	659	16,690	617	723	16,660	638
Narok	784	14,920	529	1,561	20,744	596
Nakuru	851	14,158	294	946	15,179	492
Kisumu	591	16,512	726	646	8,545	397
Homa Bay	752	6,771	324	669	8,249	394
Machakos	795	9,500	246	689	12,765	381
Kiambu	986	16,545	692	965	9,132	327
Meru	928	7,903	230	1,050	9,951	323
Bomet	862	10,785	284	527	9,047	261
Lamu	360	7,719	285	374	7,190	248
Others	5,265	89,108	2,790	5,147	83,189	2,599
Total	**18,387**	**330,679**	**12,922**	**20,111**	**341,026**	**13,687**

Source: HCDA validated report, 2016. Note that the total is for all the tomatoes produced in Kenya.

Table 2.3: Tomato production in the top ten counties in Kenya in 2017 and 2018

County	2017			2018		
	Area (Ha)	Volume (MT)	Value (Million KES)	Area (Ha)	Volume (MT)	Value (Million KES)
Kajiado	2,452	54,827	1,914,835,250	3,024	71,250	2,379,680,250
Kirinyaga	3,219	60,490	2,247,500,000	2,460	60,587	2,037,800,00
Narok	2,277	54,220	1,700,200,000	2,420	54,082	1,886,227,500
Machakos	2,453	39,255	1,029,775,000	4,075	56,225	1,328,475,000
Kiambu	544	7,099	270,033,750	769	24,499	1,249,126,000
Taita Taveta	726	22,990	904,500,000	783	28,610	1,238,650,000
Makueni	575	22,250	893,600,000	931	27,675	941,600,000
Homa Bay	1,143	8,490	482,811,240	1,541	12,104	743,706,000
Lamu	275	10,700	242,508,000	491	16,242	693,153,000
Kisumu	663	16,341	542,320,000	536	19,030	592,650,000
Trans Nzoia	672	19,804	613,560,000	441	14,633	518,266,000
Kitui	311	6,743	245,790,000	735	13,588	459,685,000
Murang’a	1,258	8,888	417,409,550	1,315	9,250	448,946,300
Bungoma	538	10,041	456,710,000	564	11,129	442,570,000
Siaya	741	10,674	442,675,000	628	9,523	431,532.500
Laikipia	578	19,670	674,420,300	321	10,999	376,500,000
Bomet	545	7,535	236,650,000	550	9,849	320,578,000
Kwale	448	6,989	320,023,000	420	6,966	319,660,000
Meru	549	12,386	485,356,018	498	9,702	316,985,000
Nyeri	273	6,670	239,619,940	356	11,348	299,950,768
Others	6,812	101,214	3,018,982,134	5,045	97,167	2,877,810,938
Total	**27,053**	**507,275**	**17.379,279,182**	**28,263**	**574,458**	**19,903,552,256**

Source: AFA-Horticulture Crops Directorate, 2019. Note that the total is for all the tomatoes produced in Kenya.

2.3 Postharvest losses of tomatoes

Tomatoes are one of the most important vegetable crops in Kenya, both for domestic consumption and export. However, postharvest losses of tomatoes in Kenya are a significant problem. Despite the tomato's economic importance, it faces numerous constraints that make its production unprofitable in Kenya, among them is postharvest losses. Tomatoes are perishable fruits prone to postharvest losses (Varela et al., 2003). Those losses have been established to be either an on- or off-farm problem. Pest and diseases, high cost of inputs such as fertilizers, poor quality seeds, poor growth conditions such as adverse weather conditions, inappropriate irrigation, poor crop husbandry, poor cultural practices, improper harvesting stages, inappropriate harvesting methods, improper harvesting containers, and improper packaging materials all contributes to the on-farm losses. On the other hand, causes of off-farm problems include inappropriate mode of transport and poor access roads, inappropriate tomato sorting and grading, poor storage conditions and storage areas, inappropriate packaging, lack of processing equipment and factories, and lack of reliable market information. Low-cost intermediary technology interventions can be crucial in decreasing some of these post-harvest losses (Arah et al., 2015). Tomatoes are susceptible to pests and diseases, which can reduce their quality and shelf life. Common pests and diseases that affect tomatoes in Kenya include fruit flies, whiteflies, and bacterial wilt. There has been efforts to implement pest and disease control measures: Farmers should be trained on proper pest and disease management practices to reduce the incidence of pests and diseases and improve the quality of their tomatoes (Ndirangu et al., 2017).

2.4 Postharvest quality traits in tomatoes

Tomatoes are one of the most widely grown and consumed fruits worldwide. They are harvested at different maturity stages depending on the consumer's and market's preference. During the postharvest period, several important quality traits are affected, which can affect their shelf life and overall quality. Some of the most important postharvest quality traits in tomatoes include firmness: Tomatoes should have a firm texture, as soft or mushy tomatoes are undesirable to consumers. This trait is determined by the composition of the cell walls and their integrity. Color: The color of the tomato is an important factor in determining consumer acceptance. A uniform red color is preferred in most markets. Flavor: Tomatoes should have a sweet, tangy flavor and aroma. The sugar/acid ratio and the volatile compounds responsible for the aroma are important factors in determining the flavor. Nutritional content: Tomatoes are rich in vitamins, minerals, and antioxidants. The nutritional content can be affected by the growing conditions and postharvest handling. Disease resistance: Tomatoes are prone to several diseases, including fungal and bacterial infections. Resistance to these diseases can prolong the shelf life of the fruit. Weight loss: During the postharvest period, tomatoes lose moisture and weight, which can affect their appearance and texture. Proper storage conditions can reduce weight loss. Shelf life: The shelf life of tomatoes is an important factor in determining their marketability. Proper postharvest handling and storage can extend their shelf life. Overall, maintaining the quality of tomatoes during the postharvest period requires proper handling and storage practices, which can help preserve their firmness, color, flavor, nutritional content, disease resistance, and shelf life.

2.5 Bacterial wilt disease

Bacterial wilt disease of tomatoes is as a result of a pathogen *Ralstonia solanacearum*. The bacteria has five races, each attacking different species in different regions (Champoiseau & Momol, 2008). It can thrive in infested soils for longer periods of 1 to 3 years in the absence of the host and 40 years in the presence of the host. Factors like high pH levels, high humidity, high temperature of 29-35°C, and excess rainfall increase the survival of this wilt (Onduso, 2014). The disease is highly infectious in both soil and soilless cultures, causing wilting of leaves and stems that are usually visible during the day and eventually death of the whole plant. The youngest leaves are the first to be affected with a flaccid appearance causing wilting of the leaves. However, if they attain maturity, they produce small fruits with diminished quality characteristics (Tahat & Sijam, 2010).

The pathogen can be isolated from any part of the plant, but stems are most commonly used (Chaudhari et al., 2016). In most cases, the stem close to the root produces a large number of adventitious roots and buds, indicating vascular bundle infection. Plants may have vascular system discoloration that appears as a streaky brown to yellow cream discoloration and a bronze stint and epinasty of the petiole on the infected leaves (Bharathi, 2004).

2.6 Bacterial wilt disease management

Bacterial wilt is a threat to tomato production due to limited control strategies that cannot be effectively managed with chemicals (Humphrey, 2007). Tomatoes are being grafted on wilt-resistant crops to solve this wilt disease (Kanyua, 2018). Kago et al., (2016) reported bacterial wilt incidences in tomatoes and an overall prevalence of 24.9 percent in Kirinyaga, Nakuru, Kiambu, Nyeri, Embu, Murang'a, and Nyandarua counties. The extensive spread, high prevalence, and high incidence of bacterial disease were due to poor seed systems. Crop rotation and uprooting strategies were applied in managing this disease, with many farmers demonstrating a lack of elaborate measures to manage the disease. Onduso, (2014) reported incidence of bacterial wilt, severity, and yield data in Ruiru, Kiambu, Isinya, and Karen sites in farmers' greenhouses and open fields, where the highest incidence was recorded in Kiambu and the lowest in Kajiado county. In addition, greenhouses tomato production reported higher wilt disease incidence than open field production. Grafting susceptible Anna F1 tomato variety on the Shin cheong gang, Cheong gang, and a wild tomato variety rootstock reduced bacterial wilt incidence by 95%, 92%, and 64%, respectively. Ignatius, (2018) reported the incidence of bacterial wilt in Kirinyaga County. Distinct colonies of *Ralstonia solanacearum* bacteria were identified by bacterial inoculum isolation using Casamino Acid-Peptone-Glucose (CPG) and triphenyl tetrazolium chloride (TTC) media. Bacterial wilt-resistant tomato cultivar (Mt56) was used as a rootstock in grafting Anna F1 and Cal-J tomato varieties with Anna F1/Mt56 scion-rootstock combination demonstrating a higher survival rate.

2.6.1 Grafting

Grafting is a new technology identified as a solution to curb bacterial wilt (Davis et al., 2008). It is, however, an expensive method of propagation (Mudge et al., 2009).

Grafting technique is used as an alternative to breeding for disease resistance against highly variable pathogens with numerous biotypes, which may delay the incorporation of broad-spectrum resistance into the selected desirable cultivars (Louws et al., 2010). Furthermore, grafting may protect scions from the pleiotropic effects of disease resistance genes that result in changes in plant morphology and fruit quality. Grafting applications have been primarily expanded in the Solanaceae and the Cucurbitaceae, which comprise major vegetable crops worldwide (Rouphael et al., 2010). The sole reason for grafting is to minimize soil-borne pathogens by enhancing pests and disease resistance. This is achieved through selecting rootstocks that have demonstrated resistance to bacterial diseases such as bacterial wilt on tomatoes, fire blight on apples, and insect pests like Phylloxera on grapes, among others (Quamruzzaman et al., 2018).

Grafting has also been associated with reducing tolerance to abiotic stresses. This technique also propagates sterile plants with little or no seed production. Additionally, it has also been demonstrated to minimize the juvenility of fruit trees that can last several years, thus, speeding up the onset of flowering. Recent studies have also demonstrated that using genetically different and compatible rootstocks for perennial crops may influence the quality traits of fruits and vegetables (Mudge et al., 2009). It involves joining the upper part of the plant of the desirable cultivar (scion) onto wilt-resistant rootstocks from species that are compatible, and the two parts subsequently grow as a single plant, as shown in (Fig. 2.1) (Bletsos & Olympios, 2008). The union is determined as a successful graft union upon healing and growing as one plant.

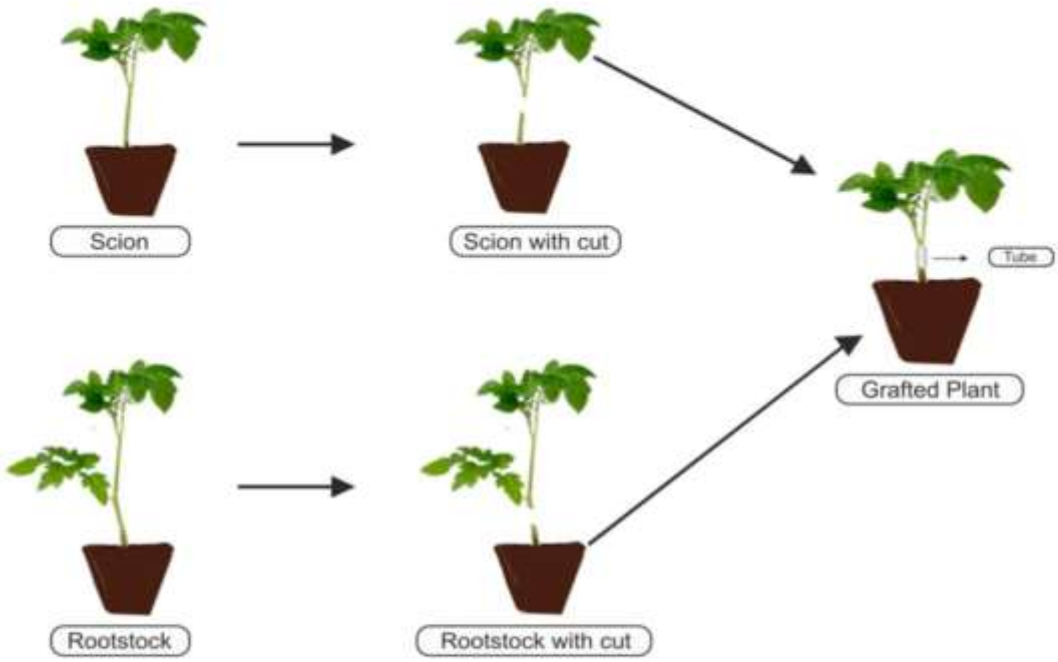

Figure 2.1: Schematic diagram showing the process of grafting a scion on a rootstock

Source: Tomato Grafting: A Global Perspective (Singh et al., 2017)

2.6.1.1 Intra-generic and intergeneric grafting

Intra-generic grafting is a cross between plant tissues in the same genus. In contrast, intergeneric grafting is a cross between two plant tissues of different genera but from the same family. For instance, in intra-generic grafting, the tomato in question is grafted onto a wilt-resistant tomato rootstock, while in intergeneric, it is grafted on the eggplant rootstock from the same family (Davis et al., 2008).

Eggplant (*Solanum melongena*) is a purple fruit from the family Solanaceae, just like the tomato. For successful grafting, a variety used as a scion should be susceptible and compatible with the rootstock. Interspecific grafting of tomato scions onto eggplant (*Solanum melongena*) rootstock has a history of successful use in conferring environmental tolerances to fruit-producing scions and is recommended for flooded or water-logged soils (Black et al., 2003). The World Vegetable Research Center (WorldVeg) found that the rootstocks of EG195 and EG 203 eggplant accessions were compatible with most tomato scions and conferred resistance to bacterial wilt, fusarium wilt, and root-knot nematode (Keatinge et al., 2014).

Using different scion-rootstock combinations has been associated with varying quality characteristics of the tomato (Mudge et al., 2009). A compatible scion-rootstock combination produces grafted tomatoes with improved quality than the non-grafted (Mišković & Marković, 2009). On the other hand, poor combinations can significantly reduce tomato quality (Turhan et al., 2011).

2.6.1.2 Scion-rootstock combination

The response of grafted seedlings after transplanting is influenced by the scion/rootstock combination, genetic materials, and the grafting process (method, scheduling, and acclimatization). Therefore, selecting the appropriate rootstock is critical in grafting. Every rootstock has its own effect when combined with the scion. It can perform differently under different environmental conditions, so selecting both the scion and the rootstock is critical for the success of a graft union (Guan & Hallett, 2016).

Research has shown that specific scion-rootstock combination compatibility determines changes in the survival of the grafted stock as it affects water and nutrient uptake, hydraulic conduction, levels of oxidative stress, callus formation, cohesion, vascular differentiation, and connectivity. In addition, it also affects scion leaf retention synthesis, stomatal behavior, and translocation of water, minerals, and plant hormones among the selected rootstock genotypes (Velasco-Alvarado et al., 2017).

Upon selecting scion and rootstocks, grafting success solely depends on the genotypic factors for compatibility or incompatibility. It is evident that compatible graft combinations positively affect plant growth and development while incompatible combinations negatively impact plant growth, reducing yields and fruit quality (Davis et al., 2008). An incompatible graft union may be attributed to weak graft union, physiological incompatibility due to effects of growth regulators, wounding responses, and lack of cellular recognition. Production of incompatibility toxins and failure of the grafted unions to grow is also an outcome of an incompatibility graft despite graft success (Keatinge et al., 2014). It is generally considered that scions and rootstocks that are taxonomically closer have higher graft compatibility (Iqbal et al., 2019).

Successful combinations enhance a robust root system in non-infested soils, improving productivity and quality. In addition, the interaction of high-yielding scion genotypes with complementary rootstocks may improve plant vigor, thus improving overall crop performance that enhances fruiting behavior and quality traits, mainly when grafted under optimal environmental conditions (Grieneisen et al., 2018). Compatible scion-rootstock combinations have also been associated with activating inherent antioxidant defense enzymes, regulating stress response genes, and lowering lipid peroxidation levels (Ilić et al., 2020).

There are recommendations for different rootstocks for each species based on their resistance or tolerance to soil-borne diseases and nematodes. However, the lack of detailed information on the degree of this tolerance and their response to inoculation under controlled conditions poses problems in selecting a suitable rootstock (Ibrahim et al., 2014). Rootstocks may originate from a seedling, micro propagated plant or a rooted cutting. Rootstocks that confer specific traits on the grafted plant are generally vegetatively propagated by cuttings or layering. Using the tried and trusted species combinations is crucial to give viable grafts (Vieira & Hanada, 2019). The effect of grafting in terms of growth, yield level, and product quality varies in some cases in relation to the scion rootstock combination (Soare et al., 2018a). There is a functional relationship interaction between scion and rootstock that determines grafting success on grafted plants. They could be directly or indirectly involved in the scion-rootstock relationship and, on the whole, the response of a grafted plant. These mechanisms may depend on different assimilation, translocation, water, and nutrient uptake, root growth, synthesis, and translocation of hormones, alkaloids, phospholipids, and proteins (Velasco-Alvarado et al., 2017). Grafted plants from the inappropriately paired scion and rootstocks lack these advantages. They instead report no impact or detrimental effects of specific graft combinations on growth, yield, and quality (Bletsos & Olympios, 2008).

Barreto, (2017) found that when the rootstock selection is poor, vegetable grafting does not boost yield and improve quality. Rootstocks impact yield, quality, and growth only if suitable combinations are considered (Davis et al., 2020; Sora et al., 2019).

2.7 Effects of grafting on quality and yields

Grafting focuses on fruits and vegetables has been on yield and overcoming pest and disease problems overlooking the equally important quality aspect. However, the focus is now diverging to quality (Rouphael et al., 2010). Grafting has therefore, evolved to incorporate increased growth, abiotic stress resistance, increased yield, and produce quality (Savvas et al., 2011).

The effects of grafting using different rootstocks on fruit quality greatly vary across scions. Callus formation as a result of reconnection of vascular continuity between different scion and rootstock genotypes may alter the flow rate of metabolites across the graft union, thus, leading to changes in scion morphology and fruit quality (Davis et al., 2008). Moreover, grafting may cause epigenetic changes in the scion that affect gene transcription (Mohamed et al., 2012).

Positive effects of grafting on fruits and vegetables have been associated with increased synthesis of endogenous hormones, induced resistance against low and high temperatures, enhanced nutrient uptake, reduced uptake of persistent organic pollutants, the limited negative effect of soil toxins, improved water use efficiency, and improved alkalinity tolerance (Ozturk & Ozer, 2019).

With successful grafting, the scion variety affects the final yield and quality of grafted fruits and vegetables. However, rootstock effects can positively or negatively alter these quality characteristics (Soare et al., 2018a). Several conflicting reports on these fruit quality changes due to grafting raise questions about whether grafting effects are advantageous or deleterious (Flores et al., 2010). Sakata et al., (2008) reported that varying results might be partly attributable to different production environments such as temperature, light intensity, and grafting methods such as soilless or soil culture, application of fertilizer, and irrigation and harvest date.

Furthermore, Nkansah et al., (2013) have demonstrated that scion/rootstock combinations are used to play an important role in fruit quality. These combinations have been associated with altering the amounts of hormones produced and influencing sex expression and flowering order of the grafted plants (Singh & Rao, 2014).

2.7.1 Effects of grafting on other fruits and vegetables

Peppers are grafted onto the rootstocks that have resistance to soil-borne diseases such as phytophthora blight and bacterial wilt, besides improving yield and quality (Bletsos & Olympios, 2008). Jang et al., (2013) reported varying results on pepper quality upon grafting on 'Nokkwang' and '*Saengsaeng Matkkwari*'rootstocks. Fruit weight, dry matter, fruit length, and flesh thickness were affected by grafting on the 'Nokkwang' rootstock. Whereas on the other hand, grafting on the '*Saengsaeng Matkkwari*' rootstock affected fruit shape index and fruit width, but there was no effect on the length and thickness. Contrary, Ramón et al., (2020) reported similar results where grafting pepper onto "Sueca" and "Valencia" rootstocks positively affected quality measured in terms of vitamin C, phenolic compounds, and lycopene content. The two rootstocks were significantly different from the nongrafted control but were not significantly different from each other. Kyriacou et al., (2017) reported desirable and undesirable changes in fruit shape, size, and weight upon grafting peppers on different rootstocks. In addition, Sánchez et al., (2015) reported improved nutritional content in grafted pepper fruits.

Watermelon grafting is crucial in minimizing soil-borne diseases, such as Fusarium wilt, Verticillium wilt, and nematode infections (Louws et al., 2010). This is expected to improve yields and quality. There are varying results on the effects of grafting on watermelon quality upon using different rootstocks (Sacha, 2012). Devi et al., (2020) reported consistent watermelon quality traits with the slightly improved quality compared to nongrafted fruits. Grafting onto cv. PS 1313, cv. RS 1330, and cv. RS 1420, except bottle gourd rootstock, reported increased watermelon fruit flesh firmness, lycopene content, and total soluble solids compared to nongrafted fruit. These traits were specific to rootstock-scion combinations that contribute to contradictory reports of the impact of grafting on fruit quality. Kyriacou & Soteriou, (2015) reported reduced soluble solids content and decreased firmness on grafted watermelon fruits. However, Davis et al., (2008) reported positive effects of grafting watermelon, such as increased lycopene content, fruit firmness, and Brix.

On the other hand, Miguel et al., (2004) reported no difference in soluble solids concentration of watermelon fruit from *C. maxima* grafted on *C. moschata* hybrid rootstock compared with the nongrafted controls. Fouad et al., (2012) reported varying fruit skin thickness, fruit weight, soluble solids, and lycopene content quality traits upon grafting Aswan F1 onto Strongtosa F1, Nun 6001 F1, Shintoza F1, Ferro F1, and Tetsukabuto F1 with Nun 6001 F1portraying the best characteristics. Huitrón et al., (2009) reported similar watermelon quality traits and varying yields upon grafting Tri-X 313 on 'RS841' and '*Shintosa Camelforce*.' They both portrayed improved fruit weight and fruit firmness than the nongrafted fruits with soluble solids that were not significantly different. However, graffiti on '*Shintosa Camelforce*' demonstrated lower yields than 'RS841'. In Hungary, Németh et al., (2020) reported higher yield and quality compared to nongrafted fruits upon grafting watermelon on 'RS 841' and Lagenaria 'FR Strong' interspecific rootstocks. Pumpkins have been widely used as rootstocks in watermelon production. Scion/rootstock combinations demonstrated improved quality measured in terms of fruit size and texture quality traits and were significantly different from the nongrafted control. The incompatible combinations negatively affected the rind color, texture, and flesh color of the grafted fruits (Fallik & Ziv, 2020).

Using suitable rootstocks that are tolerant or resistant to soilborne diseases, arthropods, weeds, and foliar pathogens is crucial for cucumber production, majorly for farming practices with limited crop rotations (Rysin & Louws., 2015). Lee et al., (2010b) demonstrated interspecific cross *C. maxima* × *C. moschata* yielding improved quality traits that were significantly different from the non-grafted, thus being exploited as favorable rootstocks commonly used for commercial cucumber production. Rouphael et al., (2010) reported varying quality traits upon grafting cucumber onto *C. ficifolia*, *C. pepo*, *C. argyrosperma*, *C. moschata*, and *C. maxima* with deteriorating sweetness and acidity quality traits in grafted fruits compared to the nongrafted controls. Nevertheless, Sakata et al., (2008) demonstrated no effect on cucumber fruit firmness upon grafting on *C. moschata* or *C. maxima* × *C. moschata* rootstocks as compared to nongrafted control. Rootstocks implicate fruit firmness variation may be attributed to several mechanisms such as increased synthesis of endogenous hormones, cell morphology variation, uptake and translocation of calcium, modulated water relations, and nutritional status (Hamdan et al., 2007). Rouphael et al., (2010) reported an improved cucumber quality in terms of ascorbic acid content with grafting.

Grafting apples onto dwarfing rootstocks reduces a juvenile phase, where they can take up to six years to flower (Kotoda et al., 2006). According to a study by Kviklys & Samuolienė, (2020) in Latvia, Lithuania, and Estonia, grafting twelve different dwarfing rootstocks on an early apple variety 'Auksis' demonstrated that the effect of rootstock on fruit weight was not significantly different from the nongrafted control. It was also concluded that fruit quality was affected by scion/rootstock combinations and soil, vigor, crop husbandry, climate, and precipitation.

2.7.2 Effects of grafting on tomato fruits

Studies have reported a positive grafting effect on the quality characteristics of tomatoes (Velasco-Alvarado et al., 2017; Flomo, 2010; Turhan et al., 2011). For instance, Youssef et al., (2010) reported firmer grafted tomato fruits than non-grafted ones, thus minimizing postharvest losses. Vieira & Hanada, (2019) also reported bigger and heavier grafted tomatoes than the nongrafted. Furthermore, grafting has also been associated with increasing tomato yields. A study by Grieneisen et al., (2018) shows that Dixie Red variety which was not grafted, produced 27.1 tons/acre; when grafted on Maxifort rootstock, production increases to 34.7 tons/acre, and grafting on DRO138TX rootstock produced 38.0 tons/acre yields (Grieneisen et al., 2018). Kumar et al., (2015) reported that tomato quality traits measured in terms of skin color, titratable acidity (TA), fruit shape index, dry matter content, and soluble solids content (SSC) were positively affected by grafting and scion/rootstock combinations played a crucial role. Helyes et al., (2009) reported that grafting indeterminate and cherry tomatoes onto Nívó, Daniela F1, and Early Fire rootstocks greatly affected lycopene content.

Grafting tomatoes has also demonstrated no grafting impact or detrimental grafting effects on quality. Naif et al., (2011) reported that grafting cv. Yankı F1 and cv. Esin Fı tomatoes onto R801, Groundforce, body, ES30501, Spirit F1, ES30502, ES30503, Beaufort, K- 8, Titron, and 8411 rootstocks had no impact on yield and quality. These rootstocks were not significantly different from the nongrafted control. Grafting had no effect on the titratable acidity, Vitamin C, and water-soluble dry matter and was not affected significantly by the scion-rootstock combinations. Another study by Vrcek et al., (2011) reported a decline in total phenolics compounds, vitamin C, and total antioxidant activity in tomatoes with grafting. Khah et al., (2006) reported that grafting 'BigRed'tomato onto 'He-man' rootstock yielded higher produce in both open-field and greenhouse, but grafting did not have any significant effects on the fruit quality. Also, grafting Cecilia on He-man and Spirit rootstocks reported reduced quality in total soluble solids, vitamin C, lycopene, and β- carotene content, and antioxidant capacities (Qaryouti et al., 2007). Furthermore, grafting Lemance F1 scion on Beaufort rootstock reported significantly lower Brix° and carbohydrate content in grafted fruits than the nongrafted control. This study also reported no significant difference in the acid content of the grafted and nongrafted tomato fruits (Pogonyi et al., 2005). In Greece, Savvas et al., (2011) demonstrated that salinity significantly improved total soluble solids (TSS), titratable acidity, and vitamin C contents quality traits of tomato fruits, whereas grafting and scion/rootstock combinations had no effect on any quality traits under study.

However, there are varying results on the quality characteristics of these grafted fruits. For instance, a study by Velasco-Alvarado et al., (2017) involving Catalena tomato grafted on two types of rootstocks Maxifort and '43437 F1' showed improved quality characteristics on tomatoes grafted on Maxifort while reduced quality upon grafting on '43437 F1' rootstock. Another study by Mohamed et al., (2012) involving grafting Catalena and 'Santazian' cherry tomatoes onto 'Beaufort' rootstocks reported overall improved fruit yield and quality upon grafting Catalena onto 'Beaufort' rootstocks, whereas grafting of 'Santazian' on the same rootstock decreased vitamin C content and did not improve fruit yield compared to the nongrafted fruits. Another study by Barrett et al., (2012b) involving interspecific grafting of Heirloom and Brandywine tomato varieties onto tomato hybrids 'Multifort' and 'Survivor' rootstocks reported variation in tomato quality in the two years of study. For instance, TSS, TTA, vitamin C, and pH were reduced by grafting in 2010 and improved by grafting in 2011. Mohammed et al., (2009) also reported improved soluble solids upon grafting Cecilia tomato onto Beaufort rootstock while reduced quality upon grafting on Arnold rootstock. Turhan et al., (2011) study on Beril tomato scions on Arnold and Beaufort rootstocks also showed varying quality traits. From the results, grafting Beril onto Arnold rootstock improved tomato weight, dry matter, and fruit index. At the same time, vitamin C content, ^{o}Brix, and total soluble solids were significantly lower in grafted tomatoes than in the nongrafted fruits. In addition, the pH and lycopene content of the grafted fruits were not significantly difference from the non-grafted fruits.

On the other hand, grafting Beril onto Beaufort rootstock reported improved quality in all the quality traits under study. Ilić et al., (2020) reported grafting 'Optima F1' and 'Big beef F1' onto 'Maxifort' rootstock had a significant difference from nongrafted control with varying quality traits in terms of more elastic fruit skin, loss in firmness, lower lycopene, malic, total phenol, citric acid contents, and sugar, and higher ascorbic acid content, succinic acid contents, and succinic acid content. It was concluded that scion/rootstock compatibility, convenient grafting, and shading combinations greatly affected tomato quality. Turhan et al., (2011) observed varying results where grafting did not affect tomato fruit quality traits such as pH and lycopene content. In contrast, grafting decreased titratable acidity, soluble solids, and vitamin C. Also, Similarly, in Spain, Flores et al., (2010) demonstrated that grafting had no positive or detrimental effects on tomato yield and quality traits under standard growing conditions. Still, it enhanced soluble solids and titratable acidity tomato quality upon grafting under saline conditions. This was concluded that besides scion/rootstock combinations, growing systems and environmental conditions also play a big role in quality. Savvas et al., (2011) reported that grafting tomato on 'Resistar,' 'Beaufort,' and 'He-Man' under low to moderate salt-stress conditions had an effect on quality measured in terms of ascorbic acid content, titratable acidity, salinity, and soluble solids but grafting and rootstock choice characteristics had no effect on any quality traits. Di-Gioia et al., (2010) reported that grafting tomatoes onto ‘Beaufort’ F1 and ‘Maxifort’ F1rootstock decreased vitamin C contents, but soluble solids, dry matter, and titratable acidity were not significantly different from nongrafted treatment.

2.7.3 Success/failures of grafting tomatoes or other vegetables in Kenya

Waiganjo et al., (2011) grafted Anna F1 and Cal J scions onto eggplant, Sodom apple, and wilt-resistant tomato cultivar Mt56 rootstocks in a greenhouse at Kenyatta University Teaching and Research Farm. The graft compatibility was considered a success if 67% of the graft unions had healed within fourteen days after grafting. The grafted unions were compatible at varying rates with rootstock/scion combinations survival rates as follows; *S. melongena* + Anna F1 (96.7%), *S. melongena* + Cal J (83.3%), *S. incarnum* + Anna F1 (73.3%), *S. incarnum* + Cal J (100%), and Mt56 + Anna F1 (93.30%), Mt56 + Cal J (76.7%). All the graft unions performed well except those on Sodom apple rootstock. There was a variation in the rate of expansion of the scion and Sodom apple rootstock. Another study in Kirinyaga county by Ignatius, (2018) reported a successful grafting of Anna F1 and Cal J scions onto a wilt-resistant tomato cultivar (Mt56). Tomato cultivars well adapted to the greenhouse environment (Anna F1) and one grown under field conditions (Cal J) were used as the scions. Anna F1 grafted plants had a higher percentage of survival rate and reduced disease severity than the grafted Cal-J and nongrafted controls. Another study in Kiambu, Karen, Isinya, and Ruiru by Onduso, (2014) entailed Anna F1scion on Cheong gang, Shin cheong gang, and a wild tomato variety rootstock where there was a reduction in bacterial wilt incidence by 92%, 95%, and 64% respectively. Cheong gang and Shin cheong gang grafted plants had the lowest bacterial wilt disease incidence, leading to higher tomato yield than the non-grafted control.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental design and planting materials

The experiment was laid out in a complete randomized block design with six treatments (control and five grafted rootstocks), each replicated three times for both varieties as shown in Figure 3.1 below. The scions used in this study were Anna F1 and Cal-J, indeterminate hybrid tomato varieties preferred by Kenya farmers due to their fast maturity, higher yields, and deep red colored fruits, but they are susceptible to bacterial wilt. They were subjected to intraspecific grafting onto two commercially available hybrid tomato rootstocks resistant to bacterial wilt (Armada and B.B from Takii Seed, Kyoto, Japan). In the second experiment, Anna F1 and Cal-J scions were grafted on three African eggplant accessions (*Solanum aethiopicum L.*) rootstocks; Manyire Green, AB2, and Sangawiri. The African eggplant rootstocks were obtained from the World Vegetable Centre, Arusha, Tanzania. In our previous study, these African eggplant rootstocks had shown compatibility with Anna F1 and Cal-J and showed resistance to bacterial wilt under both laboratory and field conditions. Non-grafted Anna F1 and Cal-J were used as controls. The Anna F1 and Cal-J seeds were sown in germination trays filled with media at a ratio of 2:1:1 peat moss: perlite: vermiculite (v/v) and germinated in an 8 by 10 inches greenhouse in JKUAT with a temperatures range of 26 - 28 ◦C and relative humidity of 95%.

The tomato rootstock seeds were initially sown, then two weeks later; the scions were sown to ensure similar stem diameters during grafting. The African eggplant rootstocks grew much more slowly and reached the desired grafting diameter in 21-30 days. Rootstock and scion seedlings at similar growth stages and/or matching stem diameters were selected and grafted using the cleft grafting technique, most commonly used on solanaceous crops. For both varieties, in each of the independent experiments, forty plants per graft combination were transferred into pots (25 L) in a greenhouse after the grafts had been established (2 weeks after grafting). Plants were grown in the pots, and all cultural practices recommended for tomato cultivation under greenhouse conditions were adopted uniformly according to crop requirements. Figure 3.2 shows an overview of grafting to the maturity of the tomatoes in the JKUAT greenhouse.

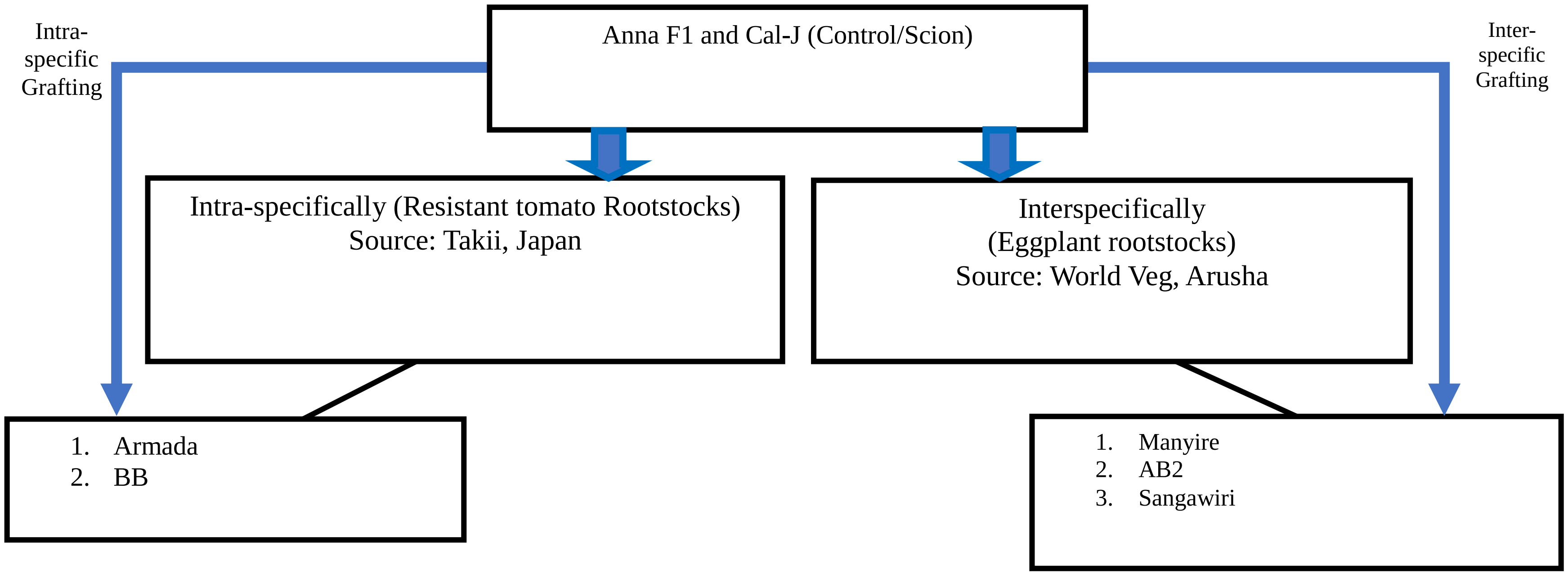

Figure 3.1: Schematic illustration of intra- and interspecific grafting

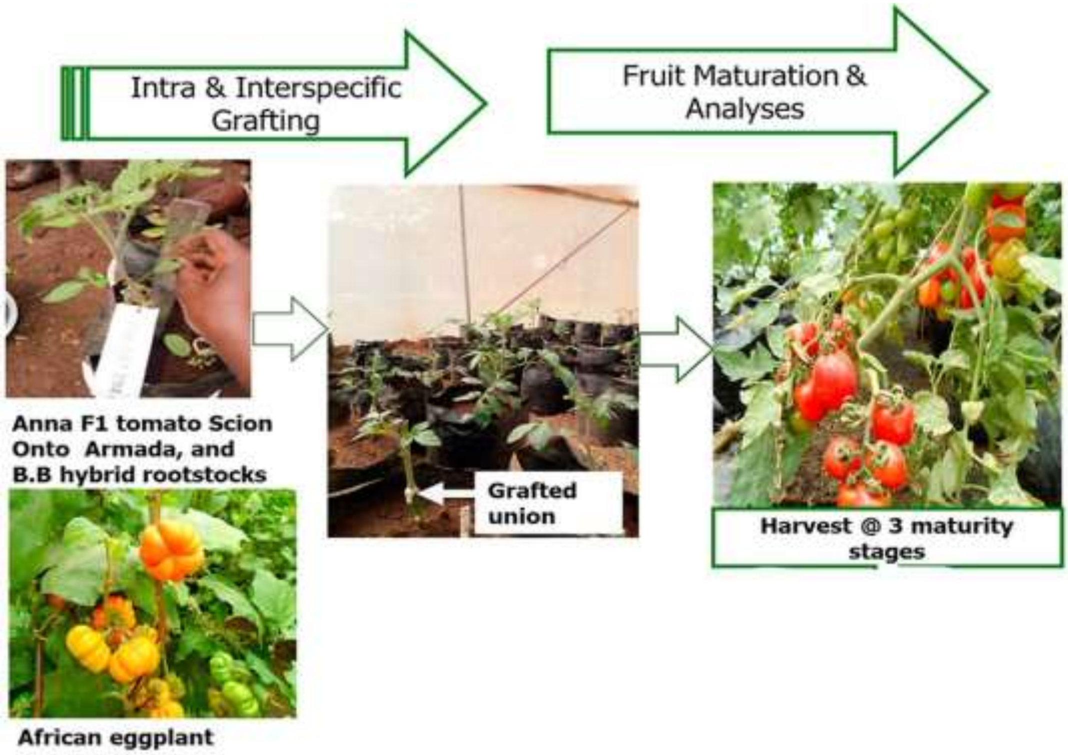

Figure 3.2: Grafting of tomato plants and tomato maturity at the at three stages (mature green, turning, and ripe) in the JKUAT greenhouse

Tomatoes were harvested at three maturity stages: mature green, turning, and red ripe, which were determined as 28, 40, and 45 days after flowering, respectively. All the tomatoes harvested at the specific stage were similar in shape and size and without defects. They were taken to the Postharvest Laboratory at JKUAT, where they were washed with distilled water and wiped to remove surface moisture. They were then stored separately in plastic crates at room temperature (approximately 25 ^{o} C) till the following day and subjected to specific analyses.

The analysis for weight loss, color, texture, respiration, ethylene production rates, vitamin C, and lycopene was done from day zero until day 14 (most of the tomatoes were rotten on this day). Size, weight, and sensory evaluation analyses were only done on day zero. Figure 3 shows a flow diagram of the overall methodology.

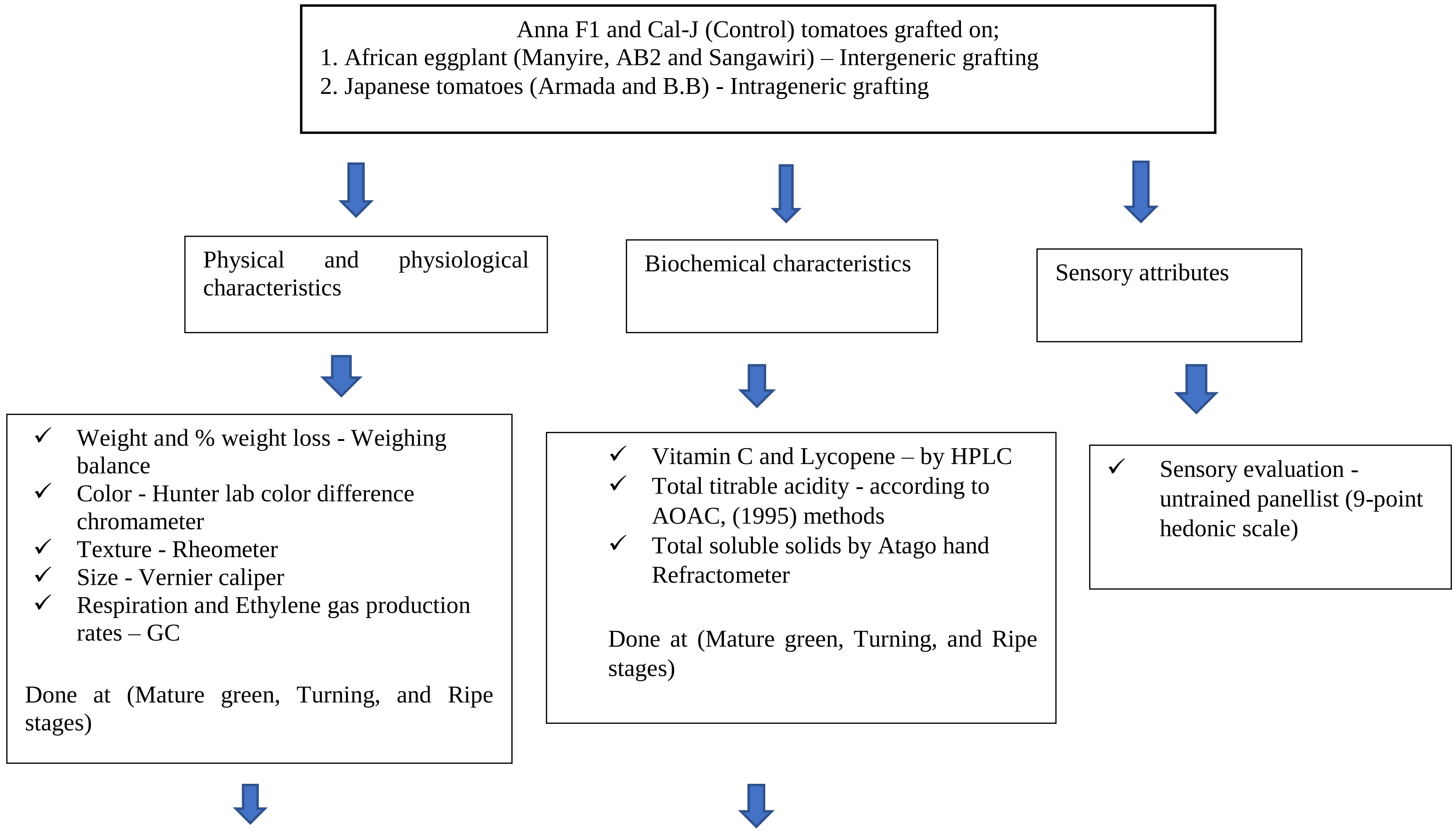

Figure 3.3: Schematic illustration of the experimental approach of the study

3.2 Physical characteristics

3.2.1 Size

The length and width of fifty tomatoes at each maturity stage were measured in centimeters using a Vernier caliper. The final dimension measurement was the average of the fifty fruits. The length was considered the longest side of the tomato while width was considered the shortest side of the tomato fruit.

3.2.2 Weight

The weight of fifty tomato fruits at each maturity stage was determined using a digital weighing scale (model SF-400D digital). The final weight was the average of fifty fruits.

3.2.3 Weight loss

Five tomatoes from each rootstock and control were marked and weighed on a digital weighing scale. The tomatoes stored at room temperature (approximately 25°C) were weighed at an interval of 2 days for 14 days. Weight loss of the tomatoes was calculated in percentage, as shown in equation 3.1 below.

$$\%\ Weight\ loss = \frac{Initial\ Weight\ - Final\ Weight}{Initial\ Weight} * 10 \qquad \text{Equation 3.1}$$

3.2.4 Texture

A benchtop rheometer (Sun rheometer compact -100, Japan) was used to determine the texture of tomato samples according to the method described by Milenković et al., (2019). The equipment was fitted with a cylindrical probe of 5 mm to the load cell of 10 kg at a probe speed of 6 mm/s diameter. Five tomatoes were each measured through a puncture test at three points along their equatorial region. The texture was expressed as force in Newtons (N) and the final texture was the average of the five fruits. Texture of the tomatoes was measured at an interval of 2 days for 14 days.

3.2.5 Color

Color of the tomatoes was determined using a hunter lab color difference chromameter machine (Minolta, Tokyo, Japan) according to the method detailed by López Camelo and Gómez, (2004). A white and black ceramic plate was used to standardize the instrument every time for accuracy. Five tomatoes were each measured at four regions along the mid-section set apart at 90 ^{0}. The reflected L*, a*, and b* color values were recorded as displayed and then transformed to color hue angle values using the formula in Equation 3.2.

$$Hue\ angle\ (h°) = tan - 1(b*/a*)$$ …………………….. Equation 3.2

3.3 Biochemical and Nutritional characteristics

3.3.1 Lycopene content

Lycopene content of tomato samples was determined according to a method described by Mwende et al., (2018). Tomato sample was crushed into a paste using motor and pestle. About five grams of tomato paste was weighed into amber bottles. Fifty ml of hexane-acetone-ethanol solution in the ratio of 2:1:1 (v/v/v) with 1% BHT (w/v) was added for lycopene dissolution. The contents in the amber bottles were agitated for about 20 mins. Fifteen ml of distilled water was added to the mixture and agitated for 10 mins. The solution was then separated using a separating funnel. The upper hexane layer of 50 ml was collected and sieved through 0.45 µm pore size microfilter. About 20 µL sample was injected into the high-performance liquid chromatography, HPLC (20A model; Shimadzu Corp., Tokyo, Japan) comprising an auto sampler, UV-VIS detector (SPD 20A) at a wavelength of 450 nm, and a C-18 ODS column.

The mobile phase was acetonitrile: methanol: dichloromethane: hexane in the ratio 40:20:20:20 (v/v/v/v), set at a 1.5 mL/min flow rate. Various concentrations of lycopene standards were made to generate a standard curve for quantification of lycopene content in the tomato sample. Lycopene content was analyzed at an interval of 2 days till day 14.

3.3.2 Vitamin C content

Vitamin C content of tomato samples was determined according to a method described by Abushita et al., (1997). About five grams of the tomato was crushed into a paste using a mortar and pestle and transferred into centrifuge bottles. The samples were topped up to 30 mL with 0.8% metaphosphoric acid and centrifuged at 10000 rpm. The supernatant was filtered using a Whatman No 4-filter paper and diluted with 10 mL of 0.8% metaphosphoric acid, then sieved through a 0.45 µm pore size microfilter. The analysis was done using HPLC (20A model; Shimadzu Corp., Tokyo, Japan) comprising an auto sampler, UV-VIS detector (SPD 20A) at a wavelength of 266 nm, and a C-18 ODS column. The mobile phase was 0.8% metaphosphoric acid at a 0.9 mL/min flow rate.

Various concentrations of vitamin C standards were used to generate a standard curve for quantification of vitamin C content in the tomato samples. Vitamin C was carried out at an interval of 2 days till day 14.

3.3.3 Total soluble solids

Total soluble solids (TSS) content of tomato samples was determined by an Atago hand refractometer (Model 500, Atago, and Tokyo, Japan), and results were expressed as ^{o} Brix. Tomato juice was extracted in triplicates. The analysis was done at an interval of 2 days till day 14.

3.3.4 Total titratable acidity

Total titratable acidity (TTA) analysis was analyzed according to AOAC, (1995) methods (943.02 method number). The samples were homogenized using a pestle and mortar. About 5 grams of the sample was weighed. The sample of 10 ml was pipetted into a conical flask then 2 drops of phenolphthalein indicator added. Titration was done using 0.1N NaOH to a persisting faint pink color. The titre volume was recorded and used for the calculation of TTA using the formula in Equation 3.3. The analysis was done at an interval of 2 days till day 14.

$$\text{Titrable acidity \%} = \frac{\text{Vol.of 0.1 NaOH used} \times \text{Cconversion factor} \times 100}{\text{Volume of sample used}} \quad \text{…. Equation 3.3}$$

Where the conversion factor is the principal acid in tomato is citric acid = 0.064

3.4 Physiological properties

3.4.1 Ethylene production and respiration rates

Ethylene production and respiration rates were determined as described by Mwendwa et al., (2016). Five tomatoes were incubated for approximately one hour in 1000 ml air-tight containers sealed with rubber septa. The ethylene production rate was determined using a Gas chromatograph (Models GC-9A, Shimadzu Corp Kyoto, Japan) fitted with an activated alumina column and a flame ionization detector (220^{o} C). Gas chromatograph (GC-8A Shimadzu Corp Kyoto, Japan) fitted with a Poropak N column, and a thermal conductivity detector (150^{o} C) was used for carbon dioxide determination. Ethylene and carbon dioxide pure gas standards were used to quantify the production rates. The rate of carbon dioxide production (used to estimate respiration rate) was expressed as ml per Kg per hour at standard atmospheric pressure, while ethylene production was expressed as µl per Kg per hour, as described by (Mwendwa et al., 2016).

3.5 Sensory evaluation

Only the ripe tomatoes from the different rootstocks and control were analyzed. Sensory evaluation was carried out according to the method described by Auerswald et al., (1999) using 50 untrained panelists from the Department of Food Science in JKUAT. Sensory attributes, including firmness, sweetness, saltiness, juiciness, overall appearance, and overall acceptability, were evaluated. Tomatoes were chopped into pieces, coded with random numbers, and presented in random order to the panelists. Tomatoes were tasted and held in the mouth while chewing for 5 seconds. The panelists rinsed their mouths thoroughly between samples with provided water. Each attribute was scored based on its intensity scaled on a 9-point hedonic scale where; 9 - Like extremely, 8 - Like very much, 7 - Like moderately, 6 -

Like, 5 - Neither like nor dislike, 4 - Dislike, 3- Dislike moderately, 2 - Dislike very much, 1- Dislike extremely.

3.6 Statistical analysis

The data was subjected to analysis of variance (ANOVA) using STATA (version 12) to determine significant differences ($p < 0.05$). Post hoc analysis using Bonferroni test was then carried out to determine significant differences within means. Graphs were generated in Microsoft Excel.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical characteristics

4.1.1 Size

Both intra- and interspecific grafting (onto Manyire green and AB2 rootstocks) had a positive effect on the size of the tomato fruit in terms of length and width at all the stages of maturity (Table 4.1). Intraspecific grafting produced significantly larger fruits compared to the interspecific grafted fruits and the non-grafted control. However, interspecific grafting onto African eggplant accession, the Sangawiri rootstock, produced smaller-sized fruits as compared to the non-grafted control.

In general, Cal-J grafted fruits recorded the largest fruit size and were significantly different from the Anna F1 grafted fruits. At the mature green stage, fruits with the largest size were Cal-J grafted onto B.B rootstock (length 72.83±0.53 cm, width 52.80±0.53 cm). Fruits from Cal-J grafted onto Armada rootstock (length 74.00±0.56 cm, width 51.30±0.0.44 cm) had the highest fruit size at the turning stage and were not significantly different from those grafted onto Manyire, AB2, and B.B. Fruits from Cal-J grafted onto B.B rootstocks (length 79.53±0.65 cm, width 64.30±0.98 cm) had the highest in size at the red ripe stages. For both varieties in all three maturity stages, fruits grafted onto Sangawiri rootstocks had the smallest size.

Turhan et al., (2011) reported similar results where there was a significant difference in tomato length of fruits from grafted Yeni Talya/Beaufort and Yeni Talya/Arnold. This suggests that grafting effect on tomato fruits is dependent on the scion/rootstock combination.

Table 4.1: Length and width of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at three maturity stages

			Mature green		Turning		Ripe	
			Length (cm)	Width (cm)	Length (cm)	Width (cm)	Length (cm)	Width (cm)
		Control	57.20±0.82^{e}	40.61±0.51^{e}	58.41±0.31^{c}	40.70±0.24^{e}	61.00±0.77^{d}	42.50±0.84^{d}
Anna F1	Interspecific graft	Manyire	69.70±0.85^{c}	43.00±0.42^{c}	72.31±0.61^{a}	44.60±0.88^{c}	74.00±1.21^{a}	45.00±0.85^{b}
		AB2	68.74±0.93^{d}	42.23±0.54^{d}	71.10±0.77^{b}	43.25±0.56^{d}	73.00±0.80^{a}	43.43±1.29^{c}
		Sangawiri	56.00±0.27^{f}	40.01±0.97^{e}	54.40±0.92^{d}	39.96±1.55^{e}	60.20±0.99^{e}	41.20±1.00^{e}
	Intraspecific graft	Armada	72.10±0.30^{a}	50.60±0.46^{b}	72.30±0.92^{a}	51.8±0.68^{b}	77.30±1.06^{c}	64.20±0.83^{a}
		B. B	70.50±0.65^{b}	51.61±0.43^{a}	72.00±1.05^{a}	53.61±1.31^{a}	78.20±0.88^{b}	63.62±1.03^{a}
Cal-J	Interspecific graft	Control	57.90±0.35^{c}	41.50±0.47^{d}	59.20±0.42^{d}	41.30±0.36^{d}	60.30±0.63^{e}	42.10±0.38^{d}
		Manyire	70.10±0.62^{b}	42.30±0.52^{c}	72.50±0.49^{b}	43.20±0.56^{c}	75.40±1.01^{a}	44.20±0.85^{b}
		AB2	70.01±0.86^{b}	43.81±0.31^{c}	71.60±0.69^{c}	43.50±0.66^{c}	75.00±0.50^{c}	43.60±1.12^{c}
		Sangawiri	57.10±0.53^{d}	40.30±0.56^{e}	57.60±0.49^{e}	41.70±1.55^{d}	64.70±0.45^{d}	40.20±0.99^{e}
	Intraspecific graft	Armada	71.38±0.43^{a}	51.02±0.52^{b}	74.00±0.56^{a}	51.30±0.44^{b}	77.90±1.02^{b}	65.00±0.69^{a}
		B. B	72.83±0.53^{a}	52.80±0.53^{a}	72.00±1.01^{b}	54.21±1.33^{a}	79.53±0.65^{a}	64.30±0.98^{a}

Values are mean ± standard deviation, n=50. Means with different superscript letters in the same column are significantly different at $p \leq 0.05$.

4.1.2 Weight

Similarly, for both Anna F1 and Cal-J, intra- and interspecific grafting led to a significant increase in the average fruit weight compared to non-grafted control at all the three maturity stages (Table 4.2). Intraspecific grafting produced significantly heavier fruits than the interspecific grafting. Also, there was no significant difference in the fruit weight of Anna F1 and Cal-J varieties. Fruits from Cal-J grafted onto B.B rootstock had the highest weight (91.11±1.03 g) at the mature green stage. Fruits from Cal-J on Armada rootstock had the highest weight (106.42±1.43 g) at the turning stage, while Anna F1 grafted on Armada rootstock reported the highest fruit weight (108.40±1.54 g) at the red ripe stage. Both Anna F1 and Cal-J grafted onto Sangawiri rootstock had the lowest weight at all the three maturity stages. Similar results were reported by Soare et al., (2018), where tomato fruits from 'Lorely F1'/'Beaufort' intraspecific scion-rootstock combination had higher weights than non-grafted control.

Table 4.2: Weight of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at three maturity stages

			Mature greenweight (g)	Turningweight (g)	Ripeweight (g)
		Control	62.40±1.37^{d}	64.10±0.70^{d}	71.60±0.80^{e}
Anna F1	Interspecific graft	Manyire	81.30±1.17^{c}	98.60±0.74^{b}	101.00±1.47^{c}
		AB2	80.70±1.44^{c}	95.90±1.62^{c}	94.90±1.66^{d}
		Sangawiri	60.10±1.89^{e}	61.50±1.99^{e}	67.60±1.77^{f}
	Intraspecific graft	Armada	89.30±1.04^{b}	103.20±1.79^{a}	108.40±1.54^{a}
		B. B	90.20±0.96^{a}	102.60±0.97^{a}	105.10±1.81^{b}
Cal-J	Interspecific graft	Control	63.10±1.11^{d}	64.90±0.30^{d}	72.33±0.40^{e}
		Manyire	82.00±1.13^{c}	98.90±0.86^{b}	98.93±1.32^{c}
		AB2	81.63±1.42^{c}	96.45±1.13^{c}	96.47±1.41^{d}
		Sangawiri	62.10±1.08^{d}	63.56±1.22^{d}	63.58±1.52^{f}
	Intraspecific graft	Armada	89.70±1.05^{b}	106.40±1.35^{a}	106.42±1.29^{a}
		B. B	91.11±1.03^{a}	105.40±0.37^{a}	105.44±1.93^{b}

Values are mean ± standard deviation, n=50 per rootstock. Means with different superscript letters in the same column are significantly different at $p \leq 0.05$.

4.1.3 Weight loss

The weight loss of the harvested fruits was monitored for up to 14 days under normal room temperature conditions (20 – 22 ^{o} C). For both Anna F1 and Cal-J varieties, the non-grafted control fruits had the highest percentage weight loss compared to the grafted fruits on day 14. There was a significant difference in weight loss of intra and interspecific grafted fruits analyzed except for the Sangawiri grafted fruits. Intraspecific grafting produced fruits with significantly lower weight loss, and this might be due to the slow metabolism process in the grafted fruits. There was a significant difference in the weight loss of the grafted Anna F1 and Cal-J fruits, as shown in Figure 4.1a, b, and c, with Cal-J variety having higher weight loss. There was also a significant difference between fruits from non-grafted Cal-J and all the grafted fruits in all the three maturity stages. However, fruits from grafted Manyire, AB2, Armada, and B.B did not differ significantly (Fig 4.1a, b, and c). The non-grafted Cal-J control reported the highest percentage weight loss of 5.56% at the ripe stage. The Cal-J fruits interspecifically grafted on Sangawiri rootstock reported the second highest weight loss of 4.80%, while the Anna F1 fruits grafted onto Armada rootstocks had the least weight loss of 0.83% at the ripe stage (Figure 4.1a, b, and c). These results differed from those reported by Ozturk & Ozer, (2019), who observed a higher percentage weight loss in tomatoes derived from grafted plants than those from non-grafted control.

From these results, the effect of grafting on tomato weight loss is dependent on the scion/rootstock combination used. Lower weight loss in grafted tomatoes may have been due to tough skins/texture that decelerates the ripening process (Al-Harbi et al., 2017). Lower weight loss results in intraspecific grafted tomatoes in this study related with the tougher/high texture results that were associated with decelerating the metabolism rate hence prolonging shelf-life. The texture of tomato fruits can affect the rate of weight loss during storage. Tomatoes with a softer texture are more prone to weight loss compared to those with a firmer texture. Softer tomatoes have a higher water content and are more susceptible to damage and dehydration during handling and storage. As the water is lost, the tomato shrinks in size, resulting in weight loss (Cheng et al., 2022). The turning and ripe stages had different trends than the mature green stage. This might be due to tomatoes at the turning stage still ripening thus higher water content as a result, they may lose more weight during storage or transportation. Also, tomatoes at ripe stage are softer and more prone to damage during handling, which can also contribute to higher weight loss. On the other hand, mature green tomatoes are firmer and more resistant to damage, which may result in less weight loss during transportation.

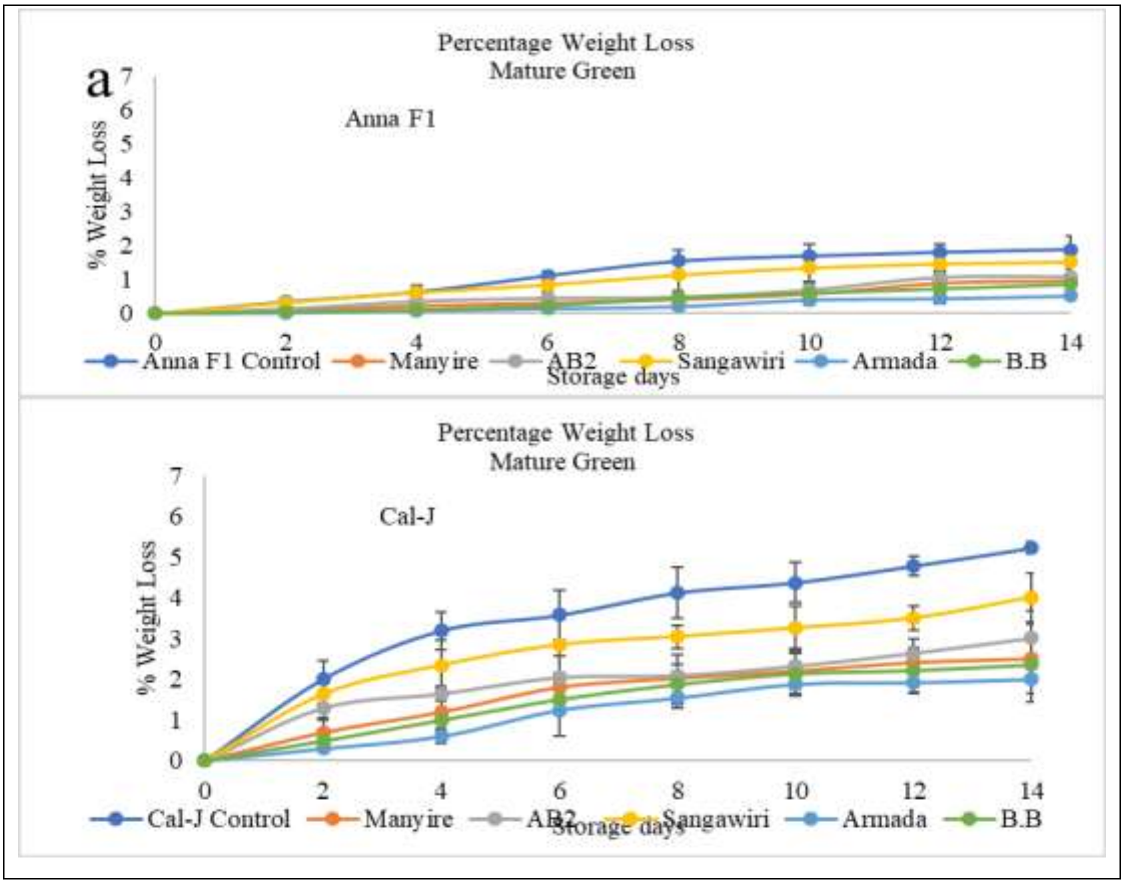

Figure 4.1a: Percentage weight loss (%) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

Figure 4.1b: Percentage weight loss (%) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

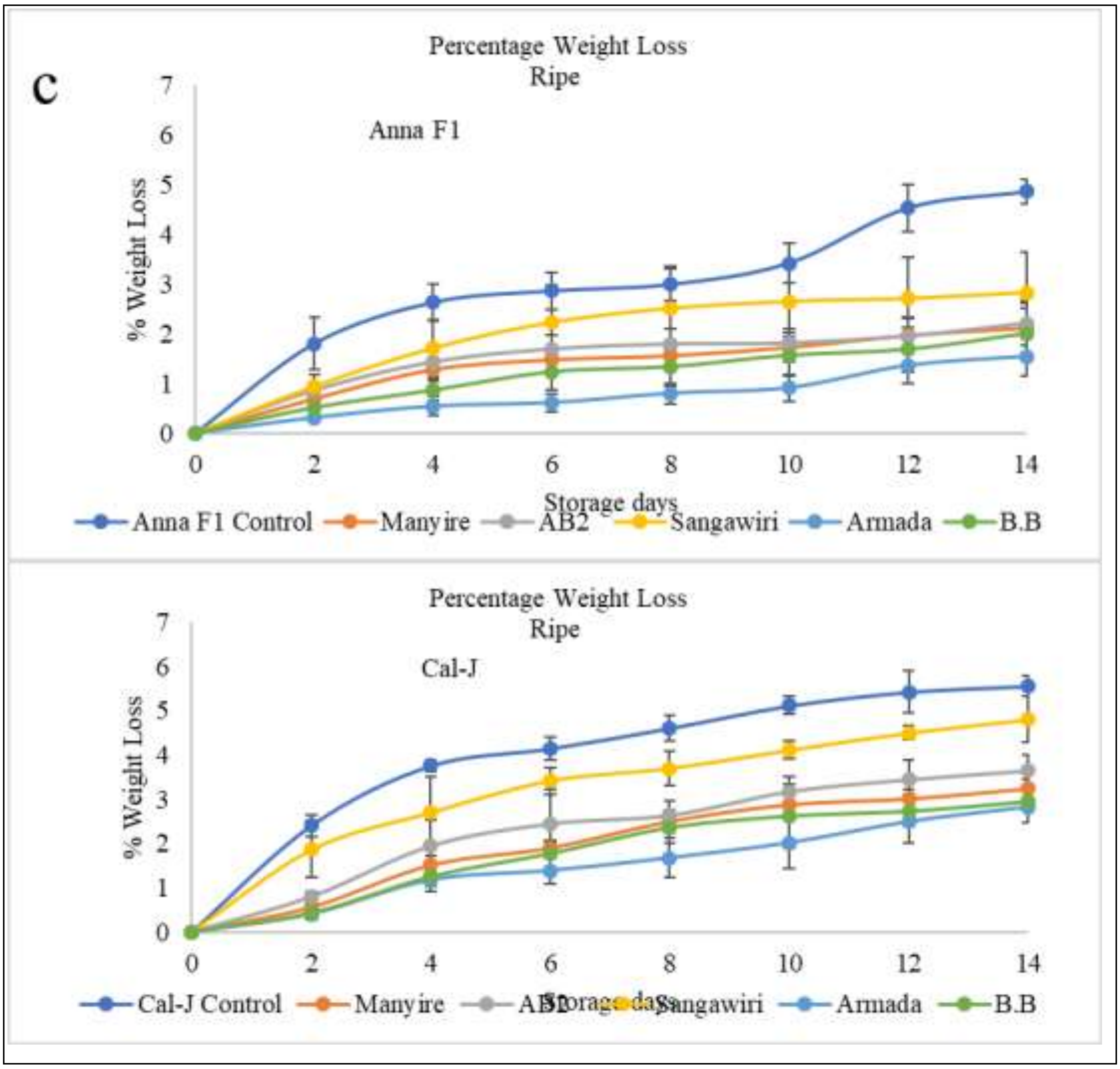

Figure 4.1c: Percentage weight loss (%) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.1.4 Texture

Firmness influences consumer preferences. In this study, there was no significant difference in the texture of grafted Anna F1 and Cal-J fruits. The highest firmness loss at mature green stage was observed in non-grafted Anna F1 control fruits (Figure 4.2a), which ranged from 4.56 to 2.00 N mm^{-1}, while fruits from Cal-J grafted onto Sangawiri rootstock showed the second highest firmness loss ranging from 3.90 to 1.09 N mm^{-1} and 3.26 to 0.54 N mm^{-1} at the turning and the red ripe stage respectively (Figure 4.2b, 4.2c). Fruits from Anna F1 grafted onto B.B rootstock showed the least firmness loss ranging from 6.64 to 4.99 N mm^{-1}, 6.11 to 4.06 N mm^{-1}, and 5.56 to 3.09 N mm^{-1} at the mature green, turning and the red ripe stage respectively (Figure 4.2a, b, and c). The firmness of fruits from Sangawiri rootstock grafts was not significantly different from the non-grafted control ($p < 0.05$) for both Anna F1 and Cal-J fruits.

On the other hand, there was a significant difference ($p < 0.05$) in the firmness of non-grafted control fruits from fruits grafted onto AB2 and those grafted onto Manyire at the three maturity stages. Grafted fruits from Manyire, AB2, Armada, and BB produced much firmer fruits, but they were not significantly different. These results varied from Grieneisen et al., (2018), who observed no significant difference in texture/firmness of grafted and non-grafted tomato fruits. Firmer grafted tomatoes are most likely due to the differences in hormone status and nutrient uptake by the rootstocks, thus, slower and gradual rate of loss in firmness (Davis et al., 2008).

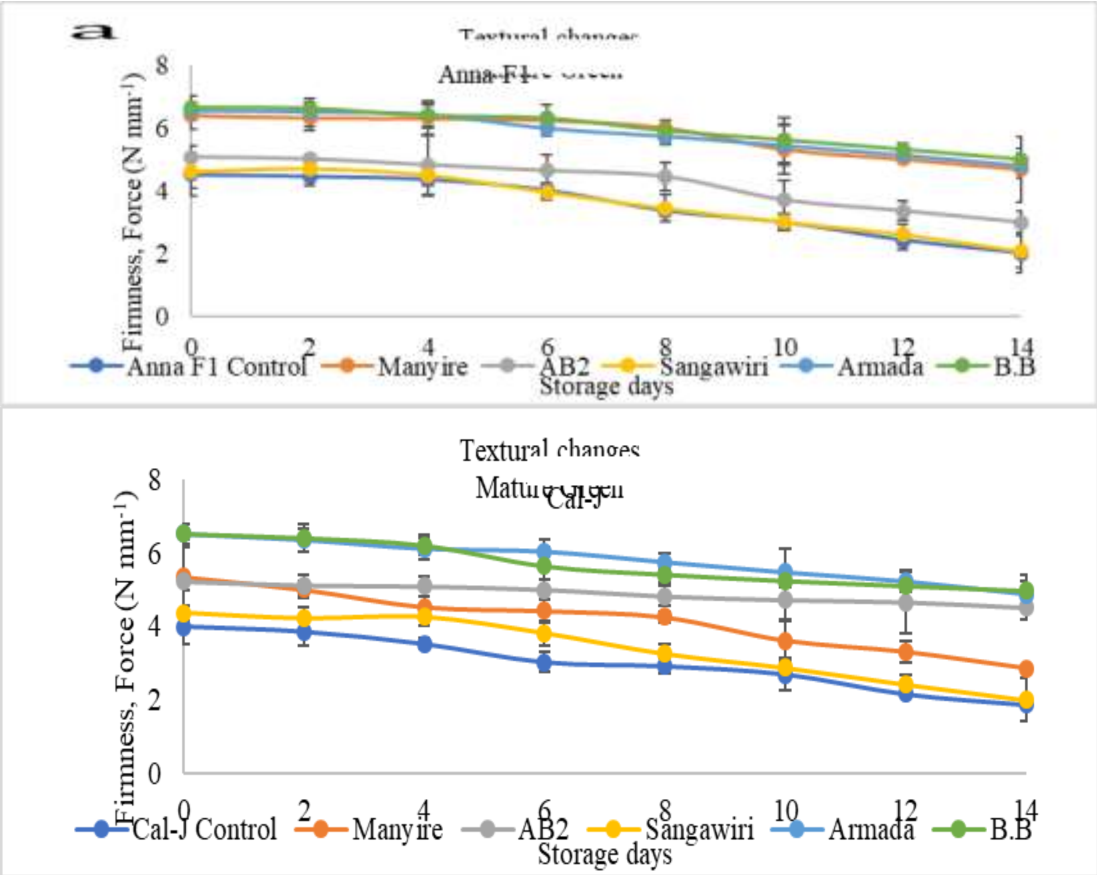

Figure 4.2a: Changes in firmness (Nmm-[1]) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

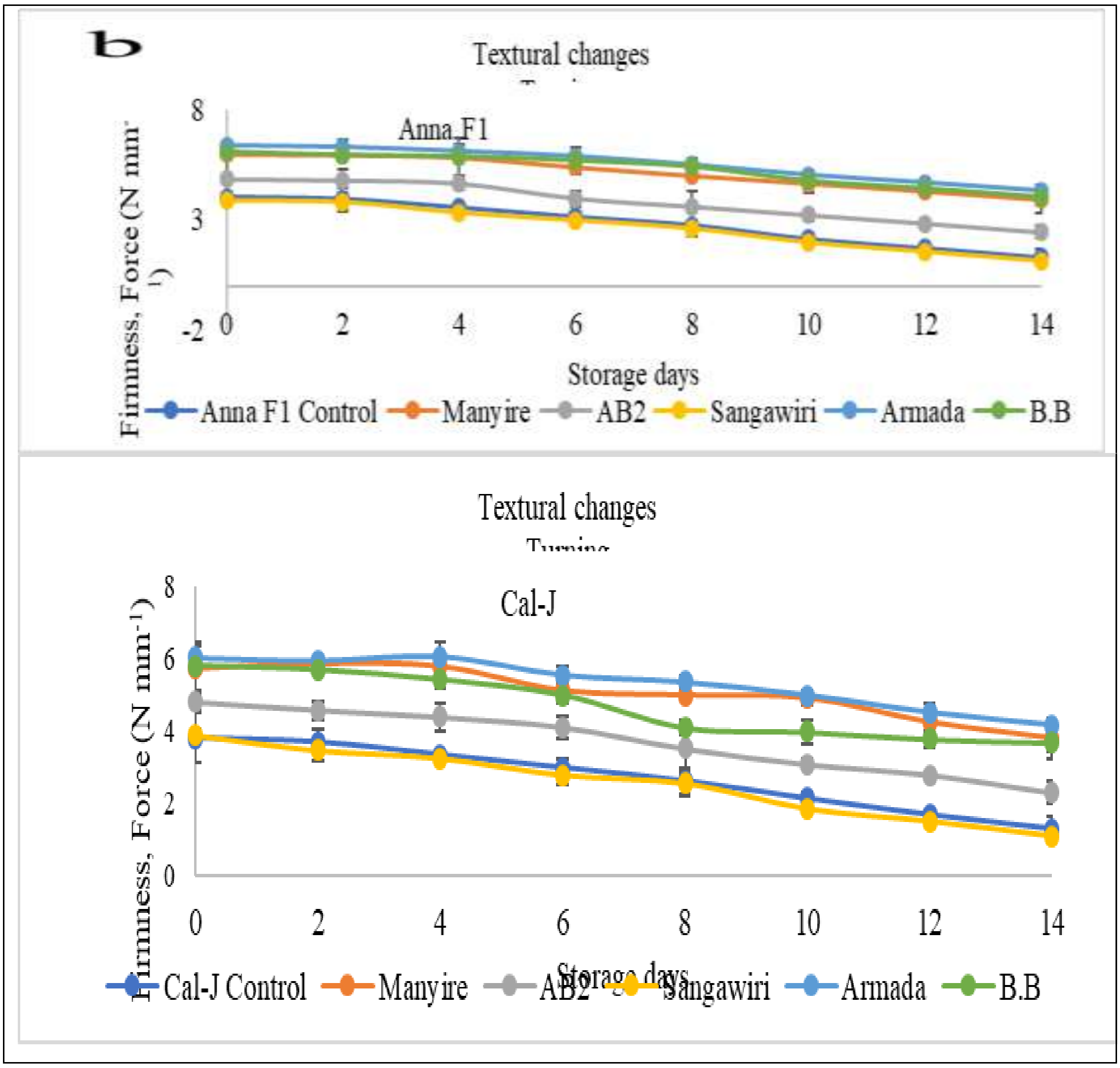

Figure 4.2b: Changes in firmness (Nmm^{-1}) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

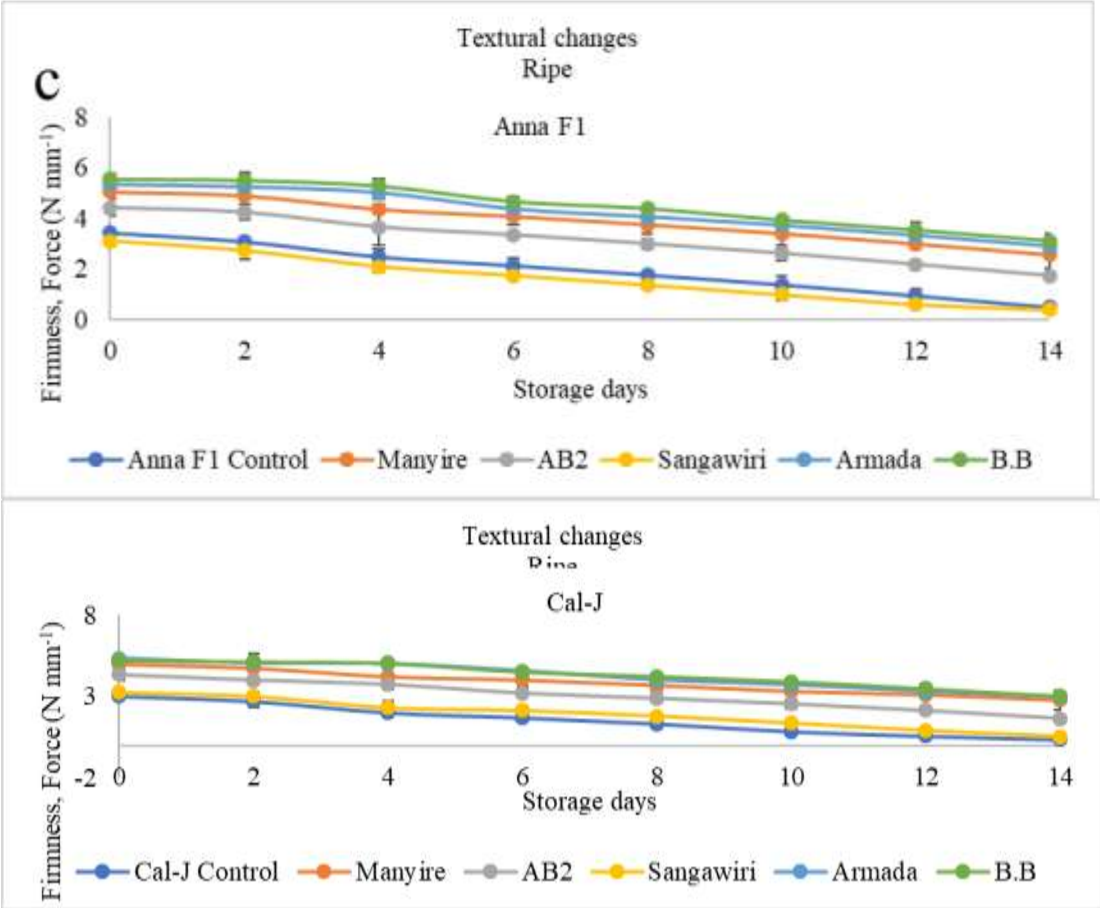

Figure 4.2 c: Changes in firmness (Nmm^{-1}) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.1.5 Color

Color is a maturity index that indicates stages of ripeness. The hue angle is a measure of color that describes the degree of redness, yellowness, and blueness of an object (Dari *et al.*, 2018). A greater color change was observed in tomatoes harvested at the mature green stage than those harvested at the turning or ripe stages (Table 4.3). This is attributed to rapid chlorophyll degradation as ripeness in tomato fruits progresses, which leads to lycopene accumulation that gives tomato fruit a deep red color (Su *et al.*, 2015).

In general, Cal-J fruits reported higher change in the hue angle as compared to Anna F1 fruits but were not significantly different. Fruits from Cal-J grafted onto Sangawiri rootstocks had the highest change in hue angle at mature green (81.25 ° to 38.59 °) and turning stage (64.22 ° to 36.20 °). On the other hand, fruits from Anna F1 grafted onto Armada rootstock had the lowest change in hue angle at the mature green (76.55 ° to 39.26 °) stage. In general, as observed in this study, grafted tomatoes exhibited a slower color change compared to the non-grafted control, leading to a longer postharvest life. A slower color change in tomato fruits is desirable since it indicates prolonged shelf life (Mwendwa et al., 2016). These results varied from those observed by Qaryouti et al., (2007), who observed no effect on color change in fruit with grafting.

Table 4.3: Hue angles (º) of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at three maturity stages

			Mature green		**Turning**		**Ripe**	
			Hue angle (º)		Hue angles (º)		Hue angles (º)	
			Day 0	**Day 14**	**Day 0**	**Day 14**	**Day 0**	**Day 14**
Anna F1	Interspecific graft	Control	77.02±0.31	38.03±0.30	61.43±0.34	35.91±0.35	41.31±0.22	33.78±0.29
		Manyire	76.35±0.34	38.00±0.31	60.88±0.27	36.02±0.30	41.33±0.28	32.56±0.24
		AB2	72.81±0.20	39.58±0.34	63.11±0.39	35.92±0.28	41.20±0.34	33.05±0.53
		Sangawiri	80.23±0.27	37.44±0.40	60.11±0.35	36.04±0.24	44.54±0.35	31.66±0.31
	Intraspecific graft	Armada	76.55±0.34	39.26±0.32	62.36±0.28	36.36±0.32	43.33±0.33	33.71±0.31
		B. B	75.01±0.26	40.03±0.36	64.55±0.41	37.54±0.33	42.72±0.26	33.06±0.35
Cal-J	Interspecific graft	Control	80.10±0.24	39.15±0.41	61.96±0.39	36.37±0.31	42.05±0.15	34.22±0.33
		Manyire	79.26±0.29	39.29±0.33	61.14±0.55	37.51±0.34	42.58±0.27	32.91±0.40
		AB2	74.33±0.31	39.89±0.32	64.01±0.19	36.14±0.35	41.95±0.31	33.25±0.36
		Sangawiri	81.25±0.41	38.59±0.36	64.22±0.38	36.20±0.29	44.93±0.27	31.41±0.37
	Intraspecific graft	Armada	78.82±0.29	40.01±0.28	62.94±0.33	37.16±0.31	44.09±0.15	34.21±0.32
		B. B	76.98±0.39	40.11±0.30	63.21±0.34	38.23±0.40	43.06±0.16	34.12±0.46

Values are presented as mean ± standard deviation, n=5 fruits per rootstock, and control

4.2 Biochemical characteristics

4.2.1 Lycopene content

Lycopene is a pigment responsible for the red color of fruits during ripening (Helyes et al., 2009). Determination of the effect of grafting on lycopene content is indicated in Figure 3a, b, and c. In this study, there was no significant difference ($p < 0.05$) in the lycopene content of the grafted fruits and the non-grafted control at harvest in each maturity stage. However, with progress in maturity, the lycopene content increased. There was no significant difference in the lycopene content of the grafted Anna F1 and Cal-J fruits. There was also no significant difference in the lycopene content of all the grafted fruits and the control in the three maturity stages. At harvest, lycopene content was highest in Cal-J grafted onto Sangawiri rootstock fruits at mature green (4.11 mg/100g), turning (10.58 mg/100g), and ripe (14.44 mg/100g) stages. During storage, lycopene content in these fruits increased up to day 8 and reached a maximum of 12.66 mg/100g, 23.25 mg/100g, and 26.12 mg/100g at mature, turning, and ripe stages, respectively (Figure 4.3a, b, and c). Lycopene concentration in tomatoes begins to decrease after harvest as a result of exposure to light, oxygen, and temperature changes. This degradation can cause a decline in lycopene content over time, which is why the results of lycopene content analysis with storage follow a sigmoidal curve (Sikorska-Zimny et al., 2019). In this study, there was a relation in the color changes and the lycopene content results where fully red ripe fruits had higher lycopene accumulation. As tomatoes ripen, the lycopene content increases, leading to a shift in hue angle from green to red. This means that as the tomatoes mature, their hue angle decreases becoming less yellow and more red due to the increasing amount of lycopene present. There is a strong positive relation between lycopene content and hue angle of tomato color changes.

For instance, as the lycopene content of a tomato increases, the hue angle decreases, and the tomato becomes more red (Brandt et al., 2006).

Previous studies have reported varying results on the effect of grafting on the lycopene content of tomatoes. For instance, Karaca et al., (2012) recorded the highest lycopene content in the YeniTalya/Anorld combination and the lowest content in Beril/Anorld combination. They concluded that the effect of grafting on tomato lycopene content was dependent on the scion/rootstock combination. In another study, Scandinavica et al., (2013) reported lower lycopene content in grafted tomatoes compared to non-grafted control fruits. Soare et al., (2018b) also reported a significantly ($p < 0.05$) lower lycopene content in grafted tomatoes than in non-grafted tomatoes.

Lycopene content increases with ripening because chloroplasts are transformed into chromoplasts. (Su et al., 2015). Temperature influences lycopene biosynthesis (Nicoletto et al., 2013). In this study, the grafted and control tomatoes were grown in the same greenhouse under the same temperature and light conditions, which could have resulted in similar lycopene content in all the fruits at each maturity stage.

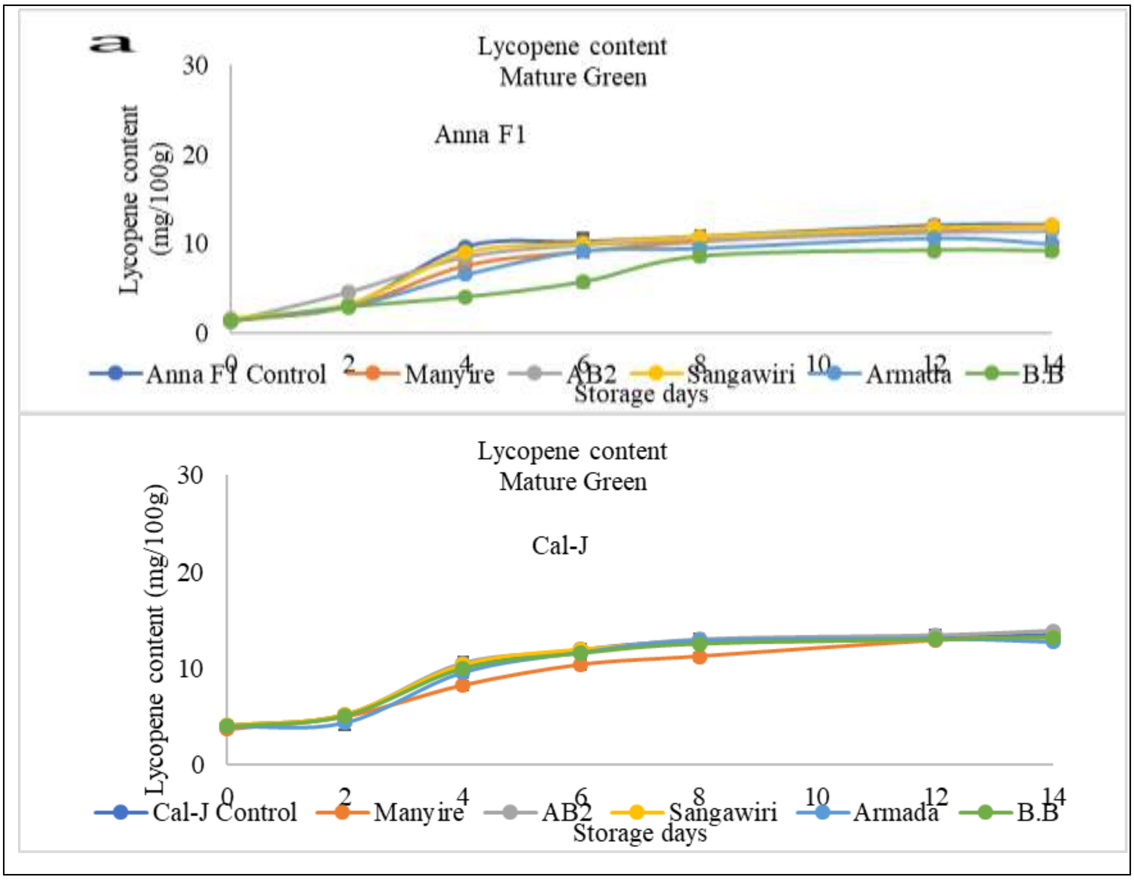

Figure 4.3a: Change in lycopene content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

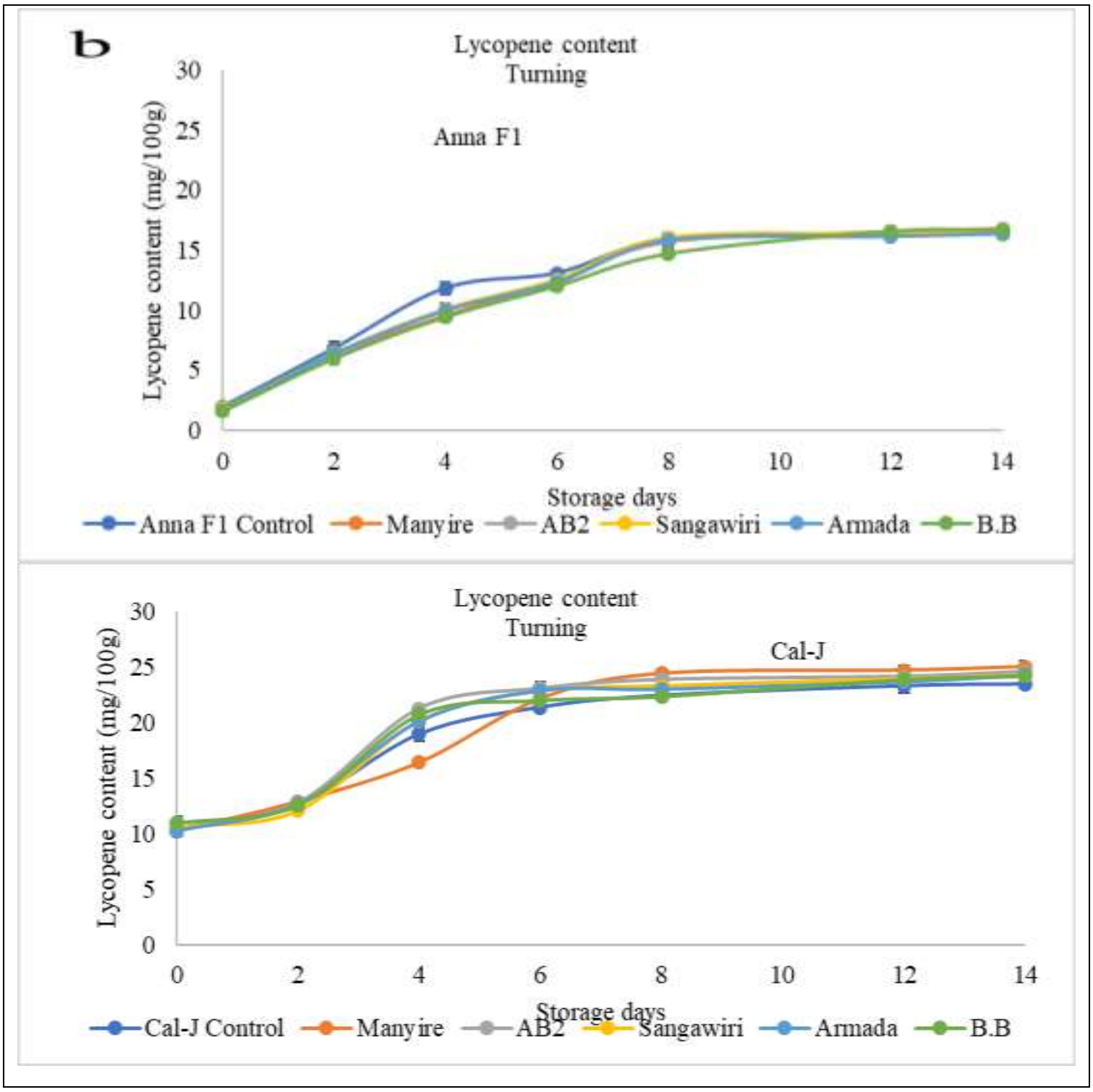

Figure 4.3b: Change in lycopene content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

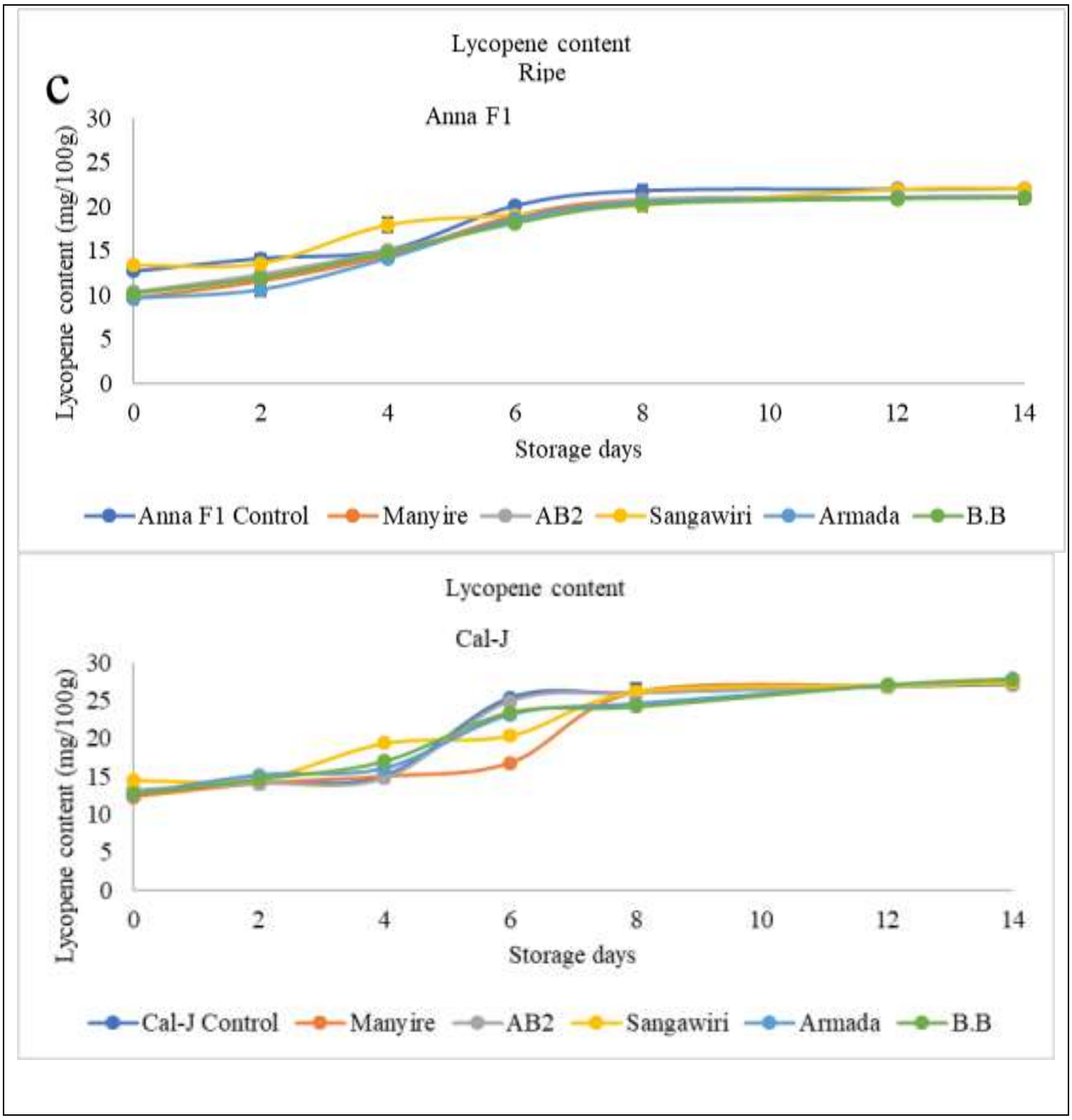

Figure 4.3c: Change in lycopene content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.2.2 Vitamin C content

In this study, vitamin C content of Anna F1 and Cal-J grafted fruits were not significantly different. The highest vitamin C content was observed in Anna F1 interspecific grafted fruits from B.B rootstocks at mature green (18.23 mg/100g) and red ripe (28.11 mg/100g) stages. Cal-J grafted fruits from Armada rootstocks reported the highest vitamin C content (18.69 mg/100g) at the turning stage (Figure 4.4a, b, and c). On the other hand, non-grafted Cal-J control had the lowest vitamin C content (8.15 mg/100g) at the mature green stage, while fruits from Cal-J grafted onto Sangawiri rootstocks had the lowest vitamin C content of 13.25 mg/100g and 16.0 mg/100g at the turning and ripe stage respectively (Figure 4.4a, b, and c). At the ripe stage, vitamin C content in Anna F1 grafted fruits declined, with storage reaching 15.88 mg/100g, 20.0 mg/100g, and 6.84 mg/100g at day 14 in Armada, BB, and Sangawiri rootstock grafts, respectively (Figure 4.4c). From this study, the intraspecific grafted fruits of B.B and Armada reported significantly higher vitamin C content compared to the non-grafted controls. However, the Vitamin C content in the fruits of interspecific grafted rootstocks was not significantly different from the non-grafted controls in all the three maturity stages. From the study, ripe stage had the highest vitamin C levels than all the stages and, it decreased with storage. Ahamd & Sarbibi et al., (2019) reported that tomatoes at the ripe stage have higher levels of vitamin C since as they ripen, they undergo a series of biochemical changes that lead to the accumulation of vitamin C. Specifically, the levels of enzymes involved in the synthesis of vitamin C increase, leading to an increase in the overall Vitamin C content of the fruit. However, after harvest vitamin C levels diminishes with storage since are highly unstable.

Different studies have reported variable effects of grafting on the vitamin C content of tomato fruit. Qaryouti et al., (2007) reported that the vitamin C content of fruits from the interspecific grafts of Beaufort, Titron, 8411, and R801 rootstocks was not significantly different from the non-grafted control. Another study by Hamdan et al., (2007) reported significantly lower vitamin C content in grafted fruits from He-man and Spirit rootstocks compared to the non-grafted control. In addition, Ibrahim et al., (2014) reported improved vitamin C content in fruits from Unifort rootstock compared to the non-grafted control. These studies and the present study indicate that the tomato vitamin C content is dependent on the scion-rootstock combination.

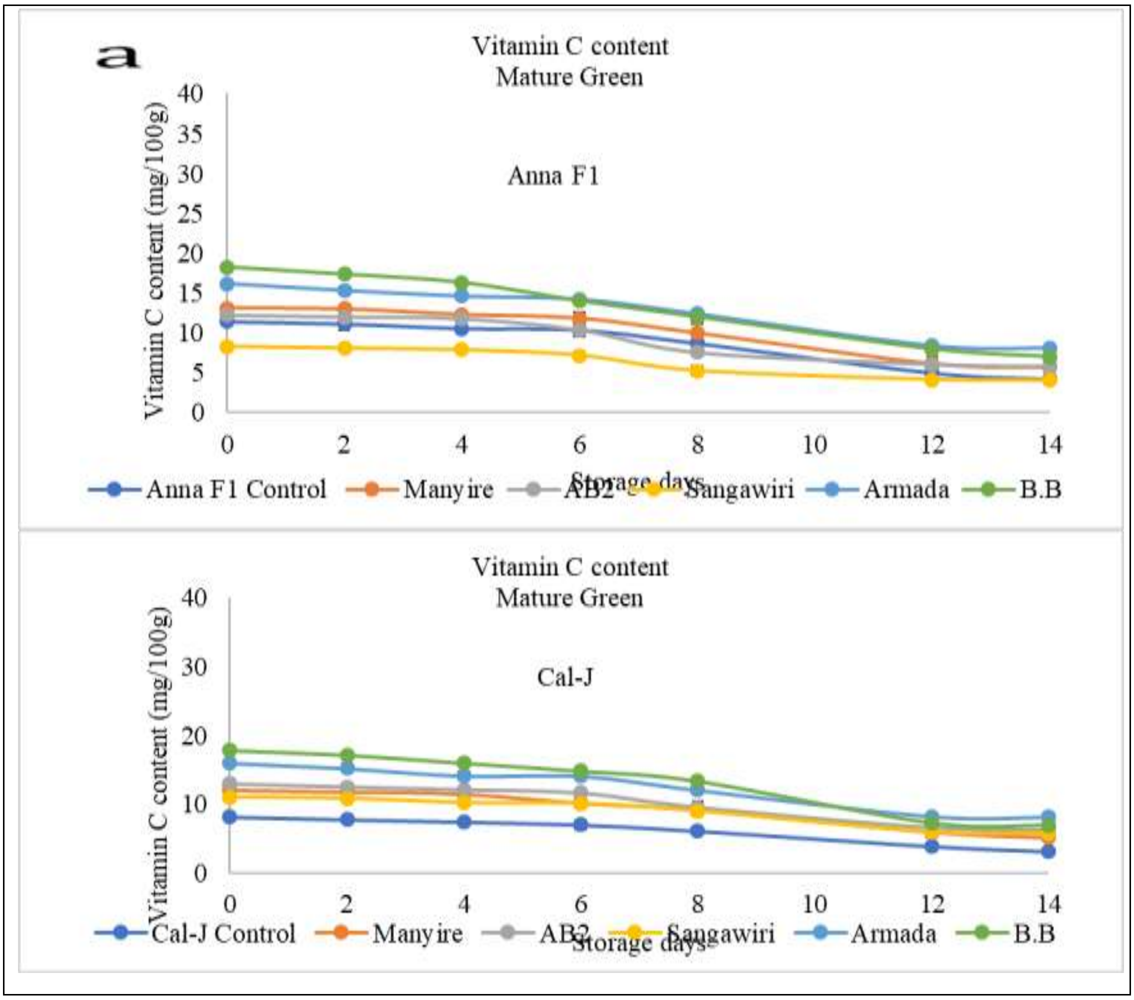

Figure 4.4a: Changes in vitamin C content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

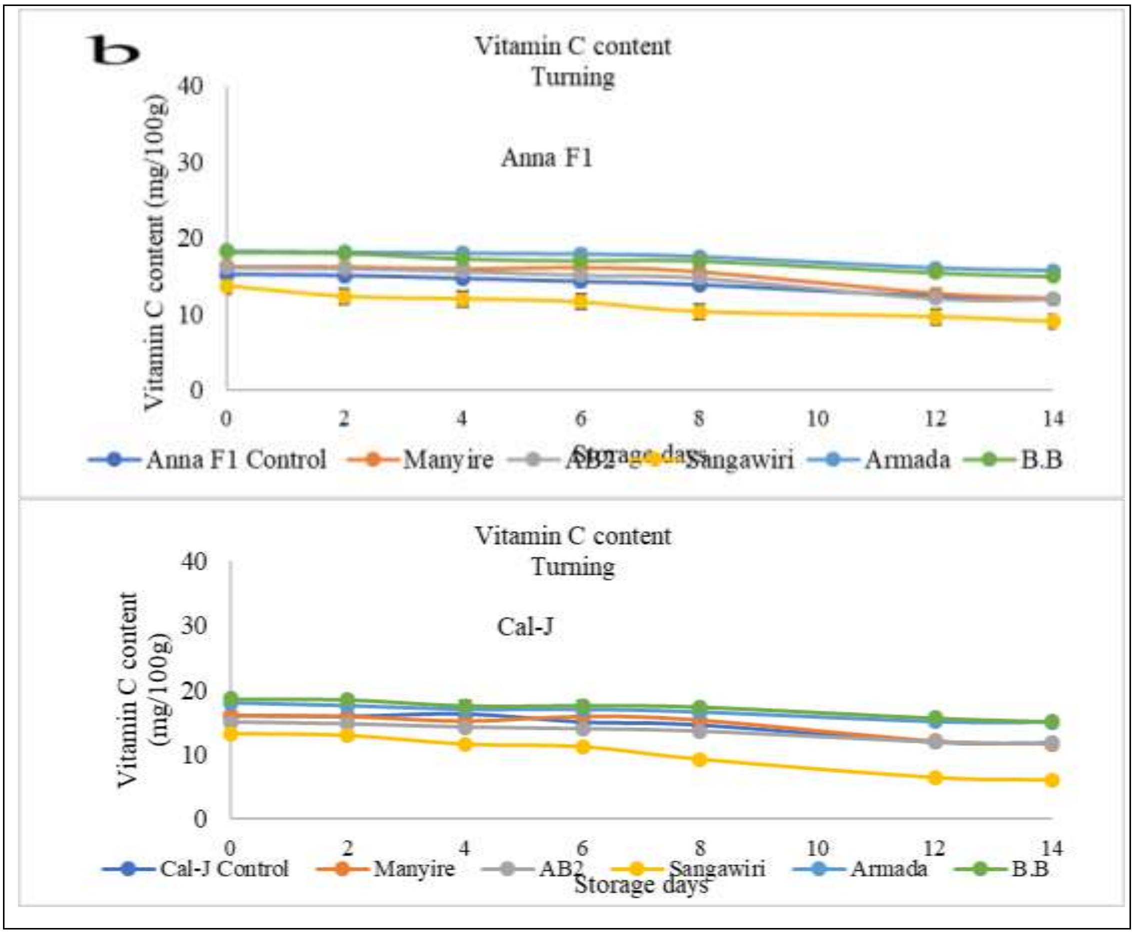

Figure 4.4b: Changes in vitamin C content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

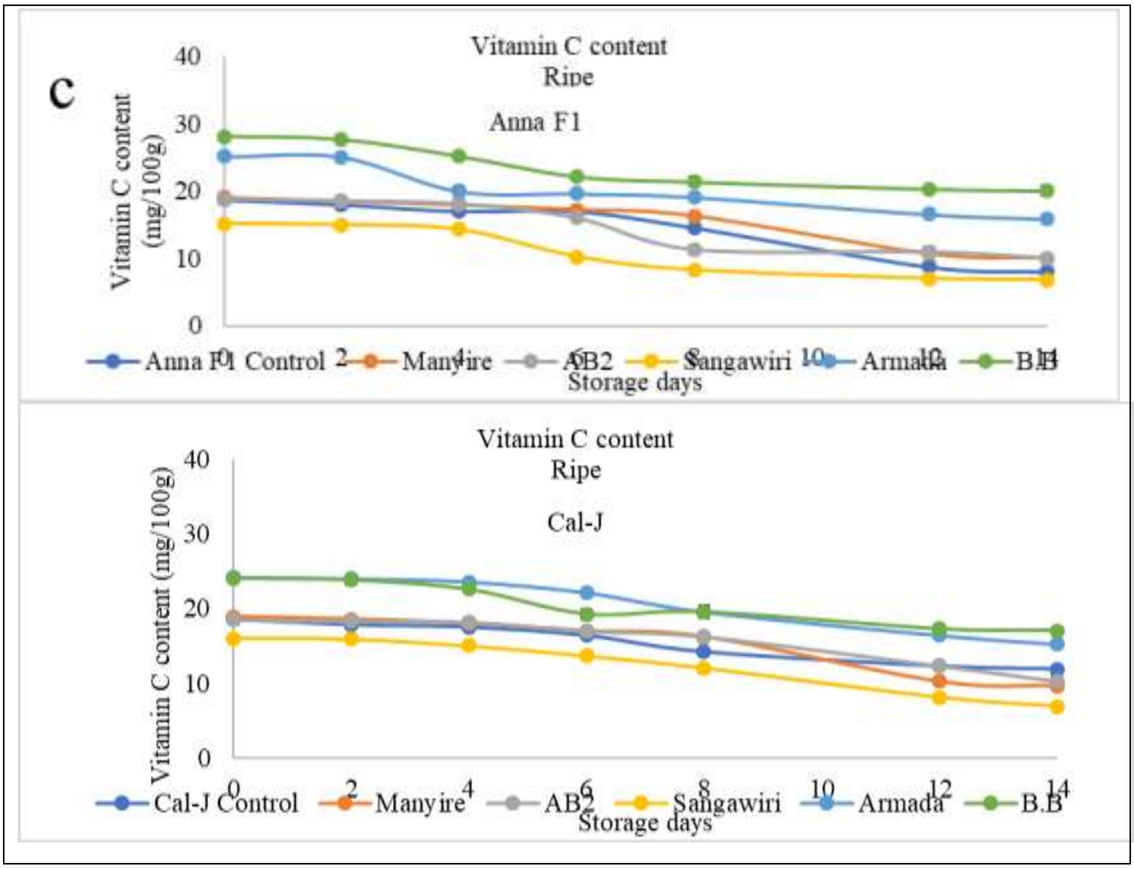

Figure 4.4c: Changes in vitamin C content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.2.3 Total soluble solids (TSS)

The highest soluble solid content was reported in grafted Cal-J fruits compared to Anna F1 grafted fruits but was not significantly different. Cal-J fruits grafted on Sangawiri had the highest TSS content on day 14 of 4.4 ^{o} Brix, 4.8 ^{o} Brix and 5.1 ^{o} Brix at the mature green, turning, and ripe stages, respectively (Table 4.4). Tomato fruits harvested at the mature green stage had the highest change in the soluble solid content on day 14 of storage compared to the turning and ripe stages. After harvest, the mature green tomatoes had soluble solid content between 2.5 – 2.7 ^{o} Brix and

achieved a range between 3.9- 4.4 ^{o} Brix by the 14th day (Tables 4). There was little change in the soluble solid content in the tomatoes harvested at the red ripe stage by the 14th day after storage; Day zero (3.2-3.7 º Brix) and day 14 (4.4-5.1 º Brix). Changes in the soluble solids are attributed to changes in their constituents, such as organic acids and glucose/fructose ratio during storage. This study indicates no significant difference ($p < 0.05$) in the TSS content of grafted tomatoes and the non-grafted tomatoes for both Anna F1 and Cal-J fruits. Thus, grafting did not affect the soluble solid contents of all the grafted fruits. Nicoletto et al., (2013) recorded significant differences in total soluble solids of tomato fruits from "Profitto" grafted onto two inter-specific P. Beaufort (B) × P. Big Power (BP) rootstocks.

Table 4.4: Soluble solid content of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at three maturity stages

			Total soluble solids (º Brix)					
			Mature green		Turning		Ripe	
			Day 0	Day 14	Day 0	Day 14	Day 0	Day 14
Anna F1	Interspecific	Control	2.6^{ab}	$.1^{ab}$	2.8^{ab}	4.1^{b}	3.2^{bc}	4.7^{d}
	graft	Manyire	2.6^{ab}	$.8^{bc}$	2.9^{b}	4.0^{ab}	3.3^{cd}	4.5^{bc}
		AB2	2.7^{b}	$.0^{de}$	2.8^{ab}	4.1^{b}	3.3^{cd}	4.7^{d}
		Sangawiri	2.7^{b}	$.1^{bc}$	2.9^{b}	4.0^{ab}	3.3^{cd}	4.6^{cd}
	Intraspecific	Armada	2.5^{a}	$.8^{bc}$	2.7^{a}	4.0^{ab}	3.1^{ab}	4.4^{ab}
	graft	B. B	2.6^{ab}	3.7^{a}	2.8^{ab}	3.9^{a}	3.0^{a}	4.3^{a}
Cal-J	Interspecific	Control	3.0^{cd}	$.2^{fg}$	3.4^{de}	4.6^{e}	3.6^{fg}	5.0^{fg}
	graft	Manyire	2.8^{bc}	$.1^{ef}$	3.3^{cd}	4.3^{cd}	3.4^{de}	5.0^{fg}
		AB2	2.9^{c}	$.2^{fg}$	3.3^{cd}	4.4^{d}	3.5^{ef}	5.0^{g}
		Sangawiri	3.1^{d}	4.4^{g}	3.5^{e}	4.8^{cd}	3.7^{g}	5.1^{g}
	Intraspecific	Armada	2.6^{ab}	$.9^{cd}$	3.4^{de}	4.3^{cd}	3.6^{fg}	4.7^{d}
	graft	B. B	2.8^{bc}	$.0^{de}$	3.4^{de}	4.3^{cd}	3.5^{ef}	4.9^{ef}

4.2.4 Total titratable acidity

Titratable acidity is very crucial in determining the peculiar sensory profile of tomato fruits. The changes in total titratable acidity (TTA) indicate that acid concentrations in the fruit decline with maturity stages and ripening. The titratable acidity after harvest ranged from 1.38% to 1.75%, 0.79% to 0.93%, and 0.53% to 0.73% at the mature green, turning, and ripe stages, respectively (Figure 4.5a, b, and c). Fruits from Cal-J grafted onto Sangawiri rootstock had the highest titratable acidity of 1.56%, 0.96%, and 0.73% at the mature green, turning, and ripe stages, respectively.

There was no significant difference ($p < 0.05$) in the TTA of grafted and non-grafted fruits at all the three maturity stages. Grafting had no impact on the total titratable acidity (TTA) of both Anna F1 and Cal-J grafted fruits.

Djidonou et al., (2016) reported that the TTA content of fruits from an interspecific graft of 'Beaufort' rootstock was not significantly different from the non-grafted control. Carbohydrates, citric and malic acids, and their interactions play a role in tomato sweetness, sourness, and flavor intensity. A high sugar-to-high acid ratio is required for the best flavor (Maul et al., 2000). Sour tomatoes are a result of high acids and low sugars. High sugars and low acids lead to a lard taste, while insipid and tasteless tomatoes are associated with low sugars. An imbalance in the acid-sugar ratio results in a higher concentration of some volatiles that may generate an off-flavor character in tomatoes when picked green and ripened off the plant (Beckles, 2012).

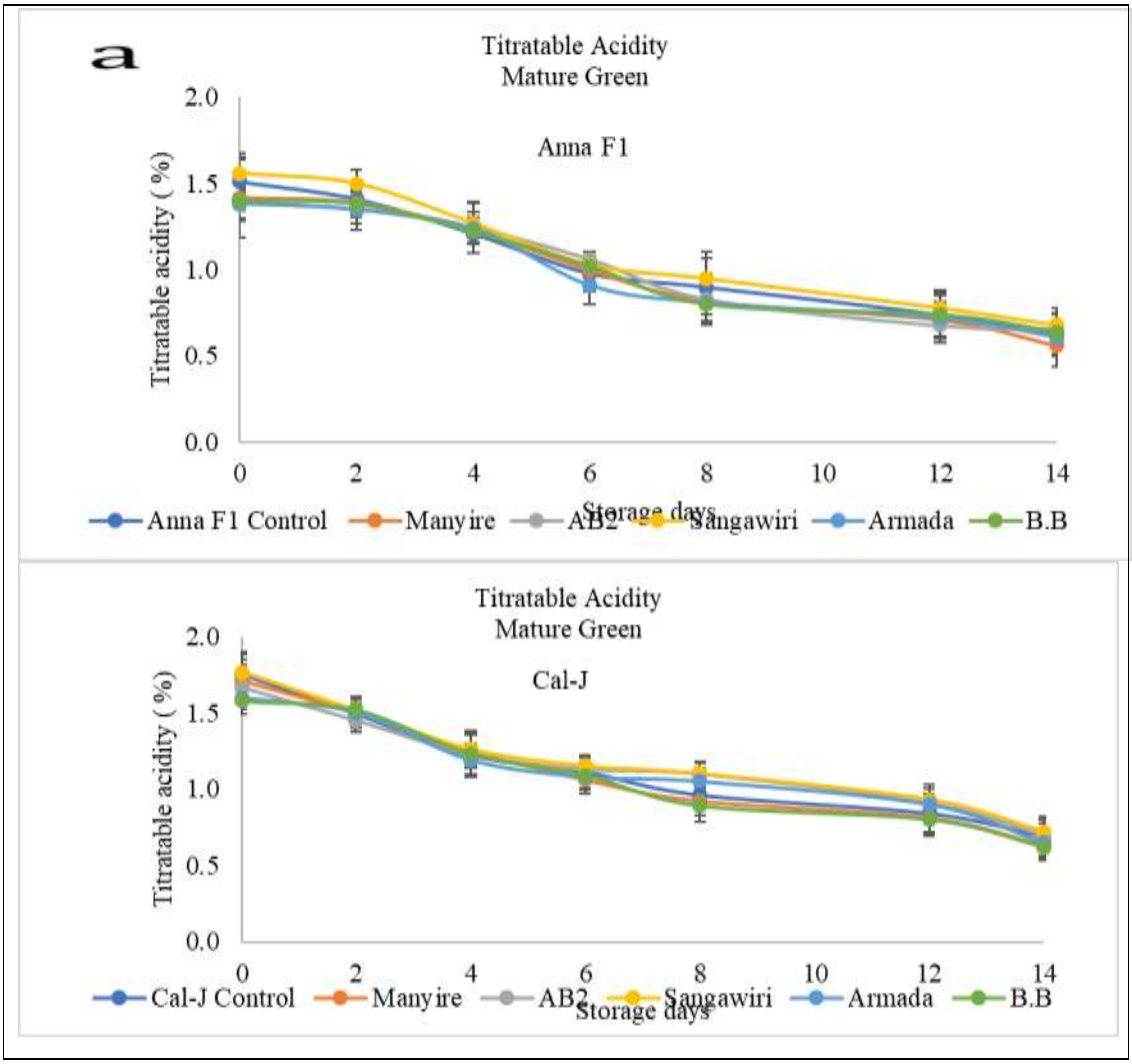

Figure 4.5a: Changes in the total titratable acidity of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

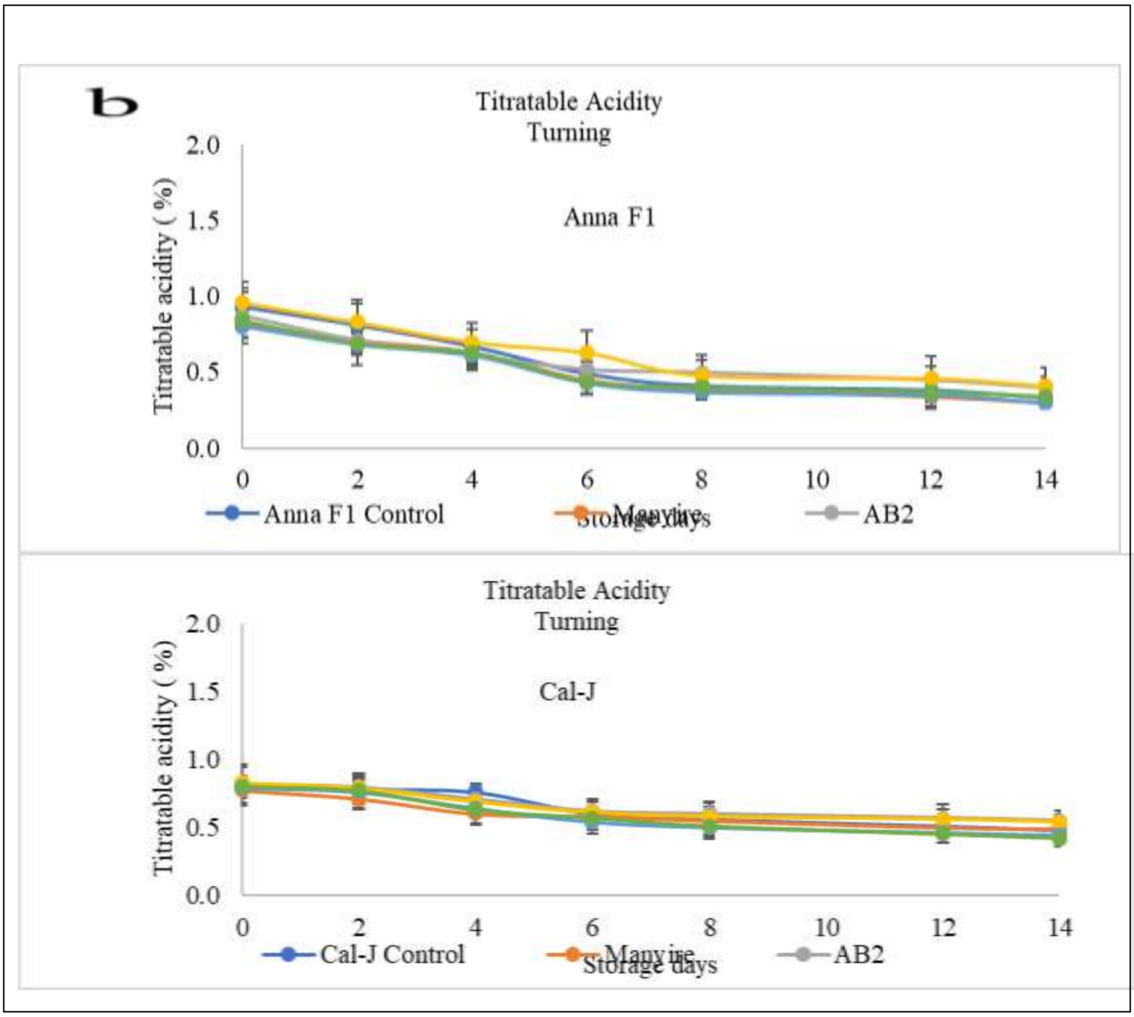

Figure 4.5b: Changes in the total titratable acidity of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

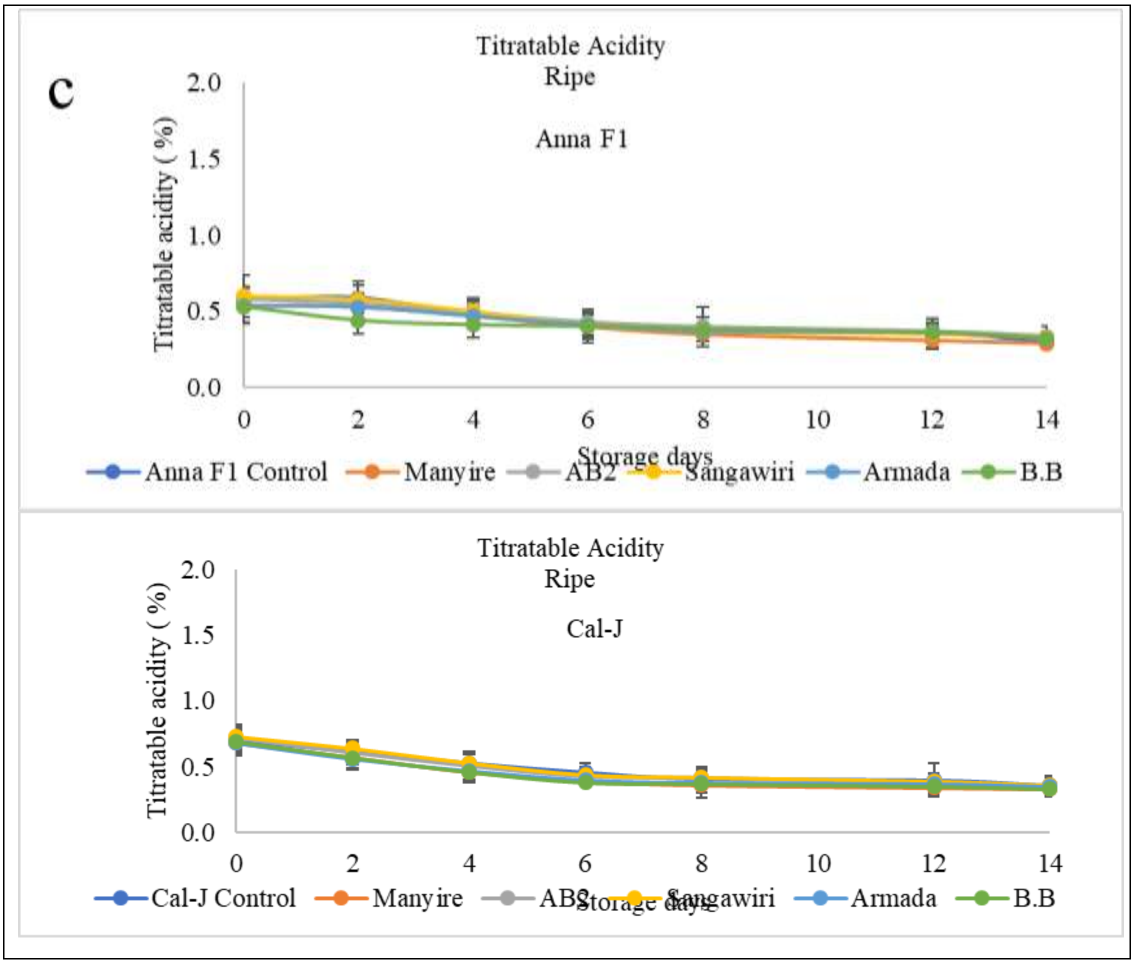

Figure 4.5c: Changes in the total titratable acidity of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.3 Physiological properties

4.3.1 Respiration rate and ethylene production

Respiration rate increased after harvest, attaining a climacteric peak on day 2 to 4, followed by a steady decline with time, as shown in (Figure 4.6a, b, and c). The lowest respiratory peak was observed in the Anna F1 grafted fruits but was not significantly different from the Cal-J grafted fruits. There was a significant difference in the respiration rate of fruits from the non-grafted control and those fruits from AB2, Manyire, Armada, and B.B, but it was not significantly different from the grafted Sangawiri fruits. Fruits from grafted Manyire, AB2, Armada, and B.B were not significantly different in all the three maturity stages. In the interspecific grafts, the lowest respiratory peak (27.5 ml/kg/h) was observed in the Anna F1 fruits from Manyire rootstock on day 4, while in the intraspecific grafts, Anna F1 fruits from B.B rootstock had the lowest respiratory peak at 20.2 ml/kg/h day 6 at mature green stage (Figure 4.6a). At the turning stage (Figure 4.6b), the lowest respiratory peaks were observed on day 2 for fruits from Anna F1 and Cal-J grafted on Armada rootstock at 18.0 ml/kg/h and 19.1 ml/kg/h, respectively. On the other hand, the highest respiratory peak was observed on day 2 in Anna F1, and Cal-J control fruits (49.8 ml/kg/h) and (52.3 ml/kg/h) at the ripe stage (Figure 9c). Ozturk & Ozer, (2019) reported the greatest respiration rates in non-grafted fruits compared to fruits from grafted King Kong rootstock. There was a relation in the fruit texture and weight loss analyzed and the respiration rates results of this study. Tougher skin/texture act as barrier to gas exchange hence affecting the respiration rate. They reduce the amount of oxygen that can reach the internal tissues of the fruit needed to break down stored carbohydrates and release energy. The slower the respiration rate, the slower the rate of weight loss (Sammi & Masud et al., 2009).

A significant difference in the respiration rate of grafted and non-grafted tomato fruits is attributed to the biochemical and physiological factors from the rootstocks that affect the scion and hence, the respiration rate of the fruit (Milenković et al., 2019). In addition, the respiration rates of tomato fruits are also dependent on the maturity stage, temperature, and surrounding gas composition (Mwendwa et al., 2016).

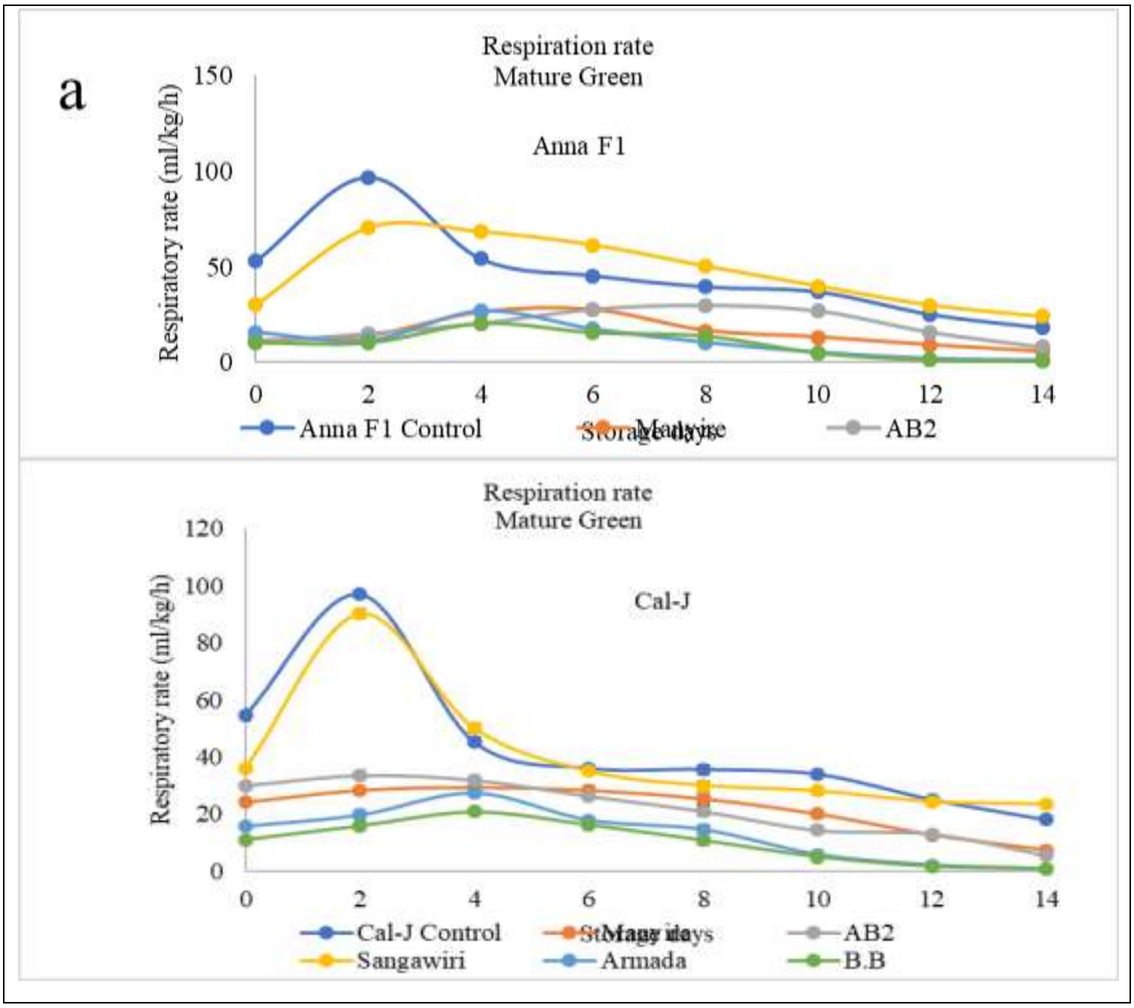

Figure 4.6a: Respiration rate of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

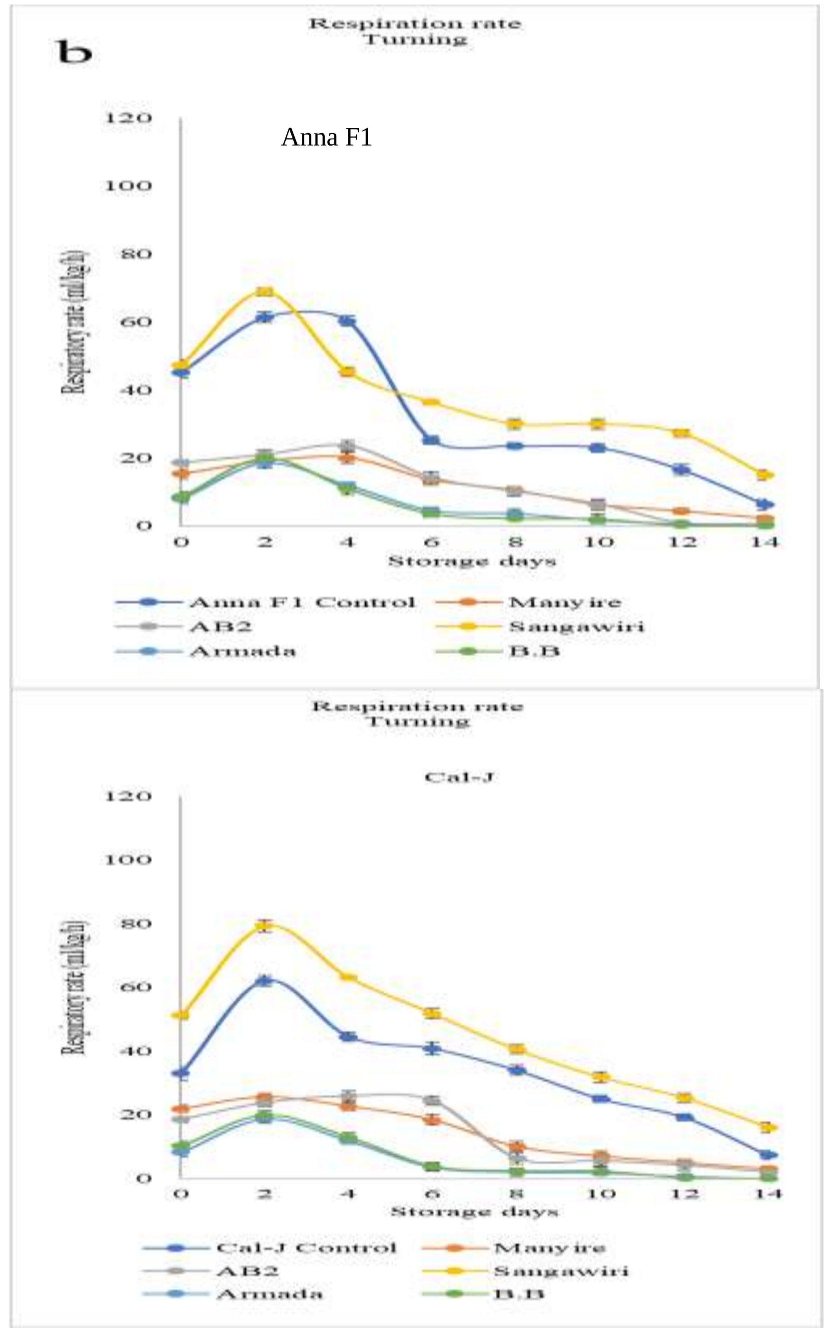

Figure 4.6b: Respiration rate of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

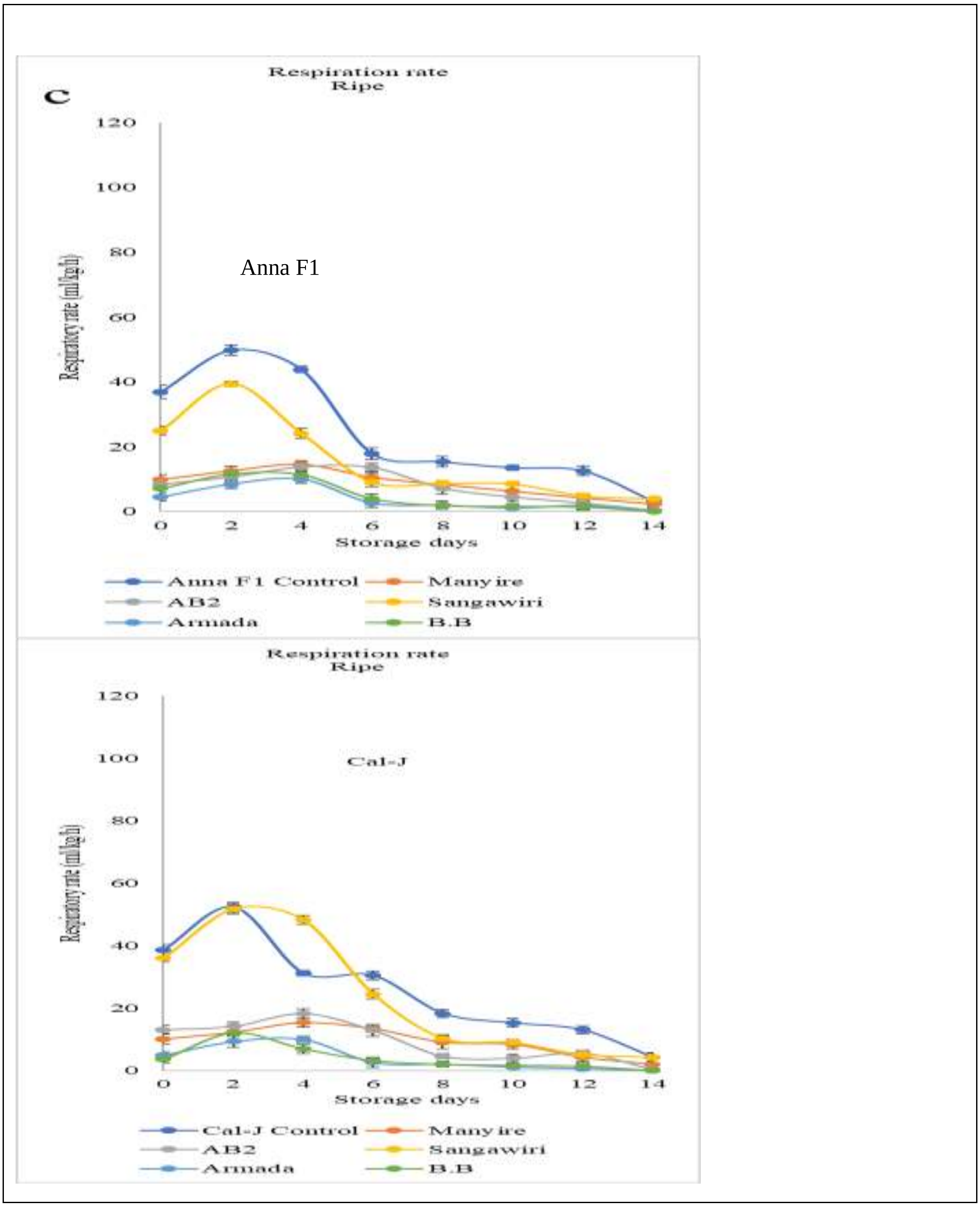

Figure 4.6c: Respiration rate of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

With regards to ethylene, the lowest ethylene peaks were observed in Anna F1 grafted fruits compared to Cal-J grafted fruits and were not significantly different.

There was a significant difference in the ethylene gas production rate of fruits from the non-grafted control and those fruits from AB2, Manyire, Armada, and B.B at the turning and ripe stage, but it was not significantly different from the grafted Sangawiri fruits. Fruits from grafted Manyire, AB2, Armada, and B.B were not significantly different in all the three maturity stages. The lowest peaks at the mature green stage (Figure 4.7a) were observed in fruits from Anna F1 and Cal-J grafted on B.B at 0.34 µl/kg/h and 0.36 µl/kg/h, respectively. At the turning stages (Figure 4.7b), the highest ethylene production rate peak (8.0 µl/kg/h) was observed in tomatoes fruits from the non-grafted Cal-J control, while fruits from Cal-J grafted on Sangawiri rootstock had the highest ethylene production rate peak of 6.7 µl/kg/h at the ripe stage (Figure 4.7c).

Ilić et al., (2020) reported that the effect of grafting on tomato respiration and ethylene production rates was dependent on the scion/rootstock combination. Maxifort rootstock produced fruits with low ethylene production rates, a desirable quality in prolonging the postharvest life. Non-grafted tomato genotype cv. Boludo F1 had higher ethylene production due to higher 1-Aminocyclopropane-1-carboxylate (ACC) concentration (a precursor of ethylene) of up to 40% in the xylem sap, in comparison with plants grafted onto some low and high vigor rootstocks (Singh et al., 2017). The ACC may be a key factor in the rootstock regulating shoot performance in tomatoes by acting on nutrient transporters and/or other shoot growth-related processes. The lower ACC concentration in the xylem sap of intra- and interspecific grafted fruits derived from AB2 and Manyire influenced lower ethylene production. The suppressed ethylene production had the positive attribute of suppressing the respiration rate and other ripening and postharvest quality attributes leading to the extended postharvest life of the grafted fruits, as demonstrated in this study.

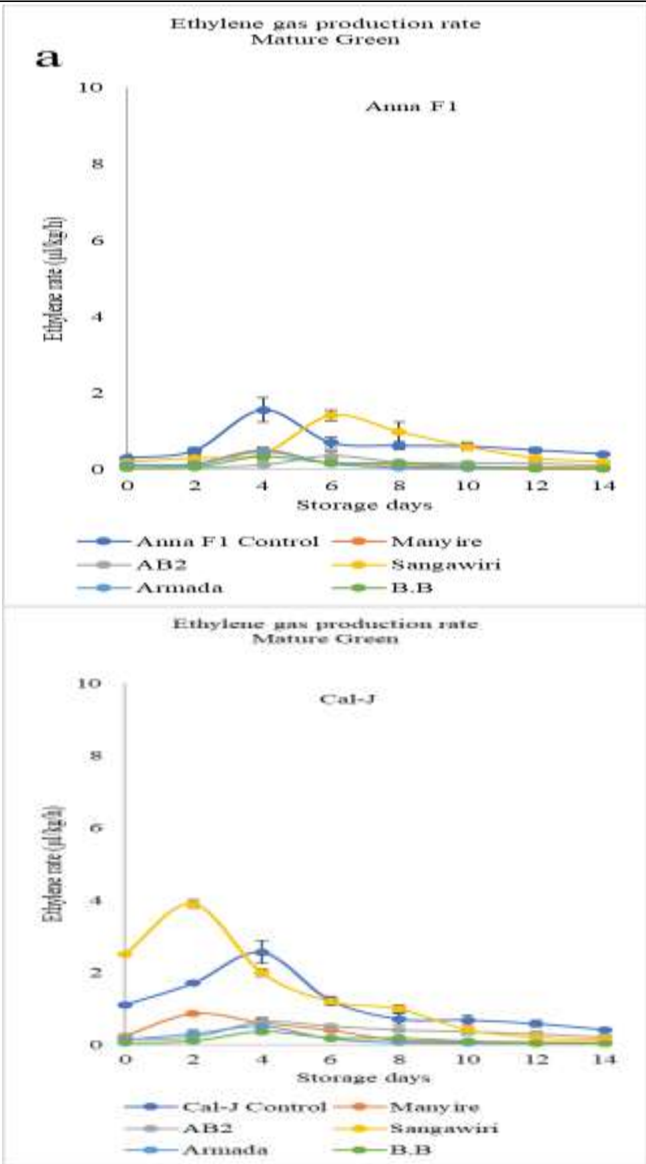

Figure 4.7a: Ethylene production rates of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at mature green stage

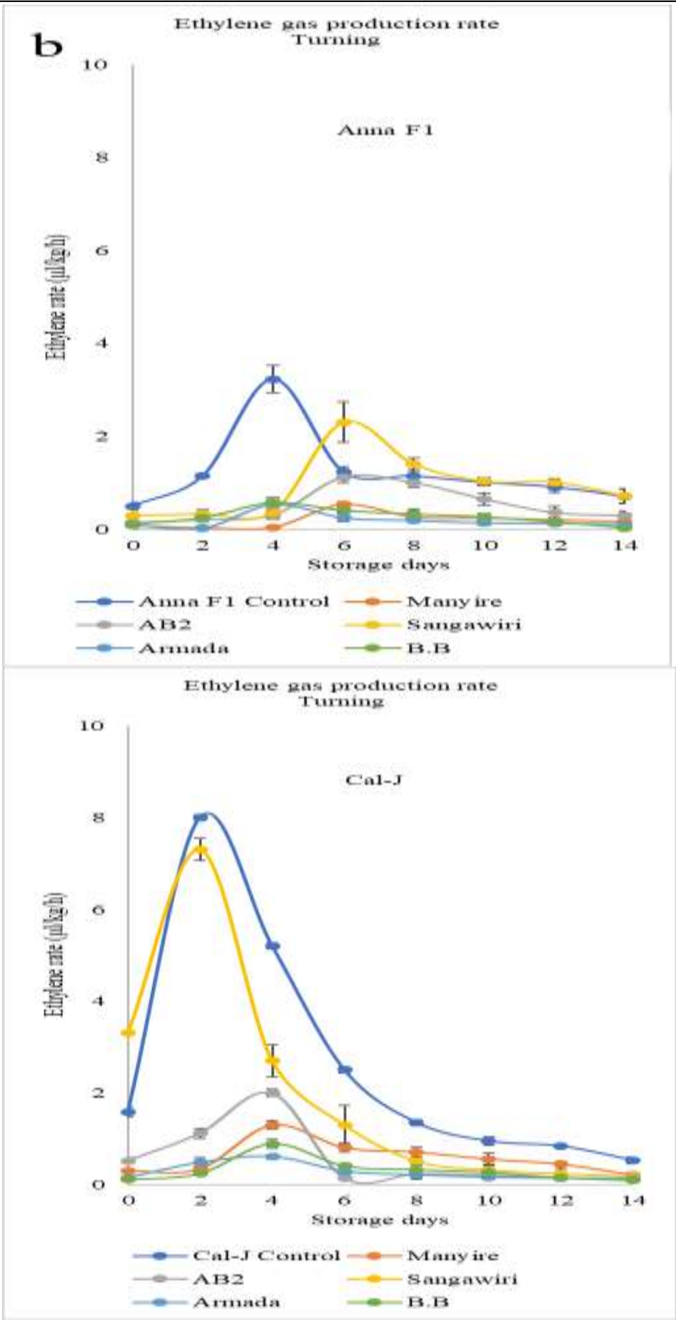

Figure 4.7b: Ethylene production rates of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at turning stage

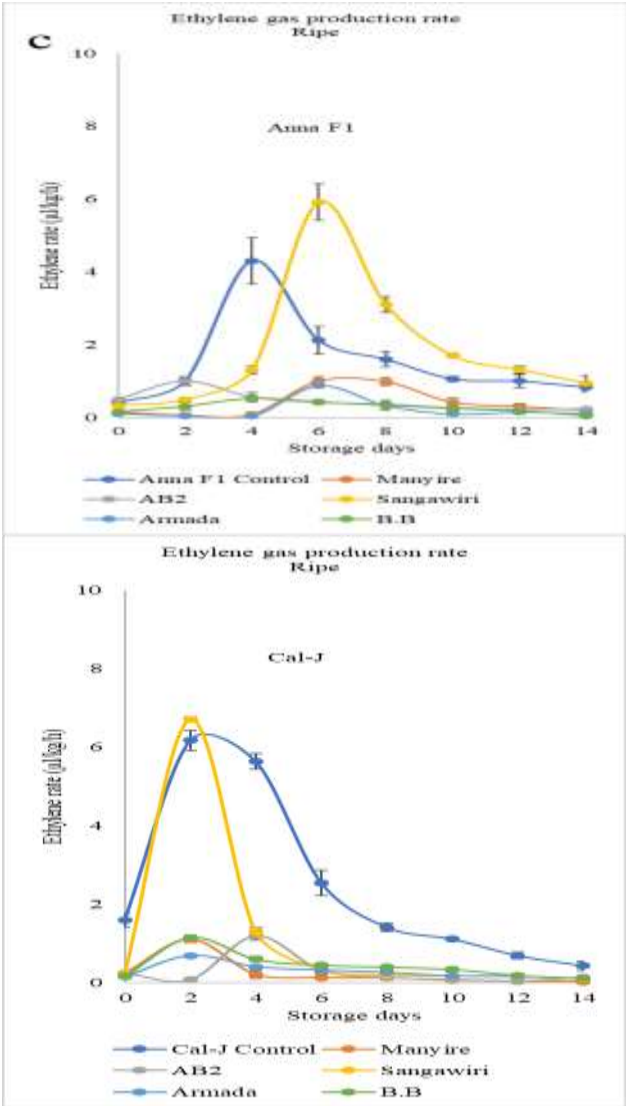

Figure 4.7c: Ethylene production rates of fruits derived from inter and intraspecific Anna F1 and Cal-J tomato scion graft harvested at ripe stage

4.4 Sensory evaluation

Grafting improved the intensity of firmness, sweetness, saltiness, juiciness, overall look, and overall acceptability of sensory attributes of interspecific grafted tomatoes for both Anna F1 and Cal-J fruits. However, the saltiness sensory attribute of all the grafted fruits was not significantly different from the nongrafted control. Fruits from Anna F1 grafted on Armada reported the highest score in all sensory attributes evaluated; firmness (9.2), sweetness (9.1), juiciness (6.6), saltiness (9.3), overall look (9.4), and overall acceptability (9.3). On the other hand, the sensory attributes of tomato grafted on Sangawiri; are firmness (5.7), sweetness (5.1), saltiness (6.2), juiciness (6.4), overall look (5.5), and overall acceptability (5.3) had no significant difference ($p < 0.05$) from the nongrafted control (Figure 4.8). Generally, the grafting effect on sensory attributes was dependent on the scion-rootstock combination. Di Gioia et al., (2010) reported similar sensory quality regardless of the grafting combination used upon grafting ‘Cuore di Bue’ onto ‘Beaufort F1’, ‘Maxifort F1’, 49 DAT, and 71 DAT rootstocks. There was a relation in the sensory attributes and the physical attributes under study. For stance, intraspecific grafting produced significantly firmer fruits in both the physical and sensory analysis. Texture is influenced by the firmness and juiciness of the tomato, which are determined by factors such as the thickness of the cell walls, the amount of water in the fruit, and the ripeness (Chaïb et al., 2007).

Similar scores given to grafted fruits and the nongrafted control for the firmness, sweetness, saltiness, juiciness, overall look, and overall acceptability could be attributed to sampling fruit at an equal stage of ripening, which is one of the major factors influencing tomato fruit sensory and quality attributes (Kader, 2008). In addition, similar scores for aftertaste and a sense of fulfillment suggest that grafting had no negative or positive effects on the sensory attributes.

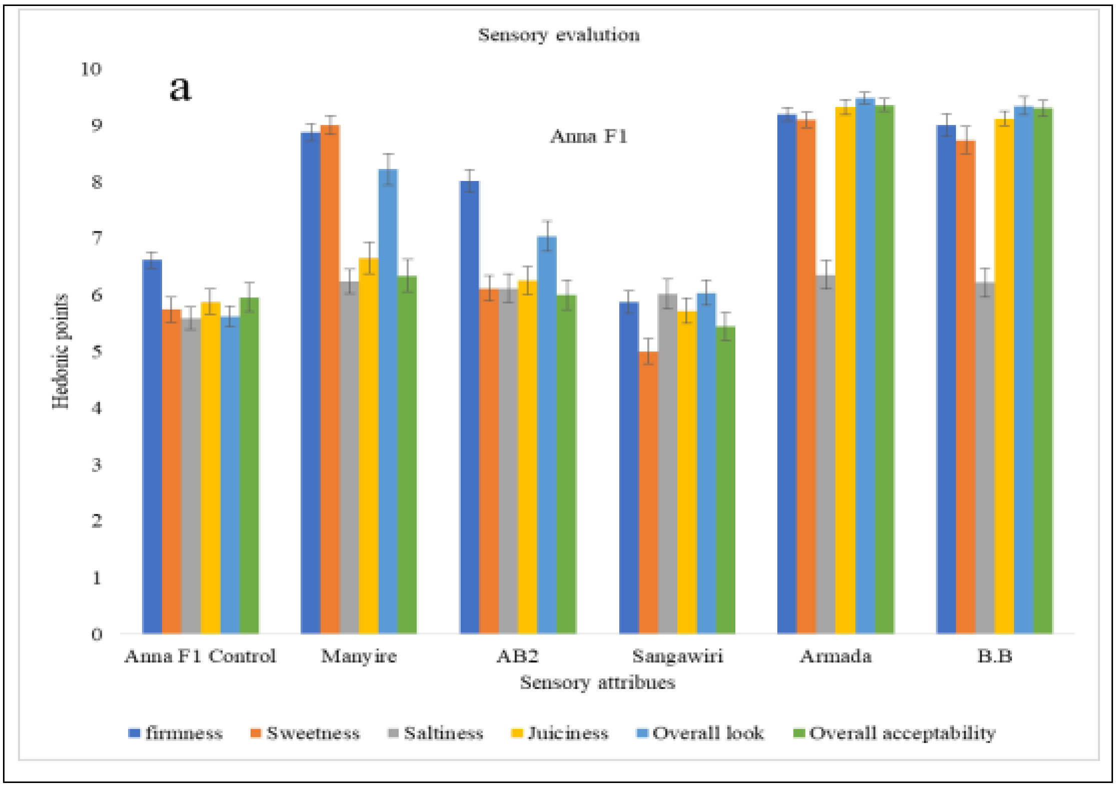

Figure 4.8a: Sensory attributes of fruits derived from inter and intraspecific Anna F1 tomato scion graft harvested at the ripe stage

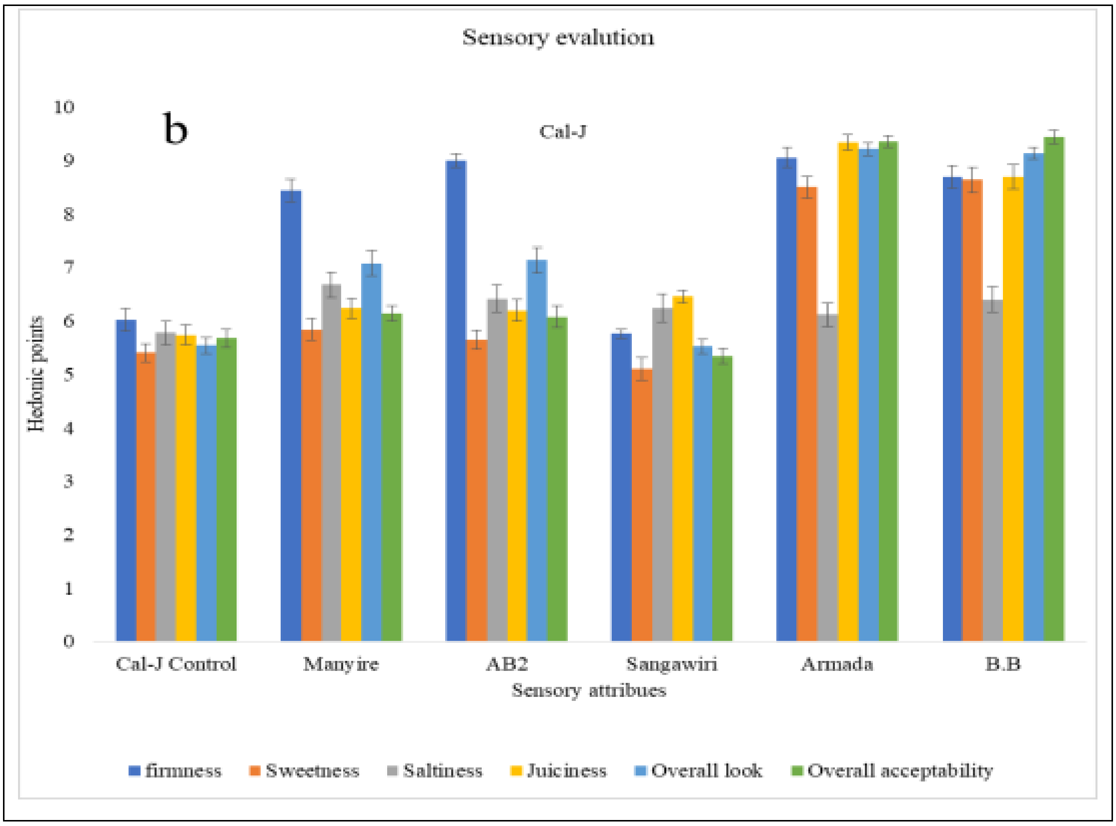

Figure 4.8b: Sensory attributes of fruits derived from inter and intraspecific Cal-J tomato scion graft harvested at the ripe stage

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Intra- and interspecific grafting on Manyire and AB2 rootstocks improved the physical and physiological qualities compared to nongrafted control except for Sangawiri which was not affected for some attributes like color but significantly reduced the fruit size. It was established that grafted tomatoes from Manyire, AB2, Armada, and BB showed superior physical and physiological attributes than those grafted on Sangawiri rootstock, which did not significantly differ from the non-grafted control fruits. Grafted tomatoes from Sangawiri rootstock had the lowest size and weight, low firmness, highest percentage weight loss, and highest respiration and ethylene gas production rates associated with shortening shelf-life. Based on this, all the rootstocks under study can be used in curbing bacterial wilt disease.

Grafting had no impact on the biochemical attributes except for vitamin C which was significantly improved and TSS which was significantly reduced upon intraspecific grafting. Grafting had no impact on the lycopene content of fruits grafted onto any of the rootstocks. Grafting also did not affect the vitamin C content of fruits from Manyire, AB2, and Sangawiri rootstocks, but intraspecific grafted on Armada and BB tomatoes showed a significant improved vitamin C content than the nongrafted. Although grafted fruits had lower total soluble solids, total titratable acidity, and lycopene content than nongrafted fruits, these values were satisfactory and fell within the adequate required ranges. Therefore, Armada and BB are the most suitable rootstocks with the intention of curbing bacterial wilt problems and achieving good nutritional content tomato quality. Anna F1 variety showed better quality characteristics than the Cal-J variety, thus concluding that tomato quality is dependent on the scion-rootstock combination.

Intra- and interspecific grafting on Manyire and AB2 rootstocks improved the sensory attributes compared to nongrafted control except for Sangawiri which was not affected. It was established that grafted Manyire, AB2, Armada, and BB showed superior sensory attributes than the grafted Sangawiri and the nongrafted control fruits, with Anna F1 reporting better quality than the Cal-J variety. Sensory attributes related to firmness, sweetness, appearance, saltiness, and juiciness were affected by grafting. Sensory changes were predominantly favorable for Anna F1 grafted on Manyire, AB2, Armada, and BB rootstocks but not the Sangawiri rootstocks for both Anna F1 and Cal-J. Therefore, tomato sensory attributes are dependent on the scion-rootstock combination.

From this study, it is evident that the effect of grafting on tomato quality is dependent on scion/rootstock interactions and/or a combination of both among other unknown factors.

5.2 Recommendation

All the rootstocks in this study are suitable for curbing bacterial disease. Grafting Anna F1 on Armada and BB cultivars gave the best quality traits and, thus, should be adopted by farmers to complement the existing chemical methods of curbing bacterial wilt. A clear knowledge of the quality of grafted tomatoes would give direction on adopting the grafting technique as an effective farming practice to solve the bacterial wilt problem in tomatoes.

The same study should be tried on an open field for comparison. Also, more trials should be done with other African eggplant cultivars since will inform more potential scion-rootstock combinations that might not only curb bacterial wilt but also produce either comparable or even better fruit quality. In addition, more research should be done on other solanaceous varieties, such as tobacco and wild tomato, that have the potential to be used in tomato grafting. A cost-benefit analysis of tomato grafting technology is also required.

Generally, grafting Anna F1 variety gave better tomato quality than Cal-J variety but were not significantly different. Intraspecific grafting had the best quality traits over interspecific grafting, with Armada rootstock reporting the best tomato quality. However, interspecific grafting of tomato onto African eggplant Manyire and AB2 rootstocks had comparable fruit quality to intraspecific grafting. It would play a significant role in boosting the quality of tomatoes and reducing postharvest losses among the resource-poor tomato farmers who cannot afford the costly hybrid rootstocks or resistant seeds. Harvesting at the mature green stage may result in the development of a yellow-orange color as a result of delayed ripening or immaturity, whereas harvesting at the red ripe stage results in the tomatoes quickly spoiling if not delivered to the market on time. If uniform color development and an extended storage period are required, tomatoes should be harvested at the turning stage of maturity.

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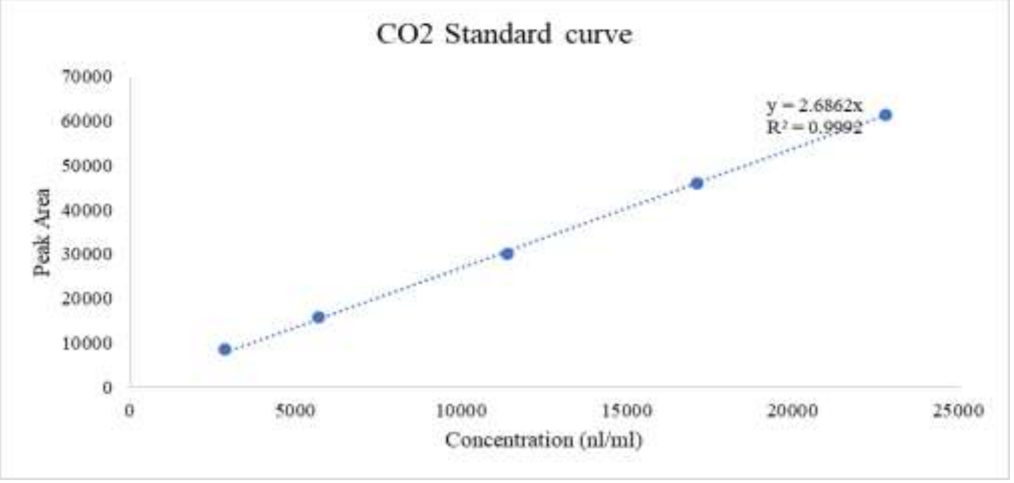
APPENDICES

Appendix I: CO_2 Standard curve



Appendix II: Ethylene Standard curve