

INFLUENCE OF GRAFTING ON THE GROWTH, YIELD, QUALITY AND SHELF LIFE
OF TOMATOES (*SOLANUM LYCOPERSICUM* L.) GRAFTED ONTO THREE
SOLANUM SPECIES

BY
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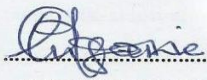
THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA LEGON, IN
PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MPhil
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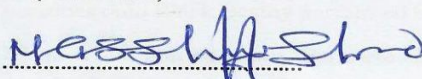
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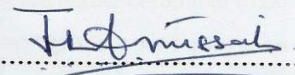
GRAFTED ONTO THREE SOLANUM SPECIES" is the result of my own research as a student of the Department of Crop Science, School of Agriculture and Consumer Science, University of Ghana during the 2014-2015 academic year. This work has never been presented in whole or part for the award of any degree of this university or anywhere else.


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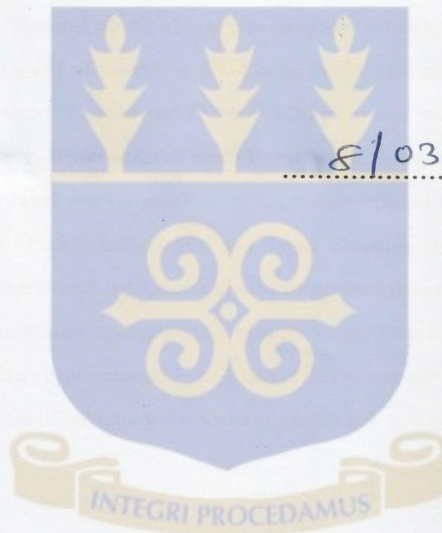
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ABSTRACT

A pot experiment was carried out from 15th December, 2014 to 20th June, 2015 at the University of Ghana Forest and Horticultural Crop Research Centre (FOHCREC), Okumaning under greenhouse conditions in a randomized complete block design to investigate the influence of grafting on growth, yield, quality and shelf life of tomato grafted onto three solanum species. Two tomato varieties 'Fadεεbege', and 'Nkansah HT' were used as scions and three solanum specie 'Gboma', 'Black Beauty' and 'Obaapa' were used as rootstocks. The rootstock-scion combinations were, 'Fadεεbege/Gboma', 'Nkansah HT/Gboma', 'Fadεεbege / Black Beauty', 'Nkansah HT/ Black Beauty', 'Fadεεbege / Obaapa', 'Nkansah HT / Obaapa', non-grafted 'Fadεεbege' and non-grafted 'Nkansah HT'. The results indicated that, grafting tomatoes onto Black Beauty performed better in terms of plant growth, yield quality, and shelf life than non-grafted plants. Earliness characterized by days to flowering and harvesting was significantly different for tomatoes grafted onto Black Beauty (21 days and 51 days) compared to non-grafted 'Fadεεbege' (31 days and 60 days) and non-grafted 'Nkansah HT' (34 days and 67 days). Fruit number and total yield of tomato grafted onto Black Beauty (27 and 5.18 t/ha) were higher compared to non-grafted 'Fadεεbege' (18 and 3.30 t/ha) and 'non-grafted Nkansah HT' (23 and 3.94 t/ha) respectively. However, the shelf life of tomatoes grafted onto 'Gboma' (46 days) and Black Beauty (43 days) were significantly higher compared to non-grafted 'Fadεεbege' (24 days) and non-grafted 'Nkansah HT' (41 days). Grafting significantly affected the brix, TA, TSS:TA, pH, vitamin C and lycopene content of grafted plants compared to non-grafted plants. The study demonstrated that grafting tomato onto 'Black Beauty' rootstock enhanced growth, yield, fruit quality and extended shelf life. The rootstock 'Black Beauty' may be recommended for use as a suitable rootstock for tomato grafting.

DEDICATION

To my lovely parents Mr. and Mrs. Ofori, my brother, Henry and to my beloved Naomi. You all loved me unconditionally, thanks for your support. I couldn't ask for more. God richly bless you.



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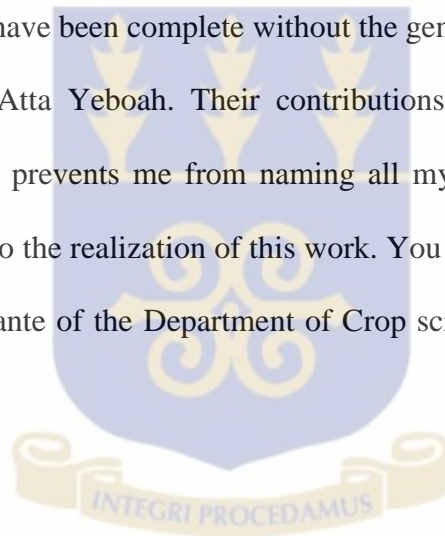


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LIST OF ABBREVIATIONS

BB: ‘Black Beauty’ (*Solanum melongena*)

FB: ‘Fadεεbεgye’ (*Solanum pimpillifolium*)

GB: ‘Gboma’ (*Solanum macrocarpon*)

GE: ‘Obaapa’ (*Solanum aethiopicum*)

HT: ‘Nkansah HT’ (*Solanum lycopersicum*)

CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum lycopersicum* L., $2n=24$), is a natural red edible fruit which has its place in the Solanum family. It is one of the most adaptable crops in terms of agricultural significance and the third most important crop family, topped only by grasses and legumes. It is the most valuable in terms of vegetable crops (Van der Hoeven *et al.* 2002) and a food security crop in Ghana (Horna *et al.*, 2007). The Tomato fruits are eaten fresh or cooked. They are added to sauces and soups as flavouring. In addition, they are processed into different forms such as candies, dried tomato fruits, powdered, paste, puree, ketchup and canned tomato fruits which are also equally important economically. As a matter of fact, it forms part of the food consumed in Ghana and this is clear in the fact that, a lot of Ghanaian dishes have tomatoes as a basic ingredient (Tambo and Gbemu, 2010). Tomato provides a rich supply of folate and with phytonutrients, the most abundant in tomatoes are the carotenoids, lycopene being the most well-known, followed by beta-carotene and gamma-carotene, photogene as well as several minor carotenoids (Beecher, 2009). Tomato is produced all over the country but the leading producing areas are located in the Northern regions (Horna *et al.*, 2007). It is also an equally important cash crop in the outskirts of urban areas in the forest zone. A booming, money-making tomato production also takes place in the Greater Accra area and in the Akumadan and Wenchi districts in the Ashanti and Brong Ahafo regions, respectively (Obeng-Ofori *et al.*, 2007).

1.1 PROBLEM STATEMENT

In Ghana, the focus and attention of the several interested participants in the tomato industry has routinely been on better production capacities of farmers leading to increased yields in order to provide for the growing population, with relatively less emphasis on fruit quality and

shelf life. According to Robinson and Kolavalli, (2010), tomato production seems to be falling since 2000. Unlike other countries, the tomato sector in Ghana has failed to reach its potential, in terms of increased yields, ability to reduce postharvest losses and in terms of improving the livelihoods of the many households involved in tomato production (Robinson and Kolavalli 2010). Agreeing to these authors, farmers do not only refuse to grow the right quality but also most importantly, they cannot produce the right quantity and quality to meet the demands of the tomato market. Robinson and Kolavalli (2010) also stated that average yields for tomatoes in Ghana are declining, typically, less than ten tonnes per hectare and that, due to production seasonality, high perishability, and competition from imports, some farmers are unable to sell their tomatoes, which are left to rot in their fields. The increase in postharvest losses, low yields, pooled with the high demand for tomatoes have given rise to the importation of fresh tomatoes and processed tomato products into the country (Horna *et al.*, 2007).

In Ghana, loss of fresh fruits is projected to be about 20-50 percent (MOFA, 2010). In addition, consumers' interest in the quality of tomato fruit products have also increased tremendously. Quality is an all-embracing term and it includes physical properties (size, shape, color, and absence of defects and decay, firmness, texture), flavor (sugar, acids, and aroma volatiles) and health-related compounds (desired compounds such as minerals, vitamins, and carotenoids as well as undesired compounds such as heavy metals, pesticides and nitrates) (Rouphael *et al.*, 2010). Since consumers demand for more varieties of higher quality and longer shelf life, strategies committed to increasing fruit quality and longer shelf life continue to be of great interest. (Dorais *et al.*, 2001; Gruda, 2005)

By the same token, the tomato market industry (fresh market, the fresh cut market and the food industry) have transformed in the sense that, the demand for products with better quality traits such as flavour, taste, texture, firmness and longer shelf life are sought after. This has

led to the adaptation of breeding goals towards increased quality traits which are pooled together with high yield and extended shelf life. Yet, these breeding goals meant for increasing tomato fruit quality and shelf life are virtually slow. More or less breeders have had some amount of feats increasing the quality of fruits with extended shelf life without losing other production traits due to the high variability that exist in the solanum group, to which tomatoes is an important affiliate (Caliman *et al.*, 2010). Similarly, the use of plant modification tools to obtain genetically modified tomato plants that are high yielding with improved quality and extended shelf life, gives rise to socio-economic issues, as a result of the fact that, consumers are not willing to accept the use of genetically modified organisms in food production systems. An integrated approach to enhance fruit quality, increased productivity with extended shelf life is very important, for a doable and sustainable tomato production, particularly, in Ghana.

1.2 JUSTIFICATION

A rapid and an efficient alternative to achieve this, is by vegetable grafting. Grafting has been well-known to be an effective and environmentally sustainable method to provide improved resistance and/or tolerance to soil-borne diseases, nematodes, bacterial wilt, viruses (King *et al.*, 2010; McAvoy *et al.*, 2011; Cheng *et al.*, 2012). A study by Nkansah *et al.*, (2013) and Cheng *et al.*, (2012) showed that grafting tomatoes enhances growth, increase yield and improves the quality of fruit. Presently, grafting tomatoes has demonstrated remarkable evidence to develop better resistance and/or tolerance against abiotic stress such as soil salinity, (Vanema *et al.*, 2008); cold (Gao *et al.*, 2006); heat and drought (Abdelmageed and Gruda 2009; Voutsela *et al.*, 2012), waterlogging, (Black *et al.*, 2003). In addition, grafting has been reported to improve the uptake of nutrients (Leonardi and Giuffrida, 2006), enhance water-use efficiency (Lee and Oda, 2003; Rouphael *et al.*, 2008a), fruit quality (Balliu *et al.*, 2008; Turhan *et al.*, 2011), increases the rate of photosynthesis, and anti-oxidant enzyme

activities (He *et al.*, 2009), thereby increasing crop yields under natural growing environment and heavy metal toxicity (Rouphael *et al.*, 2008b; Edelstein and Ben Hur, 2006), longer harvest duration (Lee, 1994) and extended shelf life (Nkansah *et al.*, 2013; Davis *et al.*, 2008a, b).

This can be a positive tool that can help as a quick alternative to the socio-economic issues of genetically modified food and the relatively slow breeding methods aimed at improving fruit quality combined with increased productivity and extended shelf life (Nkansah *et al.*, 2013). It may also be an alternative to crop management strategy to reduce postharvest losses due to rootstocks that can enhance fruit quality attributes of the scion with increased yields and extended shelf life. The advantages that vegetable grafting offers, primarily with high-value crops such as tomato (*Solanum lycopersicum* L.) point to the fact that growing tomatoes using grafting is a profitable enterprise. (Barret, 2011). It may be a ground-breaking method that can offer farmers, new profitable commercial prospects, better production solidity, increased fruit quality with longer shelf life and increased yields. (O'Connell, 2008).

In addition, grafting may provide an effective management tool for growers to control soil borne pathogens and cope with environmental stressors. But, if fruit quality is poorly affected as an outcome of grafting, farmers may be less likely to take on this technique. (Barret, 2011). Similarly, in Ghana, vegetable grafting is quite unknown. It has received limited attention not only for the effort needed to practice it, but also the delusion that grafting is a difficult practice (Alai, 2014) and cannot be applied to vegetables but to tree crops. The likelihood of applying grafting to improve fruit quality with longer shelf life and increased yields has not quite been investigated in Ghana. It is against this background that this research study was conceived to investigate the influence of grafting on the growth, yield, fruit quality and shelf life of tomatoes grafted unto different solanum rootstocks.

1.3 MAIN OBJECTIVES

- To develop an improved protocol for grafting of tomato that is successful and adaptable for farmers.
- To evaluate the grafting survival rate of grafted plants.
- To determine the effect of grafting on the period of flowering and harvesting.
- To identify the rootstock and scion/rootstock combination with positive impact on growth, yield, fruit quality and shelf life.

1.4 RESEARCH QUESTIONS

- Can grafting influence flowering and harvesting periods of tomatoes?
- Does grafting extend the shelf life of tomatoes?
- Can grafting produce tomato fruits with good fruit qualities?
- What is the best rootstock that has a positive impact on growth, yield, fruit quality and shelf life of tomatoes?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN AND DISTRIBUTION OF TOMATOES

Tomato (*Solanum lycopersicum* L.), a perennial plant with red edible fruits that stay alive for short periods of time and grown as an annual, is an indispensable vegetable crop used up globally (Brown *et al.*, 2005). Per an estimated aggregate production of approximately 159.347 million tonnes in 2011 (FAOSTAT, 2013), it is one of the most commonly consumed vegetable in Ghana. From 2004, worldwide consumption of tomatoes have increased by 4.5% each year (Aherne *et al.*, 2009). Comparatively, it is a short duration crop that gives an unusual yield, though, in South America, the same tomatoes can be reaped for several years in succession. It is economically lucrative and the area under tomato farming is on the rise.

Tomato takes its place in the *Solanaceae* family. This family also consist of other well-known types of crop, such as potato, tobacco, peppers and eggplant (Grubben and Denton, 2004)..The tomato plant is thought to have originated from the Andes Mountain (South America Andes) area with wild relatives in Peru, Bolivia Chile and Ecuador (Acquaah, 2007). The domesticated tomato was taken to Europe by the Spanish traders in the sixteenth century and later made it known from Europe to southern and eastern Asia, Africa and the Middle East. (Morejon, 2013).

2.2 BOTANY

Tomato, a crop that stays alive for short periods of time, can stretch to a height of two metres or more (Grubben and Denton, 2004). The stems of the tomato plant are quit solid, rough, and hairy with a strong odour. The growth form of the tomato plant is either straight or level to the ground. The terminal bud frequently grows into a floral bud which is continued by an

auxiliary bud. The flowers are about two centimetres in diameter and they are embedded in inflorescences of four to twelve flowers (Rice, 1993). The leaves are arranged in such a way that, they wind around in a continuous form. They are fifteen to fifty centimetres (15-50 cm) long and ten to thirty centimetres (10-30 cm) wide. The leaflets are egg-shaped to oblong, covered with hairs. The Inflorescence is huddled and produces six to twelve (6-12) flowers. The flowers are Bisexual, consistent and one to two centimetres (1-2 cm) in diameter. The flowers either grow opposite or between the leaves (Rost, 1996). The duct of the Calyx is short and hairy, with fixed sepals. It is usually made up of six petals up to one cm in length, yellow and they open when they are matured. The stamens and anthers are yellow in colour next to the style with a long-drawn-out spotlessly clean tip.

The ovary is large with about two to nine compartments (phytochemicals.info, 2015). Tomatoes are typically self- pollinated, though, cross pollination do occur fairly. The tomato fruit is a fleshy berry, globular to oblate in shape, almost two to fifteen centimetres (2-15 cm) in diameter. The fruit is green when it is immature and riped when matured. The fruit colour ranges from yellow, orange to red. It is usually round, smooth or rough depending on the variety grown. Two different types of tomato plants are well-known (Relf *et al.*, 2009). These are; the indeterminate type and the determinate type. The indeterminate varieties or types are the best choice for a long harvest period. They keep growing after flowering, especially when they properly maintained. The indeterminate types have to be staked, caged or trellised or trained. The Determinate types stop growing after flowering (Grubben and Denton, 2004) and do not require staking. But, under harsh weather conditions such as heavy rainfall, staking may be useful. The determinate type require less labour, as a result of this, they are widely cultivated for commercial purposes. They usually have high amount of fruit set which survives only for two or three weeks. The fruits of the determinate types ripen much faster than those from indeterminate types (Grubben and Denton, 2004).

2.3 HISTORY OF GRAFTING

Farming and domestication of crops and animals as sources of food, led to human settlements and in the long run, civilisation. For several centuries, humans' have tried to discover diverse ways and means to improve crop production (Barret, 2011) and one of such ways and means was grafting. Grafting, which is an old practice of unidentified specific ancient origin, was devised to improve production in woody plants species by means of joining the plant parts (vascular structures) of two plant species that are related to form a single living plant. In the long run, grafting enhanced the yield, value and capacity through the union of preferred qualities from two formerly separated plant bodies (Masterson, 2013). Even though this method started with arboreal plants, grafting had been used on vegetables, specifically solanaceous and cucurbitaceous crops in order to increase yield, enhance quality and to fight against soil borne diseases as well as abiotic stresses (Masterson, 2013).

Moreover, the reawakening of consumers' interest in quality fruits, legitimate phase out of the abusive use of pesticides, together with the socio-economic issues of genetically modified organisms in food production systems have made vegetable grafting a major subject matter throughout the world (Davis *et al.*, 2008a; Kubota *et al.*, 2008, Louws *et al.*, 2010). The starting point of grafting is often credited to Chinese horticulturalists; although the exact date is still not known, records indicates that grafting was used in China for tree plants that bear fruits by 1500 BC (Hartman *et al.*, 2002). Aristotle (384-322 BC) and Theophrastus (371-287 BC) wrote about the subject of graft compatibility, as an unavoidable challenge for plant propagation specialists.

Grafting of wooded plants species turned out to be a common practice throughout the Roman Empire. The practice of grafting particularly tree plants which bear fruits, clearly endured the Dark Ages both on the boundaries of the European continent, in Islamic botanical gardens and at Christian nunneries (Mudge *et al.*, 2009). With time, grafting of arboreal plants came

to be a worldwide practice as it is today. Like-minded as Mascall (1589), “There is none that more doth refresh the vital spirits of men, nor more engender admiration in the effects of nature, or that is cause of greater recreation to the weary and travailed spirit of man, or more profitable to man’s life, than is the skill of planting and grafting”, All the same, vegetable grafting is related in belief and in concept to grafting of arboreal plants. Basically, vegetable grafting involves the use of a rootstock resistant to soil borne diseases and a scion of a less-resistant variety that produces desirable fruit, etc. (Grubinger, 2007).

Vegetable grafting was scientifically advanced in Asia during the early 1920s to fight against soil borne disease in melons (Lee, 1994), and it has since gained acceptance in areas with strict land use and less important farming areas (Hartmann and Kester, 2002). By and large, vegetable grafting has been increasing in comprehensive cultivation practices. In Europe, grafted transplant production has increased steadily with Spain leading the helm of affairs (129.8 million annually), and Italy and France (47.1 million and 28 million) respectively. (Lee *et al.*, 2010; Morra and Bilotto, 2009). Majority of Korean and Japanese vegetable cultivation makes use of grafting, with approximately 700 million seedlings being produced in each country.(Lee *et al.*, 2010).The benefits that vegetable grafting offers, specifically with high-value crops such as tomato (*Solanum lycopersicum*) point to the fact that cultivating tomatoes using grafting may be a lucrative enterprise. (Barret, 2011)

2.4 SIGNIFICANCE OF GRAFTING TOMATOES

One of the most limiting conditions that affect crop production and utilization is environmental stress (Schwarz *et al.*, 2010). Notable elements that adds-up to environmental stress are water, temperature, nutrition, light, oxygen availability, metal ion concentration, and pathogens. A more proactive way of solving these problems is to grow crops that are more resistant or tolerant to these environmental stress (Schwarz *et al.*, 2010). Even though this is being reinforced by breeding programmes with remarkable efforts; these breeding

methods have become a slow-moving and an ineffective method. An excellent way of adapting plants to bear up with these environmental stress is by grafting carefully chosen cultivars, onto carefully chosen strong resistant rootstocks (Lee and Oda, 2003).

Today, grafting is well thought-out as a quick substitute to the comparatively slow breeding methods designed to increase environmental-stress tolerance and resistance of fruit vegetables (Flores *et al.*, 2010). It does not involve the practice of applying pesticides to the crops and for that reason, vegetable grafting has been considered to be an eco-friendly technique which can be very useful to an integrated and sustainable crop management systems. (Rivard and Louws, 2008). Owing to grafting, the purpose and cultivation of grafted plants especially Solanaceae and Cucurbitaceae have increase in considerably in recent years (Lee *et al.*, 2010). The benefits of grafting are numerous and they must be harnessed to improve crop production, especially in fruit vegetables in Ghana.

2.4.1 Disease resistance and tolerance

Plant diseases are unquestionably one of the major factors which causes reduction in crop productivity (Louws *et al.*, 2010). Thus, a vital action to control and manage the effect of these diseases on crop production, especially, high valued crops such as tomatoes needs to be considered. Most of these diseases are caused by viruses, fungi, bacteria and nematodes (Louws *et al.*, 2010).A proactive way of confronting these diseases is by grafting. Over the past decades, graftings were used to control soil borne pathogens such as *Fusarium oxysporum* watermelons (Rivero *et al.*, 2003a). It has been well documented that this method can be used effectively against a variety of fungal, bacterial, viral, and nematode diseases. In addition, these studies have proven that the use of this technique can be effective in managing soil borne disease, as well as the reduction in the excessive use of pesticide to control these diseases (Besri, 2001; Pavlou *et al.*, 2002; Giannakou and Karpouzas 2003;Bletsos, 2005).

Grafting can be an excellent ‘modus operandi’ for the management and control of soil-borne fungal pathogens. It has been used to eliminate *Verticillium* and *Fusarium* wilt in melon and cucumber production in Japan, Korea, and Greece (Oda 1999; Ioannou 2001; Bletsos 2005). In tomato, grafting onto resistant rootstock has been effective against *Verticillium dahlia* as well (Tsrer and Nachmias, 1995; Ioannou, 2001). Grafted tomatoes were able to reduce levels of corky root rot, caused by *Pyrenochaeta lycopersici*, leading to a highly developed root system and in the long run, better nutrient uptake (Bradley, 1968). Resistance to this pathogen has been shown in additional studies as well (Ioannou 2001). When cucumber was grafted onto resistant rootstocks under infestations of root and stem rot of cucumber, caused by *Fusarium oxysporum* f. sp. *radicis-cucumerinum*, they exhibited higher yields. (Pavlou *et al.*, 2002).

Research in soils infected with *Phytophthora cryptogea* also pointed out that, this technique could be applied to manage root rot in tomato production either in a greenhouse or open field conditions (Upstone, 1968). Grafting is used commercially to control root-knot nematodes and other soil borne diseases under greenhouse and open field in tomato, melon and watermelon production (Besri, 2001; Abdelhaq, 2004; Barret, 2011). Grafting onto resistant rootstock has been rewarding for cucumbers against root-knot nematodes (*Meloidogyne* spp.) (Giannakos and Karpouzas, 2003). Grafting onto resistant rootstocks for has also been carried out in eggplant production systems. This technique is highly effective for managing root-knot nematodes, and offers the same control as compared to fumigants (Ioannou, 2001). Similarly, eggplant being used as rootstocks may provide resistance to root-knot nematodes for eggplant production (Rahman *et al.*, 2002).

Despite the fact that very few cases have been mentioned, grafting can equally be used to control viral diseases as well. The use of resistant rootstock have been shown to be very effective for the control and management of tomato yellow leaf curl virus (ToYLCV) spread

by the whitefly, *Bemisia tabaci* (Rivero *et al.*, 2003a). Even though grafting, with time, has become more important for all soil borne diseases, it is also been very helpful in reducing losses caused by bacterial wilt (*Ralstonia solanacearum*) of tomato. This specific disease is usually controlled by lengthy rotation periods so as to effectively get rid of primary inoculum (Rivard, 2006). Likewise, breeders continue to bawl, as the genetic traits for resistance are closely connected to inherent characters linked with poor fruit quality (Caliman *et al.*, 2010). Attempts to separate these traits have been relatively unsuccessful. In Asia, grafting has been very crucial for the eradication of bacterial wilt incidence in solanaceous crops such as tomatoes and eggplants (Oda, 1999).

Equally, in tropical environments, where the prevalence of bacterial wilt is so high that tomatoes cannot be cultivated except the soil is sterilized. As such, grafting unto resistant rootstocks have been very effective (Peregrine and Binahmad, 1982). The hybrid rootstock ‘CRA 66’, was used in India to reduced bacterial wilt incidence I n tomato production system. Plant survival ability increased remarkably at first harvest, from 54.5% in the control to 100% in grafted plant (Tikoo, *et al.*, 1979). However, with the control plants, none of them stayed alive by the end of the growing season, but with the grafted plants 100% of them stayed alive and continued to live and produce (Tikoo, Mathai, and Kishan 1979). In addition, the yield of the tomatoes grafted onto resistant rootstocks was outstanding compared to the susceptible lines. It was four times the susceptible lines. The same hybrid ‘CRA 66’ rootstocks were used to control bacterial wilt in Germany. Similar results were observed (Grimault and Prior, 1994). More than a few hybrid lines (Hawaii 7996-7998) have also been identified as suitable resistant rootstocks to control bacterial wilt (Tresky and Walz, 1997; Oda, 1999).

The use of wild eggplant species for rootstock in tomato production has also been well-acknowledged (Matsuzoe *et al.*, 1993; Morejon, 2013). The wild eggplant species used as

rootstocks are highly resistant to bacterial wilt as well as root-knot nematodes. Fruit quality is higher with the use of these eggplant species. (Matsuzoe *et al.*, 1996). Grafting has shown to be an efficient broad-spectrum management tool in an integrated approach to manage and control pest in a number of vegetable crops. The use of grafting in addition to other techniques such as soil solarisation and other chemical substitutes can have a mutual effect in decreasing the obnoxious use of pesticides, soil borne disease and improve crop productivity (Ioannou, 2001; Giannakou and Karpouzas 2003; Bletsos, 2005).

2.4.2 Environmental stress

2.4.2.1 Salinity

Indisputably, salinity, either in the soil or water is one of significant environment stress factors that has an enormous impact on crop productivity (Santa Cruz *et al.*, 2002). As a result of over-fertilization and desertification, about one third of all the irrigated land in the world is affected by salinity, and this technique could contribute significantly in decreasing yield losses as a result of salinity (Rivero *et al.*, 2003a). The physiology, biochemistry and yield of plants are expressively affected by salinity. Quite a number of approaches have been initiated to cope with the harmful effect of salinity. This includes the use of plant transformation tools, use of genetic markers, cultural techniques, and improved land-use management systems (Cuartero *et al.*, 2006).

Grafting tomato with tolerant rootstock genotypes has been highly effective at producing a saline-tolerant plant, (Fernandez-Garcia *et al.*, 2004a). When the resistant rootstocks ‘Radja’, ‘Pera’ and hybrid ‘Volgogradskij’ x ‘Pera’ were used as rootstocks at high levels of sodium chloride, a significant increase in yields were observed. This increase in yields were 80% more than the non-grafted and self-grafted plants. Likewise, the amount of sodium and chlorine in the leaves of the grafted plants proved that these rootstocks barred the delivery of these harmful ions into the shoot. These findings support the conclusion that the tolerance of

the scion (shoot) depends largely on the rootstock, irrespective of the scion used (Estan *et al.*, 2005). Wittily, similar outcomes were revealed when tobacco scion was grafted onto salt-tolerant tomato rootstock (Ruiz *et al.*, 2005). Correspondingly, watermelons grafted onto salt-tolerant rootstocks remarkably exhibited high yield, which was up to 81% in a greenhouse production system (Colla *et al.*, 2006b). The use of salt-tolerant rootstock may possibly be a key management tool for vegetable production under saline in anticipation of better land-use systems that can significantly reduce the amount of salinity problems especially in areas where salinity is intolerable.

2.4.2.2 High and low temperatures

An important critical element of environmental stress that greatly affects crop production is temperature. Temperature causes huge economic and yield losses and this is characterized by reduction in plant growth and crop productivity. It affects the physiological, biochemical and morphological characteristics of the plant (Ahn *et al.*, 1999). In cold climate areas, growing of crops, especially vegetables, goes through a lot of challenges because of the low and chilling temperature conditions that prevail during this periods. Different kinds of crops do not have the same optimum temperatures for growth and development. They have different optimum temperatures within which they can grow and develop very successfully.

For instance, most vegetables, particularly fruit vegetables such as tomatoes, eggplants and pepper, are very sensitive to chilling (Schwarz *et al.*, 2010). They have their threshold temperatures within which they can survive chilling temperatures. Below this threshold temperatures, most crops that hail from the tropical and sub-tropical areas will suffer enormously from physiological disorders.

In addition, When these fruit vegetables are exposed to very low (chilling) amount of temperature for an extended period of time, it brings about growth retardation, death of cells and finally plant death (Allen and Ort, 2001; Venema *et al.*, 2005). Low or chilling

temperature stress may be described as the reduction in plant growth and development brought about by exposure to temperatures below the optimum temperature ideal for any plant to successfully complete its life cycle (Greaves, 1996). In and between plant species, every phase of growth and development has its own optimum temperature. At extremely low temperatures, flowering, fruit set, fruit size and truss formation is reduced drastically throughout the growth and development of tomatoes (Van der Ploeg and Heuvelink, 2005). This leads to low yields. In addition, fruit quality characteristics are cruelly affected (Adams *et al.*, 2001; Dorais *et al.*, 2001).

More than a few studies have shown that grafting cucumber onto figleaf gourd rootstocks enhanced plant growth and timely harvest at low temperatures (Bulder *et al.*, 1991; Zhou *et al.*, 2007). The aforementioned has also been established that cucumber scion grafted onto a squash rootstock (*Cucurbita moschata* Duch) improved tolerance low temperatures conditions as likened to self-grafted cucumber plants (Shibuya *et al.*, 2007). Similarly, research studies have shown that grafting tomatoes onto high altitude rootstock 'LA 1777' of *S. habrochaites*, 'KNVF' (the interspecific hybrid between *S. lycopersicum* x *S. habrochaites*) and a back cross hybrid rootstocks between *S. habrochaites* 'LA 1778, x *S. lycopersicum* cv. T5, low temperature stress were remarkably enhanced by these rootstocks that were used (Okimura *et al.*, 1986; Bloom *et al.*, 2004; Venema *et al.*, 2008).

A study by Gao and Liao, (2006) pointed out that these rootstocks are related to eggplant and tomatoes, therefore, they can also be used to improve the vegetative growth rate and yields of eggplants and tomatoes at very low temperatures. A similar rootstock that can be used for this purpose is 'Torvum vigour' an accession of *solanum torvum* (Okimura *et al.*, 1986). Likewise, grafting watermelon onto 'Shintosa' type (an interspecific squash hybrid, *Cucurbita maxima* x *C. moschata*) rootstocks improved tolerance during cold periods (Davis *et al.*, 2008b).

Production of fruit vegetable are adversely affected by high temperatures, most under hot dry and hot wet conditions in the arid, subtropical and tropical regions. (Abdelmageed and Gruda, 2009; Palada and Wu, 2008). An experiment conducted by Abdelmageed *et al.*, (2004) revealed that, plants grafted onto heat tolerant rootstocks increased growth and productivity significantly under high temperature conditions. Temperatures above 35 degrees impedes the cultivation of Solanaceae rather than Cucurbitaceae (Wang *et al.*, 2003). High temperatures, just as other abiotic stresses, causes a chain of complicated morphological, physiological, molecular and biochemical alterations that cruelly affects vegetative growth and yield. It is a matter of enquiry, as to whether rootstocks are able to improve these defence processes and finally contribute to enhance the heat tolerance of the whole plant (Schwarz *et al.*, 2010).

A lot of experimental results have been documented by AVRDC examining the exploit of Solanaceae rootstocks selected against extreme temperatures. These outcomes proved that, grafting tomato unto selected heat-tolerant rootstocks offers a certain degree of resistance against thermal stress (Rivero *et al.*, 2003b). As eggplants are better adapted to hot arid environment and have a better tolerance against extreme soil temperature, the use of eggplants as rootstocks for tomato at higher temperature seems to be positive. (Abdelmageed and Gruda, 2009). On the other hand, eggplants (*S. melongena cv. Yuanqie*) grafted onto a heat-tolerant rootstock (*S. melongena cv. Nianmaoquie*) performed very well, giving rise to extended growth and yield increase up to 10% (Wang *et al.*, 2007). Comparatively different accessions of chilli pepper rootstocks (*C. chacoense*, *C. baccatum*, *C. frutescence*, and *C. annum*) confirmed high yields under high-temperature environments. (Palada and Wu, 2008).

2.4.2.3 Drought

Nowadays, in many parts of the world water is gradually becoming an unprotected resource. This generally occurs in arid and semi-arid regions. This is because, the high demand for water by agricultural, industrial, rural and urban consumers have risen up. This has generated

the need for continuous improvement of irrigation practices in commercial crop production systems, especially vegetable production systems. Extreme drought conditions leads to unavailability of water and high temperatures. This causes reduction in growth, poor development (sometimes death of plants) and subsequently huge economic losses and low yields. (Pervez *et al.*, 2009). A rapid and proactive way of reducing these losses in production and to improve the efficient use of water under drought conditions in crops, particularly, fruit vegetables is by grafting them onto rootstocks that can provide protection against water stress particularly drought (Garcia-Sanchez *et al.*, 2007; Satisha *et al.*, 2007).

Grafting experiments on drought with fruits, such as kiwi and grapes, provided evidence that drought tolerant rootstocks can promote growth, yield and fruit quality under drought conditions (Clearwater *et al.*, 2004). Quite a handful of research studies exist on grafted fruit vegetables. Petran (2013) stated that most eggplant are drought tolerant and these eggplant can impact resistance to drought. As eggplants are more effective to water uptake than tomato root systems, it would be interesting to see their grafting potential under water-stress conditions such as drought. Petran, (2013), found out that grafting unto wild eggplants and interspecific hybrids improved yield and fruit quality under drought conditions. A study by Schwarz *et al.*, (2010) also pointed out that grafting unto drought tolerant rootstocks improves yield and fruit quality characteristics. In addition, Sanchez-Rodriguez *et al.*, (2012) disclosed that grafting cherry tomatoes unto drought resistant rootstocks enhanced fruit quality and yield significantly. Mini-watermelons grafted onto a commercial rootstock 'PS 1313' (a hybrid cross between *Cucurbita maxima* Duchesne x *Cucurbita moschata* Duchesne) clearly proved that marketable yields increased by 60% when grown under conditions of insufficient irrigation or water stress compared with non-grafted melons (Rouphael *et al.*, 2008).

Similar results were also confirmed by Abdelmageed *et al.*, (2004) when tomato was grafted onto water stress resistant lines. The increase in marketable yields noted with grafting onto drought resistant rootstocks was as a result of better uptake of nutrient and water. These were shown by a higher nitrogen, potassium, and magnesium concentration in the leaves, and higher carbon dioxide assimilation. The combined use of grafting unto drought resistance rootstocks and good agronomic practice to put up with water status, may possibly maintain plant growth under conditions where yield would otherwise be considerably low, especially, under drought conditions.

2.4.2.4 Flooding

Flooding, waterlogging and submergence are major abiotic stresses that earnestly upsets the development and productivity of crops. Flooding conditions results in oxygen deficits. This is because, there is slow diffusion of oxygen gas in water and from oxygen consumed by biological activities of organic matter and microorganism in soils and plant roots (Schwarz *et al.*, 2010). These obstacles caused by flooding and waterlogging may be fixed by grafting crops that are not tolerant onto tolerant ones. Liao and Lin (1996) found out that, grafting bitter melon (*Momordia carinthia* L.) onto luffa (*Luffa cylindria* Roem cv. Cylinder #2), the flooding tolerance of the bitter lemon (*Momordia carinthia* L.) was improved significantly although a trivial decline in the rate of photosynthesis, stomatal opening and closure, transpiration, soluble proteins, were detected. This was perhaps, related to the alterations in flooding tolerance (Schwarz *et al.*, 2010). On the other hand, the chlorophyll content decline in the leaves of the cucumber induced by waterlogging as noticed, was improved by grafting onto squash rootstocks (Kato *et al.*, 2001). The reduction in chlorophyll content may be attributed to chemical signals that are present in the sap of the xylem, stimulating the synthesis of ethylene in the leaves (shoots) resulting in decreases (Kato *et al.*, 2001) The same observations were also made when watermelon [*Citrullus lanatus* (Thunb.) Matsum

and Nakai cv. 'Crimson Tide'] was grafted onto *Lagenaria siceraria* SKP rootstocks, under water logging conditions (Yetisir *et al.*, 2006; Liao and Lin, 1996).

Likewise, adventitious roots and parenchyma formation were also witnessed in grafted water melon plant but not in non-grafted watermelon plants under flooding conditions. Additionally, a study by Petran (2013) found out that, grafting tomato on *S. torvum* rootstocks improved the flood tolerance and yield significantly. Flooding also takes place during the hot seasons in the tropics regions. Experimental studies carried out by AVRDC has revealed that grafting tomatoes onto flood tolerant eggplant rootstocks improved yield. Similar results were also confirmed for flood tolerant eggplant rootstocks (Black *et al.*, 2003). AVRDC has therefore recommended the growing of tomatoes on eggplants lines such as 'EG195' or 'EG203' and pepper on other chili pepper accessions such as 'PP0237-7502', 'PP0242-62' and 'Lee B' (AVRDC, 2003, 2009). These rootstocks recommended by avrdc are flood tolerant rootstocks. They are also resistant to bacterial wilt verticillium wilt and root knot-nematodes. Typically, waterlogging is often accompanied by an increased tolerance of these diseases mentioned. This also explains the indirect tolerance under flooding conditions (AVRDC, 2003, 2009).

2.4.3 Enhanced nutrient uptake

More often than not, rootstocks that are often used to graft vegetables such as tomatoes and eggplants are usually the wild relatives or genotypes of the same species, crossbreeds (hybrids) or a crossbreed between the wild relative and a domesticated type (interspecific hybrids). These commonly used rootstocks have been identified to have strong and tough root system than the domesticated type of the same specie (Davis *et al.*, 2008a). Irrefutably, a lot of studies have shown that grafted plants are more capable of efficiently absorbing macronutrients such as phosphorus, nitrogen, potassium, magnesium, calcium, iron, and other micronutrients as well as water to the shoot, compared to plants that are not grafted

(Pulgar *et al.*, 2000; Rivero *et al.*, 2004; Rouphael *et al.*, 2008b; Salehi *et al.*, 2010). An experiment carried out by Ruiz *et al.*, (1997) disclosed that, when melon, cv. ‘Yuma’ and ‘Gallicum’, were grafted onto three interspecific cucurbit hybrid rootstocks, ‘Shintoza’, ‘RS-841’ and ‘Kamel’, there was a remarkable increase in the uptake of nitrogen. These were also confirmed by an experiment conducted by (Colla *et al.*, 2010a).

The outcome of the results obtained by Colla *et al.*,(2010a) proved that there was significant increase in the marketable yield, nitrogen use and the efficiency of nitrogen uptake by a margin of 9%, 12% and 16% in that order when melon cv ‘Proteo’ was grafted onto ‘P360’ (an interspecific hybrid rootstock) in contrast to non-grafted Proteo plants. These findings were attributed to the differences in the nitrogen use efficiency between the grafted plants and non-grafted plants (Rouphael *et al.*, 2010). The resourceful uptake and utilization of nitrogen by grafting can reduce or abate yield losses as a result of low soil fertility. Additionally the use of grafting and breeding can be used to develop commercially adaptable varieties with better nutrient use (Simonne *et al.*, 2010). Besides the efficient use and uptake of nitrogen by grafting, the uptake and use of phosphorus can also be improved efficiently by grafting onto carefully selected and suitable rootstocks (Kawaguchi *et al.*, 2008). This was confirmed by (Qi *et al.*, 2006) for melon plants that were (*C. melon* L.) grafted onto ‘No. 1 ‘Shengzhen’ a pumpkin rootstock. In the same manner, numerous studies have proven that, the leaves of grafted plant do have high concentrations of phosphorus relative to the leaves of non-grafted plants (Flores *et al.*, 2010).

These findings were confirmed by Leonardi and Giuffrida (2006), for eggplant grafted onto ‘Beaufort’ (an interspecific hybrid); Rouphael *et al.* (2008a) for cucumber grafted onto ‘Shintoza’ (an interspecific hybrid), Salehi *et al.*, (2010) for watermelon grafted onto ‘P360’ and ‘PS1313’ (interspecific hybrids) and Colla *et al.*, (2010b) for melon grafted onto the Cucurbita rootstock ‘Shinto Hongto’ respectively. Since phosphorus has very low mobility, a

resourceful rootstock that has a strong and tough rootstock would be prudent to aid and efficiently improve the uptake of phosphorus.

By the same token, it has also been well documented that grafting enhances the uptake of potassium. A study carried out by Leonardi and Giuffrida (2006) to assess the differences that occur in plant growth and the uptake of macronutrients in eggplant grafted onto ‘Beaufort’ (an interspecific hybrid) and two *tomato* (*S. lycopersicum*) rootstocks ‘PG3’ and ‘Energy’ indicated that, there was significant increase in the uptake of potassium in the grafted eggplants in contrast to non-grafted eggplants. Similar results were also confirmed by Qi *et al.*, (2006) when melon plants were grafted onto ‘No. 1 Shengzhen’ (*C. moschata* Duch.) a pumpkin rootstock. In addition, Rouphael *et al.*, (2008b); Zhu *et al.*, (2008) and Albacete *et al.*, (2009) established related results for mini watermelon grafted onto pumpkin rootstock (‘PS 1313’), cucumber plants grafted onto ‘Chaojiquanwang’ a pumpkin (*C. moschata* Duch.), and for tomato (*S.lycopericum*) grafted onto three interspecific rootstocks resulting from a cross between cherry tomatoes (*S. lycopersicum* L. var. *Cerasiforme*) and a wild relative *S. cheesmaniae* (L. Riley)

Correspondingly, a research study by Fernandez-Garcia *et al.*, (2004b) found out that, grafting significantly increased the concentrations of calcium in the leaves of tomato plants. These findings were observed when two tomato cultivars ‘Fanny’ and ‘Goldmar’ were grafted onto the hybrid rootstock ‘AR-9704’. In addition, experimental studies comparable to the above findings brought to bare that, there were substantial increases calcium in the leaves of tomato plant that were grafted onto three interspecific hybrids ‘PG3’, ‘Energy’, and ‘Beaufort’.(Leonardi and Giuffrida, 2006).

A handful of research studies have also indicated the effect of grafting on the uptake magnesium. This largely hangs on the type of rootstock genotype chosen. More or less, some rootstocks may reduce the uptake of magnesium (Savvas *et al.*, 2009). On the other hand,

some rootstocks appear to increase significantly the uptake of magnesium (Leonardi and Giuffrida, 2006). As a final point, most of the above-referenced examples of improved uptake of nitrogen, phosphorus, potassium, calcium and magnesium by some of the graft combinations took place in experimental studies where the supply of these nutrients were adequate. It is therefore not clear whether the same result would be obtained or achieved under conditions of inadequate supply of these nutrients by grafting and also whether the uptake of these mineral nutrients would be beneficial in terms of yield. Additional research is therefore needed to come up with basic relationships which indicates higher yields owing to better uptake of these minerals by the use of grafting when the availability and accessibility of these nutrients are scarce, compared to non-grafted plants and self-grafted plants grown under the same conditions.

In some instances, grafting may either decline or has no influence on the uptake of micronutrients. This may be influenced by the selected rootstock and edaphic factors (Edelstein *et al.*, 2005; Rouphael *et al.*, 2008a; Savvas *et al.*, 2009; Huang *et al.*, 2010). Nevertheless, some rootstocks can increase the ability of grafted plants to take up and translocate micronutrients such as iron and/or manganese to the shoot, in comparison to self-grafted plant and non-grafted plants (Rivero *et al.*, 2004; Colla *et al.*, 2010b; Huang *et al.*, 2010).

2.4.4 Fruit quality

2.4.4.1 Visual appearance

The look and form of fruits and vegetables plays an important role in making buying decisions (Kays, 1999). This includes the size, shape, color, condition of the product or produce and absence of defects and decay. These quality attributes are external measures for the assessment of fruit vegetables at the market level whereas vital internal quality attributes such flavor, texture and health stimulating compounds are not well thought-out. Quite a

handful of results have been documented on the changes that occur in the quality of fruit vegetables as result of grafting and whether these changes are significant or not. Research studies by Xu *et al.*, (2005a) and Qi *et al.*, (2006) indicated that fruit size brought about higher yields owing to the fact that, grafted plants had strong root systems as well as being more resistant to soil borne diseases. Salam *et al.*, (2002) also established that, the yields were three times higher in grafted watermelon [*Citrullus lanatus* (Thunb.) Matsum and Nakai]. This was attributed to large fruit size and more fruit per plant.

Yetisir and Sari (2003) and Yetisir *et al.*, (2007) found out that watermelon plants that were grafted onto interspecific squash hybrid (*C. maxima* Duchesne×*C. moschata* Duchesne) increased the size of the fruit by 52%. Similar results were confirmed by Miguel *et al.*,(2004) when watermelon was grafted onto two squash interspecific hybrid rootstocks ‘Shintoza’ and ‘Tetsukabuto’. The grafted watermelon plants resulted an increase in the size of the fruit and yield of water melon by 90% and 26% respectively as compared to non-grafted water melon plants. In addition, Alan *et al.*, (2007) achieved larger fruit weight by 22% when watermelon cultivar ‘Crispy’ was grafted on different types of interspecific hybrids. Another study by Crino *et al.*, (2007) revealed that hybrid melon plant rootstocks, particularly ‘RS 841’, can produce fruit weight larger and bigger by 24% contrary to non-grafted melon plants. Further studies have also revealed that fruit size in eggplant and tomato can be increased by grafting (Passam *et al.*, 2005; Pogonyi *et al.*, 2005). These outcomes shows that fruit weight and size are influenced by grafting. The fruit weight and size are important elements that affect yield. Besides the fruit size and weight, the shape of the fruit was unaffected by grafting (Crino *et al.*, 2007; Proietti *et al.*, 2008; Roupael *et al.*, 2008a).

Contrary to the shape of the fruit, recent report by Tsabella *et al.*, (2013) indicated that the shape of pepper fruit is influenced by grafting. This was observed when two different pepper genotypes with round shapes were grafted onto long shaped cultivar ‘Piperaki long’. In

addition the changes that were detected in the fruit of the scion was hereditary for two generations of seeds gotten from the offspring. This shows that changes influenced by the rootstock onto the scion was heritable.

On the subject of colour, Colla *et al.* (2006a) found that colour parameters measured on the surface of melon were significantly higher in grafted plants relative to plants that were not grafted. The nonappearance of blemishes and decay is another significant quality attribute for fruits and vegetables. An experiment conducted by Chung (1995) showed that the occurrence of the physiological disorders seemed to be closely related with the rootstock. Strong rootstocks tends to absorb more nitrogen and calcium into the fruits, reducing the incidence of internal decay in 'Keumssaragi' oriental melons plants. The glossy look on the flesh of melons have been reported to be influenced by grafting (Taussig *et al.*, 1996).

2.4.4.2 Texture

An important trait that determines whether a consumer will buy or reject a product especially with fruit vegetables is texture. Certain elements such as biochemical elements, water content and the composition of the cell wall affect the texture of fruit elements. (Sams, 1999). As a result, any external factor such as temperature that upsets these elements can change the texture and for that reason lead to changes in final quality of the produce. One of the important attributes of texture is firmness. It is one of the important trait or qualities that is used to define the texture of fruit vegetables. Grafting can influence the firmness in a significant way. Research studies conducted by Yetisir *et al.*, (2003), and Huitron-Ramirez *al.* (2009) noted that watermelon fruits grown from grafted plants were firmer by 24% and 27%, respectively, compared to the fruits from the non-grafted plants regardless of cultivar and growing environments. Another study also reported a significant increase in the firmness of melon from 'Proteo' plants that were grafted onto 'P360' (*C. maxima* Duchesne×*C. moschata* Duchesne) by 32% (Colla *et al.*, 2006a).

In the same way, the flesh firmness of cucumber was higher in fruits from plants that were grafted onto 'Andong' (*Sicyos angulatus* L.) rootstock as compared to self-grafted plants (Lee *et al.*, 1999). The influence of rootstock on the firmness of the fruit may perhaps be related to modifications that might have existed in the fruit, owing to the changes that occur in the nutritional and water conditions of the scion. The firmness which is affected by grafting assured better postharvest storage and prevents injury during handling. This can prolong the postharvest quality of the fruit, especially the shelf life. Similar outcomes have been reported for solanaceous crops such as tomatoes and eggplants. (Nkansah *et al* 2013, Cheng *et al.*, 2012)

2.4.4.3 Flavor compounds

Sensitivity to fruit and vegetable flavour is a blend of sensory responses to aroma (smell) and taste. This usually takes place in the nose and mouth. Different fruit and vegetable constituents in addition to acids, sugars, volatiles and other compounds activates sensory responses that are known as flavour (Krumbein and Auerswald, 1998; Mattheis and Fellman, 1999). Several research experiments have measured these fruit and vegetable constituents in grafted plants. In addition, other parameters such as total soluble solids and juice pH have also been measured in grafted fruit and vegetables plants. It has been shown that sugar, acids, and juice pH can be influenced by grafting and the type of rootstocks used or selected (Davis *et al.*, 2008a, and b). Differences that exist in the fruit quality of grafted vegetables particularly, the flavour give the impression that flavour does not depend only on the scion but also on the rootstock. This has really instigated a lot of inconsistent reports in various research studies. Several reasons have been suggested as to why rootstocks affect the fruit quality of the scion. The best understandable reason is the rootstock/scion incompatibility or mismatch, which buoys up increase in growth or growth retardation of the scion, resulting in decreased water and nutrient flow through the graft union, in that way, causing the grafted

plants to wilt. A mismatch can be influenced by differences in tissue and structure, physiological and biochemical characteristics, growing stage of rootstock and scion, phytohormones and environment factors (Lee and Oda, 2003). A lot of reports on grafting propose that alterations or changes in the scion are governed by the rootstock, through uptake, synthesis, and translocation of water, minerals, and phytohormones (Lee and Oda, 2003).

A study by Hu *et al.*, (2009) found out that better uptake of nutrients in grafted seedlings increases photosynthesis, which is evident under adverse growing conditions. Under these adverse conditions the grafted plants produced higher yields with better sugar contents compared to non-grafted plants (Xu *et al.*, 2005b, 2006a and b). Experiments carried out by Yao *et al.*, (2003), Qian *et al.*, (2004) and Liu *et al.*, (2006) also found out that the total sugar content of watermelons that were grafted onto bottle gourd [*L. siceraria* (Mol.) Standl.] rootstock were lower than in non-grafted watermelons. These authors argued out that some of the Cucurbita spp. rootstocks can decrease the total soluble solids of watermelon fruits. Yetisir *et al.*, (2003) also gave evidence that soluble solids of watermelon were expressively influenced by grafting, however, the outcome hangs on the rootstock used or selected.

Contrarily, Miguel *et al.*, (2004), Colla *et al.*, (2006b), and Huitron-Ramirez *et al.*, (2009) pointed out that, there were no significant differences in soluble solids in watermelon fruit from scions grafted onto a squash interspecific hybrid; but then, Salam *et al.*, (2002) had disclosed a striking increase in the soluble solids of watermelon. Three different levels of irrigation arranged on different evapotranspiration rates (ET 1.0, 0.5 and 0.75) and two grafting combinations were examined by Proietti *et al.*, (2008) to evaluate the effect of grafting on the fruit quality of mini water melon under different irrigation regimes. They found out that characteristics, such as glucose, fructose, sucrose concentration and total

soluble solids concentration which defines flavour, were significantly different in grafted than in non-grafted plants

Lopez-Galarza *et al.*, (2004) disclosed that grafting watermelons onto ‘Shintoza’, (an interspecific squash hybrid rootstock) in addition with the use of synthetic cytokinin CPPU [1-(2-chloro-4-pyridyl)-3-phenylurea] hindered the build-up of hexose and sucrose, and for that reason reduced the amount of sugar in the flesh of the fruit when compared to non-grafted plants under greenhouse environment. The amount of monosaccharide sucrose was greater than before. This may possibly be related to the changes in fruit flavor. It might be possible that some amount of cytokinins were produced by the squash rootstocks which were transported to the scion prompting an undesirable effect on the quality of the fruit. It is remarkable to note that, the total soluble solids content from fruits of grafted plant reported by Lopez-Galarza *et al.*, (2004) were consistent with Miguel *et al.*, (2004). A study carried out by Lee *et al.*, 1999 indicated that there was a significant decline in flavour compounds from fruit of cucumber grafted onto ‘Heukong’ rootstock (*C. ficifolia*). These authors further established that, the reduction in flavour compounds can be abridged by using appropriate rootstocks. This suggests that, grafting onto suitable rootstocks can enhance fruit quality, mostly flavour compounds. Matsuzoe *et al.*, (1996) carried out an experiment to evaluate the fruit quality of ‘Momotaro’ tomatoes as influenced by grafting ‘Momotaro’ onto three different solanum species rootstocks, *Solanum sisymbriifolium*, *Solanum torvum*, and *Solanum toxicarium*. These authors established that, the fruit quality of the tomato plants grafted on the *Solanum* species was not different as compared to non-grafted plants. The amount of sugars and organic acids in fruits were marginally different with the rootstocks, and the quantity of fertilizer used.

Additionally, Di Gioia *et al.* (2010) also found out that there were no significant differences in total soluble solids concentration in non-grafted tomato ‘Cuore di Bue’, tomato, as

compared to tomatoes grafted onto two inter-specific (*Solanum lycopersicum* L. × *Solanum habrochaites* S. Knapp & D.M. Spooner) rootstocks ('Beaufort F1' and 'Maxifort F1') grown under greenhouse conditions. In the same way, Khah *et al.*, (2006) noticed that, no significant differences were found in soluble solids regarding non-grafted tomato cv. 'Big Red' and tomatoes grafted onto 'He-Man', an interspecific hybrid (*S. lycopersicum* L. × *S. habrochaites* (S. Knapp & D.M. Spooner) and 'Primavera' (*S. lycopersicum* L.) rootstocks under open-field and greenhouse conditions. It is also well known that aromatic volatiles add up to the flavor, in addition to sugars and acids in fruit vegetables (Krumbein *et al.*, 2004).

2.4.4.4 Sought after compounds

Medical studies have shown that there is an important relationship between the consumption of vegetables and fruits and chronic diseases in humans. Vitamins, minerals and carotenoids such as lycopene and β - carotene are essential compounds required for human health. Thus, higher amounts of these health related compounds in fruits vegetables would be very importance (Bazzano *et al.*, 2002; Schreiner, 2005). Higher lycopene levels were also found in the fruits of tomato plants that were grafted as likened to the fruits of non-grafted tomato plants (Gerster, 1997), all the same, there were no significant difference in lycopene levels among non-grafted tomato cultivar 'Big Red' (*S. lycopersicum* L.) and tomatoes grafted onto 'He-Man' (*S. lycopersicum* L. × *S. habrochaites* S. Knapp & D.M. Spooner) and 'Primavera' (*S. lycopersicum* L.) rootstocks under open-field and greenhouse conditions (Fernandez-Garcia *et al.*, 2004b). Correspondingly, Davis *et al.*, (2008b) found out that grafting watermelon improved the lycopene and total carotenoids by 20%. Proietti *et al.*, (2008) found out that, the total amount of vitamin C in grafted mini watermelons were higher than non-grafted mini-watermelons by a margin of 13% and 7% respectively. Likewise, Huang *et al.*, (2009) also pointed out that there was an increase in the vitamin C content of cucumber fruits grafted unto figleaf gourd and 'Chaofeng Kangshengwang'. Studies conducted by Fernandez-

Garcia *et al.*, (2004b) revealed significant increase in the vitamin C content of tomatoes when the tomato cultivars ‘fanny’ and ‘Goldmar’ were grafted onto the hybrid rootstock ‘AR-9704’ under salt stress conditions. On the contrary, Di Gioia *et al.*, (2010) pointed out that, the vitamin C content in the fruit of tomatoes grafted onto two interspecific hybrid rootstocks ‘Beaufort F1’ and ‘Maxifort F1’ reduced by a margin of 14% to 20% compared to fruits from non-grafted tomato plants. These results stresses on the fact that, rootstocks play a key role on the impact of fruit quality. Hence, appropriate selection of rootstocks for grafting should be a priority.

Further studies have also confirmed the effect of grafting on minerals such as phosphorus, magnesium, calcium, potassium and iron. Rouphael *et al.*, (2008a) found out that fruits from watermelon plants grafted onto the hybrid rootstock ‘PS 1313’ (*C. maxima Duchesne* × *C. moschata Duchesne*) under stress conditions showed fruits with the same phosphorus and calcium concentrations. In the same way, potassium and Magnesium levels were significantly improved by grafting combinations. This is really remarkable in the sense that, fruits and vegetables contribute substantial amount of potassium and magnesium to the food humans eat. Likewise, Khah *et al.*, (2006) also found out that the concentration of calcium in tomato grafted onto ‘He-Man’ rootstock was higher than the fruits from non-grafted tomato plants. Similar results were confirmed by Tsouvaltzis *et al.*, (2004) when the tomato cultivar, ‘Sacos’ was grafted onto ‘Primavera’ rootstock

2.4.4.5 Unwanted compounds

Toxic mineral elements such as cadmium, copper, arsenic, mercury and zinc find their way to lands used for growing crops from a different sources. These sources include industrial waste, communal (sewage water) waste and from the indiscriminate use of pesticides and fertilizers. It has been made known that grafting can be used to mitigate and avert the entry of these toxic mineral elements. A study conducted by Rouphael *et al.*, (2008b) indicated that, the

build-up of copper in leaf and tissues of fruits was significantly lower in cucumber plants grafted onto the 'Shintoza' rootstock (*C. maxima* Duchesne × *C. moschata* Duchesne) compared to non-grafted cucumber plants. The tolerance of copper in grafted plants may perchance be as a result of a lower build-up of Copper in leaves and in fruits.

Similarly, experiments carried out by Edelstein and Ben-Hur (2007) and Edelstein *et al.*, (2007) indicated that boron, zinc, selenium, manganese, copper, titanium, nickel, and cadmium concentration in the fruits of melon plants ('Arava'), grafted onto the commercial Cucurbita rootstock 'TZ-148' were significantly lower than fruit from non-grafted plants. The lower concentration levels of these mineral elements may be attributed to modifications of the root system of both the grafted and non-grafted plants. It can therefore be established that the root system of the grafted plants were more selective and absorbed smaller amount of trace elements and heavy metals than that of the non-grafted plants. Correspondingly, an experiment carried by Arao *et al.*, (2008) indicated that, eggplant grafted onto *S. torvum* reduced the cadmium levels in the fruit of eggplant by 63–75% compared to eggplants grafted onto *Solanum melongena* and *Solanum integrifolium* in Cadmium polluted and non-polluted soil.

Nitrate concentrations in vegetable has been increasing at an alarming rate and this has raised concerns in the health community owing to the fact that, it has a lot of health repercussions. Nitrates itself is reasonably non-toxic but its constituents may bring about a number of health hazards (Santamaria, 2006). Proietti *et al.*, (2008) showed that no significant difference were found in the nitrate concentration of grafted watermelon plants and non-grafted plants that were grown under three different irrigation regimes. In the same way, Colla *et al.*, (2010a) pointed out that no significant difference was detected in the nitrate concentration of melon fruits that were grafted onto the Cucurbita rootstock 'P360' as likened to non-grafted melon cultivar, 'Proteo' under three nitrogen fertilizer rates (0, 60, or 120 kg ha⁻¹). Lastly, no

significant differences were found in nitrate concentration in the fruit of grafted tomato plants and non-grafted plants (Fernandez- Garcia *et al.*, 2004b). In agreement to the few studies above, it look as if that rootstocks did not influence the build-up of nitrates in the fruits of grafted plants.

2.4.5 Improvement of crop productivity

Even though vegetable grafting is characteristically related to the reduction of disease and/or abiotic damages, yield was in excess, devoid of the incidence of these familiar abiotic stressors. There were significant increase in yield by grafting watermelon (Yetisir and Sari 2003). Similar results were also observed in cucumber (Pavlou, *et al.*, 2002). In tomato, the increase in yield indicated that vigorous root system of grafted plants lead to an unexpected crop harvest (Upstone 1968). Equally increase in yield have been seen in eggplant, even without the incidence of soil-borne diseases. Eggplants grafted unto wild solanum rootstock, showed a remarkable increase in yield compared to non-grafted plants (Ibrahim *et al.*, 2001; Rahman *et al.*, 2002). Under protected environment, eggplant grafted onto tomato rootstock showed better yields as a result of increased fruit size and fruit number compared to non-grafted plant and self-grafted eggplants. (Passam, Stylianou, and Kotsiras 2005). Similar observations were also found in tomatoes, this is typically, as the effect of bigger fruit size (Pogonyi *et al.*, 2005).

Research studies have shown that mechanisms that resulted in better yields were undoubtedly high, due to augmented water and nutrient uptake amid different vigorous rootstock genotypes. Stomatal conductance was improved in tomato when grafted onto vigorous rootstock (Fernandez- Garcia *et al.*, 2004a). The importance of rootstock genotype was realized as photosynthesis rates were higher in tomato (Matsuzoe *et al.*, 1993). As a result of the improved vigour that growers have observed from grafting with interspecific and hybrid rootstocks in tomato, many growers have gotten rid of decreased planting densities (Besri,

2003). These growers make use of production systems that can benefit them in terms of enhanced vigour. Crop productivity analysis indicated that although half as many plants were used per hectare, yields were increased by as much as 15% - 20% on a per hectare basis (Besri, 2003).

2.5 Grafting methods and innovations

2.5.1 Hole insertion grafting

Grafting is the ability to join together two living plant parts, to produce, a living single plant. Different methods have been adopted ever since man began learning the art and skill of fitting together plant parts. These techniques and methods are diverse in a number of ways and is determined extensively on the kind of crop, the experiences and preference of the grafters', facilities and tools available, the number of graftings required as well as the reason for grafting (Sakata *et al.*, 2007). In choosing the applicable grafting method, it must be taken in to thought, the plant, the rootstock, plant maturity, number of plants to graft, environmental control and healing structure (Sakata *et al.*, 2007). The grafting process involves different stages. These include (1) Selection of the rootstock and scion species, (2) Making a graft union by physical method, (3) Healing of the union, and (4) Adaptation of the grafted plant before planting them out onto the field (Lee *et al.*, 2010). There are different types of grafting methods. Manual or hand grafting is the main grafting method, although grafting machines, semi-automatic machines and robots for grafting have been made available economically (Lee *et al.*, 2010). These methods can be used for herbaceous grafting. The most frequently used methods for herbaceous grafting are

2.5.2 Splice grafting or tube grafting

Splice grafting is one of the popular method practiced by experienced growers and commercial seedling growers. This method can be done by hand, machine, or robot and can be used to graft most vegetables (Lee *et al.*, 2010). One of the benefits of using this method is

that, is the production of strong and healthy grafted seedlings. This method ensures better fusion of the vascular bundles, together with a strong union strong enough to accommodate harsh post-graft handling. For the cucurbitaceous crops, the growing point together with one cotyledon are detached.

The scion is carefully placed on the on the rootstock, and held tightly together in position using normal grafting clips. It is one of the common methods for cucurbitaceous plants (Lee *et al.*, 2010). This is also called one cotyledon splice grafting. For solanaceous crops the scion and rootstock are completely cut at the same angle of about 30 or 45 degrees or greater. The scion is placed on the rootstock and are held tightly in position by using grafting clips or elastic tubes (AVRDC, 2003; Lee *et al.*, 2010). Cut angles that are steep increases the surface area, bringing about greater pressure between the scion and the rootstock, more contact between the vascular bundles and accordingly, higher survival is achieved (Oda, 2007). This method is very easy to perform and can be used to graft a lot of plants in a relatively short time (Alai, 2014; Hartman *et al.*, 2002; Oda, 2007).

2.5.3 Cleft grafting

Cleft grafting method is also an effective method of grafting herbaceous plants and may be somehow different from those of tree plants. With this method, the rootstock is truncated and a vertical cut is made downwards through the centre of the rootstock about 1-cm long (Lee *et al.*, 2010). The scion is pruned to have 1-3 leaves and the stem cut in the form of a wedge. The wedged scion is inserted into the split made in the rootstock. A clip is then used to hold firmly the scion and the rootstock in position until the graft union is healed or formed. Beforehand, cleft grafting had been used to graft cucurbits in more than a few countries, but the practice of this method is customarily restricted to solanaceous crops these days (Lee *et al.*, 2010).

2.6 Rootstocks used for grafting tomatoes

Different kinds of rootstocks have been used in grafting tomatoes. The possibility of these rootstocks in providing prospective benefits are enormous. For instance, a wide range of resistance and/or tolerance to diseases, abiotic stress, high yields and fruit quality with long shelf life (Oda, 2002; Lee, 2003; Kubota *et al.*, 2008). Tomatoes are generally grafted onto hybrids and interspecific hybrids. However, in recent times, *S. melongena*, (eggplants) and its close relatives *S. macrocarpon* (Gboma, African eggplant) and *S. aethiopicum* (gilo, Shum, kumba group) have been identified as potential and effective rootstocks for grafting tomatoes (Gisbert *et al.*, 2011). Quite a lot of research work have also identified wild relatives of tomatoes such as the *S. torvum* for tomatoes and other solanaceous plants. Research have revealed that *S. torvum* has high resistance to many diseases such as bacterial wilt and verticillium wilt but due to uneven germination of its seeds, it is quite unmanageable to graft on large scale basis (Blesto *et al.*, 2003).

Other wild genotypes such as *S. habrochaites* have also been proven to be effective against extreme cold temperatures (Venema *et al.*, 2008). Even though resistance and tolerance to diseases are the basic factors used in selecting rootstocks for grafting tomatoes and other herbaceous plants, other factors such as resistance or tolerance to abiotic stress (drought, salinity, extreme temperature conditions) and specific qualities of interest such as fruit quality and shelf life must be well thought-out. Presently, attention has been drawn to the breeding of improved rootstocks. This has been on the increase, especially with the advent of private seed companies (King *et al.*, 2010).

2.7 The grafting process

Tomato grafting can be done at any stage of the plant. However, this depends on the purpose and the method being employed. It is done effectively at a young age ranging from two weeks to four weeks (Oda, 1999). An indispensable clue for a successful graft is that, the

scion and the rootstock must be similar to ensure direct contact of the vascular cambium (AVRDC, 2003; Kleinheinz *et al.*, 2013). When deciding to graft, sowing dates for the rootstock and scion, the germination rate of both the scion and rootstock must be considered. Growth rate and germination period differ from variety to variety and from season to season. It is therefore important for grafters' to regulate the dates according to their specific conditions. It is also very important that seedlings rootstocks and scions are grafted after they have developed 2-3 leaves with a stem diameter of 1.5mm to 2.0mm at the point of cutting out. This involves 14-16 days of development (AVRDC, 2003; Kubota, 2008; Rivard and Louws, 2006). Research studies have made known that, the tube grafting method is very simple and very effective owing to the fact that, more plants can be grafted as likened to the use of other grafting methods. The grafting procedure commences when plants are small. During the grafting process, it is important that the stem diameter of the rootstock matches with the stem diameter of the scion. The rootstock and scions are cut at an angle of 30, 45, 70 degrees slightly above the cotyledon (first true leaves) or below the cotyledon depending on what is preferred (AVRDC, 2003; Kleinheinz *et al.*, 2013). The graft union should be above the cotyledon to prevent infection and adventitious root formation (Rivard and Louws, 2006). A 10 mm long latex tube or a silicon clip is slid over the scion stem (this depends on the preferred grafting clip). While using the latex tube, the grafter must make sure that the cut angles of the tube are parallel to the stem. The scion is inserted half way into the tube. The scion is cautiously slid over the stem of the rootstock. The cut angles of the rootstock and tube must also be parallel. The tube remains fixed to the graft union of the grafted plant until the tube weakens and falls off the plant in the field. The growth medium must not be too wet. This stops the rootstock from being turgid. In addition, it also interrupts with the healing of the graft union. Graft holding materials such as silicon clips, loaded spring clips and self-made tubes could also be used. This depends on the skill and preference of the grafter. During

grafting, proper sanitation must be guaranteed. Clean working area, clean and sterilized tools must be used to limit the spread of pathogens (Kleinheinz *et al.*, 2013).

2.7.1 Graft healing process

After grafting, the grafted plants are moved immediately to the healing chamber. Several challenges are encountered in managing the healing chamber. The healing period is the most significant phase during grafting (Kleinheinz *et al.*, 2013). This is because grafted plants are highly vulnerable to wilt diseases and failure of the graft to heal. It is therefore recommended that grafted plants are kept in the healing chamber after grafting at an appropriate relative humidity and temperature rates to aid the healing of the graft union (Kleinheinz *et al.*, 2013). A number of healing chamber designs have been recommended by researchers, however, the conventionally recommended healing chamber design is a shaded plastic dome kept at a temperature range between 25 and 32 degrees Celsius with high relative humidity above 85% for the initial three to five days (Black *et al.*, 2003; AVRDC, 2003). However, other researchers have proposed a temperature range of 21-28 degrees Celsius (Kleinheinz *et al.*, 2013). Approximately after five days within the healing chamber, the grafted plants are gradually introduced to sunlight through partial shading. The grafted plant remain in the chamber approximately one week (Kleinheinz *et al.*, 2013). Research has shown that, it takes about 7 to 8 days to achieve vascular connection between the rootstock and scion and approximately 14 to 15 days for the graft union to be completely healed (Johnson and Miles, 2011). The entire grafting process takes about 30 to 33 days from sowing (AVRDC, 2003).

2.7.2 Critical factors that ensures effective grafting

Anyone experienced with grafting knows that grafting can be quit challenging. In some instances, results obtained can be inconsistent, successful with high percentage graft take whereas in some instances, the result can be discouraging (AVRDC, 2003). There are several factors that influences the healing of the grafting union, some can be controlled whiles some

cannot be controlled. Critical factors such as compatibility of the rootstock and scion, direct contact of the vascular cambium of the rootstock and scion, proper functional state of the rootstock and scion, prevention of withering, proper care of the grafted plants as well as skill of the grafter are required to warrant the success of the graft union (Kleinheinz *et al.*, 2013). Unproductive graft union can be caused by mismatching of the scion and rootstock, lack of skill and expertise, adverse environmental conditions, diseases and incompatibility (Hartman and Kester, 2011). Compatibility of the scion and rootstock is a biological expression. Graft failure is likely to occur between plants that are not compatible while with incompatibility, inadequate graft union may occur (Kumar, 2011). This may lead to either graft failure or overgrowth and retardation of growth of the scion or the rootstock. This is generally due to the fact that, poor fitting together of the vascular bundles take place between cambial layers of the scion and the rootstock (Hartman and Kester, 2011).

A successful graft union starts with a series of events that takes place during the healing process. These include multiplication of the callus from the scion and rootstock, formation of a callus bridge, vascular separation and production of the xylem and phloem (Hartman and Kester, 2011). Grafting incompatibility is frequently misrepresented as an alternative expression for “grafting failure” or vice versa. A lot of explanations of graft incompatibility are centered on biological and natural processes (Andrew and Marquez, 1993). Over and over again, grafting incompatibility is used to mean failure or stoppage of the growth of the new grafted seedling. This stoppage can take place as a result of a number of reasons, including taxonomic variations, cellular recognition and presence of diseases (Andrew and Marquez, 1993). Nevertheless, in the literature both terms are used synonymously, as a result grafting failure can be caused by grafting incompatibility, and this has definite reasons.

Additionally, fundamental environmental elements such as temperature and relative humidity must be met to guarantee successful graft union. These are critical factors that greatly affects

the success of a graft union (Alai, 2014). Temperature have been shown to have a noticeable effect on the formation of at the graft union. At high temperatures, formation of the callus is increased and the vice versa. Relative humidity also affects callus formation in various ways. Too much or low relative humidity creates conditions necessary for the development of disease and wilts. For that reason, it is important that conducive environment with optimum relative humidity and temperature to enhance the healing of the graft union are provided (Kleinheinz *et al.*, 2013).

2.8 Compatibility of the scion and the rootstock

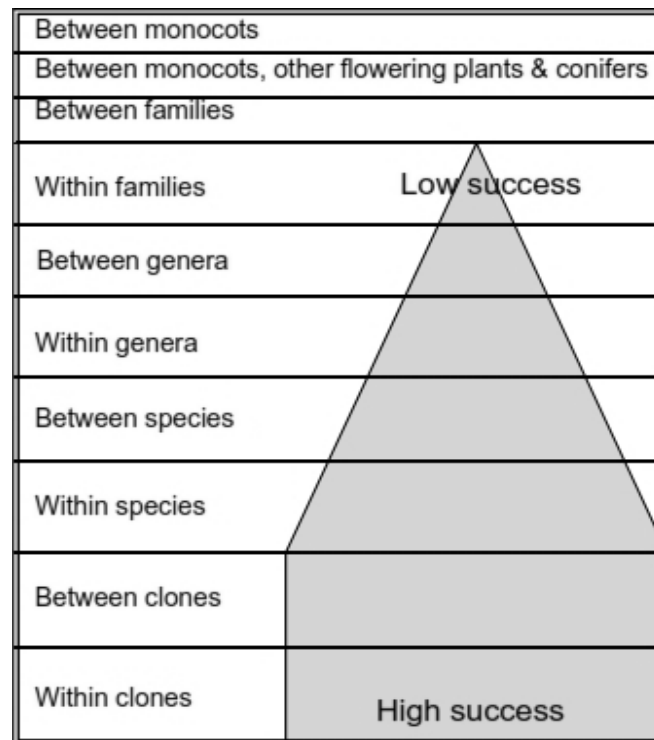


Figure 1 The Compatibility pyramid

Source: (Kumar, 2011).

From the compatibility pyramid, monocotyledonous plants cannot be grafted. These include plants in the grass family. This is due to the nature and arrangement of the vascular bundles. However, conifers, flowering plants, woody plants, in addition to a lot of the herbaceous plants can be grafted successfully. In plants, the more closely related the rootstock and the scion are (taxonomically), the better the likelihood for the graft to be effective and successful (Copes and Oliver, 1970).

To sum up, other factors such as viruses, insect pests and diseases can cause the failure of the graft union. Virus are known to cause mismatch complications which may be recognised after the graft union has been effective. Insect pest feed on the callous creating wounds allowing the entry of pathogens leading to graft failure (Hartman and Kester, 2011). It important to make sure that high sanitary standards are observed prior to grafting and after grafting. Similarly, skill and expertise are also key factors to consider. A good grafter knows all the

techniques and practices necessary for a successful graft union. It is a must to ensure that, there is precise direct contact of the scion and rootstock (Kleinheinz *et al.*, 2013). Grafting can affect countless aspects of fruit vegetable quality. Rootstock/scion combinations ought to be carefully chosen for particular climatic and environmental conditions. Proper selection of rootstock/scion combinations can help control soil borne diseases, increase yield and improve fruit quality with long shelf life (Davis *et al.*, 2008b; Nkansah *et al.*, 2013). Regardless of the benefits of vegetable grafting, it is still rare in Ghana and no peer-reviewed research exploring the potential benefits of vegetable grafting in Ghana could be found. Thus, researchers, and extension professionals need to work together harmoniously to assimilate this current technology as an effective tool for sustainable production of high-quality vegetables such as tomatoes in Ghana.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Experimental site

The experiment was conducted at the teaching and research farm of the University of Ghana Forest and Horticultural Research Centre (FOHCREC) Okumaning. The centre is 11 km from Kade in the Kwaebibirem District of Eastern Region and 123km north-west of Accra. It lies on Lat. 6° 09' and long. 0° 59'. Table 1 shows the climatic conditions during the experiment.

Table 1 Climatic data during the experimental period

Month	Temperature (°C)		Relative humidity (%)		Rainfall
	Maximum	Minimum	Maximum	Minimum	Mm
November, 2014	34.40	23.51	94.98	39.52	0.47
December, 2014	34.57	22.79	99.11	45.15	1.90
January, 2015	34.57	22.54	98.64	46.19	2.11
February, 2015	34.80	22.60	99.43	47.75	0.70

Source: FOHCREC, Okumaning, Kade

3.2 Transplant production, Grafting and healing process

Two scion varieties and three rootstock varieties were used in the experiment. The scion varieties were 'Nkansah HT' and 'Fadæbege' while the rootstock varieties were 'Black Beauty', 'Gboma' and 'Obaapa'. Initial seed test indicated that percentage seed germination was over 90% in all the varieties. 'Gboma' had the lowest germination rate and the highest germination time.

An amount of carbonated rice husk was collected and sterilized in hot water at 100 °C for forty five minutes. After forty five minutes, the carbonated rice husk was allowed to cool under ambient temperatures before potting into seed trays. The carbonated rice husk was used as a media for raising the rootstock and scion seedlings. Prior to potting, the seed trays were disinfected with 40% sodium hypo-chloride bleach solution. The rootstock seeds were sown on 5th January, 2015 and the scions were sown seven days later to ensure similar stem diameters at the time of grafting because of differences in germination rate and growth rates. The entire treatments were grafted with the cleft method. They were grafted at 5-6 true leaf stage. Grafting took place 28 days after the scions were sown. The rootstock was truncated and a cut of about 5cm long was made straight down. The scion stem was cut in a form of wedge and inserted in the split made into the rootstock. A spring loaded clip was used to hold the scion and rootstock firmly until the graft union healed. All grafted seedlings were immediately placed inside a 2m x 4m dome-shaped healing chamber with a plastic cover, damp jute sack cover and damp jute sack on the floor pan to provide and help maintain high relative humidity in the healing chamber. High Relative humidity was maintained between 95% -100% and temperature was maintained between 26°C - 28°C. After the healing of the grafted union, just about seven days later, all the grafted seedlings were removed from the healing chamber and transferred to a greenhouse nursery to harden off for 7 days for complete healing of the graft union, before transplanting.



Plate 1 Healing chamber



Plate 2 Healing of grafted plants (3 days after grafting)



Plate 3 Acclimatization of grafted plants in the greenhouse nursery (8 days after grafting)

3.3 Experimental design

A pot experiment was carried out using plastic pots filled with sterilized carbonated rice husk arranged in a randomized complete block design with eight treatments replicated four times in a greenhouse. The treatments were: (i) 'Nkansah HT' grafted onto 'Gboma', (**HT** × **GB**) (ii) 'Fadεεbege' grafted onto 'Gboma', (**FB** × **GB**) (iii) 'Nkansah HT' grafted onto 'Black Beauty' (**HT** × **BB**), (iv) 'Fadεεbege' grafted onto 'Black Beauty' (**FB** × **BB**), (v) 'Nkansah HT' grafted onto 'Obaapa' (**HT** × **GE**), (vi) 'Fadεεbege' grafted onto 'Obaapa' (**FB** × **GE**), (vii) non-grafted 'Fadεεbege' **NG (FB)** and (viii) non-grafted 'Nkansah HT' **NG (HT)**. Each experimental unit had 20 plants. The whole experiment was repeated twice.

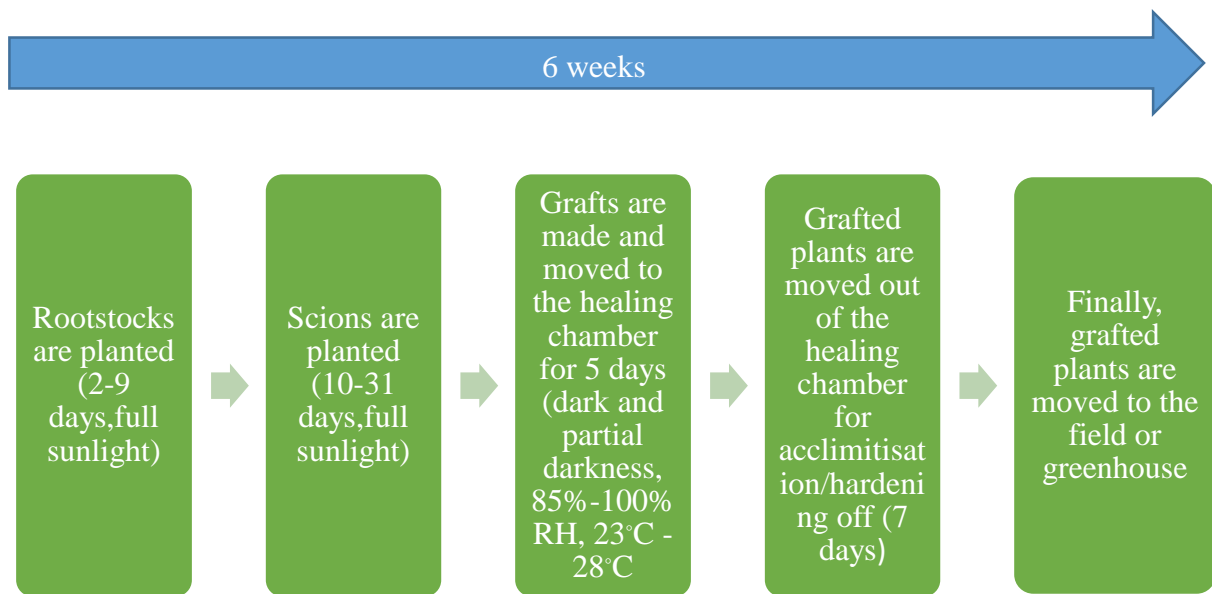


Figure 2 Schematic representation of the grafting process

3.4 Cultural management

All grafted, and non-grafted plants were transplanted into pots containing sterilized carbonated rice husk (biochar) as a potting media on 15th March, 2015. The pots were arranged at spacing of 0.60m x 0.40m to establish a density of 2.4 plants m⁻². Crop starter was applied at the rate of 60ml/ 15L of clean water. In addition, application of 19-19-19 N.P.K (Polyfeed, Haifa chemicals limited) water soluble fertilizer at the rate of 90g/15L of clean water was done every two weeks. Water soluble potassium nitrate (Multi-k, Haifa chemicals limited) was applied by foliar at flower bud initiation at the rate of 100g/15L of clean water, every two weeks until full blossom. Supplemental calcium in the form of calcium nitrate was also applied at fruit set at the rate of 5g per plant. An integrated crop protection and management approach was used to control all major pest and diseases. The potted plants were trained vertically by using strings tied to base of the plant, looped around the plant and then supported to a pole vertically. Lateral stem and basal leaf pruning operations were carried out on plants. Watering (irrigation) was provided daily throughout the growing season.

3.5 Data collection

Ten out of the 20 plants from each experimental unit in each replication were used for the evaluation. Two were used for the shoot weight measurements while the others remained as guard plants and were not included in the evaluations. Data were collected on the following parameters:

- **Percentage graft take:**

This was taken by dividing the total number of plants that survived (established graft union) after the healing process of the grafted plant by the total number of grafted plant for each graft combination, expressed as percentage.

- **Plant height**

Measurement for plant height was recorded at different growth periods. They were recorded at 14 DAT (days after transplanting), 28 DAT, 42 DAT and at 56 DAT. This was measured by using a metallic meter rule (2m long) from the base of the plant to the apical growing point of the plant.

- **Stem diameter**

The stem diameter was measured 5cm above the ground level with an electronic digital caliper. Measurements were recorded at 14, 28, 42 and at 56.

- **Leaf number per plant**

The number of leaves per plant were counted manually. Similarly, they were also recorded at 14, 28, 42 and at 56 DAT.

- **Days to flowering**

The days to flowering was measured by counting the number of days after transplanting to 50% flowering.

- **Days to harvesting**

This was measured by counting the number of days after transplanting to the day of the first harvest at fully ripened stage.

- **Fruit number, fruit weight and yield per plant**

Fruits were hand harvested, counted and weighed with an electronic digital scale, per plant from each experimental plot. The fruits were harvested at the full ripened stage.

- **Shelf life**

10 representative fruit samples from each treatment were harvested at full ripened stage and stored under ambient temperature and relative humidity conditions. The shelf life was determined by counting the number of days from day of storage to the softening of the fruits.

- **Fruit quality analyses**

The Soluble solids content (Brix), Titrable acidity, pH, vitamin C, lycopene and firmness were examined on 10 representative fruit samples from each treatment were used. An extract was obtained by blending each fruit. The soluble solids content (Brix) was determined using a portable, digital refractometer (Atago DR-A1 digital refractometer) and values expressed in percentage Brix. The titrable acidity (TA) was determined by titrating 50 mls of the tomato extract using 1M NaOH solution in a burette at pH 8.1 using phenolphthalein indicator. The results were expressed as a percentage of citric acid equivalents in the juice (10mg/100ml). The pH was determined using a pH meter and the firmness determined using a penetrometer. The vitamin C (ascorbic acid) was determined by titration method (Bekele and Geleta, 2015). The lycopene content was determined by a spectrophotometric method using the formulae:

$$\text{Lycopene} = -0.0458 A_{663} + 0.372 A_{505} - 0.0806 A_{453}.$$

The results were expressed in mg per 100ml of extract.

3.7 Statistical analysis

All data were analysed using one way analysis of variance software Genstat, 12th edition with Fisher's LSD test for comparison among the treatments. Tables, pictures and graphs were used to represent results where necessary.

CHAPTER FOUR

4.0 Results

4.1 Seed Germination Test

Germination of seeds in cell trays were observed at 5 to 6 days for ‘fadeɛɛgye’ and ‘Nkansah HT’ and 7 days for ‘Black beauty’ (BB), ‘Gboma’ (GB), and ‘Obaapa’ (GE) respectively, after sowing (Table 2). The mean germination time for the rootstocks and scions did not go beyond 10 days. ‘Gboma’ (GB), ‘fadeɛɛgye’ (FB), and ‘Nkansah HT’ (HT) exhibited high germination percentage (≥ 90) (Table 2). GE exhibited lower germination percentage, however, this was not significantly different from ‘Black beauty’ (BB), ‘Gboma’ (GB) and ‘Nkansah HT’ (HT) (Table 2). High mean germination rates could be observed at 0.16 GMR/day⁻¹ and 0.18 GMR/day⁻¹ for ‘Nkansah HT’ (HT) and ‘fadeɛɛgye’ (FB) respectively. In contrast, lower mean germination rates was observed for ‘Black beauty’ (BB), ‘Gboma’ (GB), and ‘Obaapa’ (GE). Regardless of the lower mean germination rate, they were not significantly different from each other (Table 2). On the contrary, ‘Gboma’ (GB) had the lowest mean germination rate (Table 2).

Table 2 Seed germination of *Solanum* species used in the grafting experiment

Plant material	G (%) ^X	GMT/day ^Y	GMR/day ⁻¹	CV
<i>Solanum melongena</i> ‘Black Beauty’ (BB)	88.00 b	7 ab	0.14 cd	4.43
<i>Solanum marcrocarpon</i> ‘Gboma’ (GB)	90.00 ab	8 a	0.13 d	3.57
<i>Solanum aethiopicum</i> , ‘Obaapa’ (GE)	86.67 b	7 ab	0.14 cd	4.47
<i>Solanum lycopersicum</i> , ‘Nkansah HT’ (HT)	90.00 ab	6 bc	0.16 b	4.70
<i>Solanum pimpillifolium</i> , ‘fadeɛɛgye’ (FB)	92.33 a	5 c	0.18 a	4.80

Mean values within a column marked with the same lowercase letters are not significantly different based on Fisher’s LSD (P=0.05)

^X Germination percentage; ^Y Mean germination time; ^W Coefficient of variation and

^Z Mean germination rate

4.2 Graft success

Grafting with the cleft method was very successful with success percentages $\geq 80\%$ in all grafting combinations (Table 3). No significant differences were found in the success rate among graft combinations which had percentages of graft success ranging from 87% (HT \times GE) to 90% (HT \times GB) (Table 3). Comparing to other graft combinations, HT \times GE had the lowest graft percentage success (87%). However, the lower graft success percentage of HT \times GE was not significantly different from the other graft combinations (Table 3). Shoot growth was observed at the graft union for all graft combinations.

Table 3 Percentage graft success 14 days after grafting

Treatment	Graft success (%)
FB \times BB	89^a
HT \times BB	89^a
FB \times GB	89^a
HT \times GB	90^a
FB \times GE	89^a
HT \times GE	87^a

Mean values within a column marked with the same lowercase letters are not significantly different based on Fisher's LSD ($P=0.05$). **FB \times BB** and **HT \times BB**: 'fadeebegye' and 'Nkansah HT' grafted onto 'Black beauty' rootstock; **FB \times GB** and **HT \times GB**: 'fadeebegye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB \times GE** and **HT \times GE**: 'fadeebegye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock.

4.3 Plant growth attributes

4.3.1 Plant height

Plant growth performance in terms of plant height was significantly higher for FB \times BB (46.2cm, 89.0 cm, 116.9cm and 142.5cm) followed by FB \times GB (42.8cm, 78.3cm, 114.0cm and 136.5cm), FB \times GE and the least was NG (FB) (33.7cm, 63.4cm, 78.5 and 88.4) over the growth period (Figure 3).

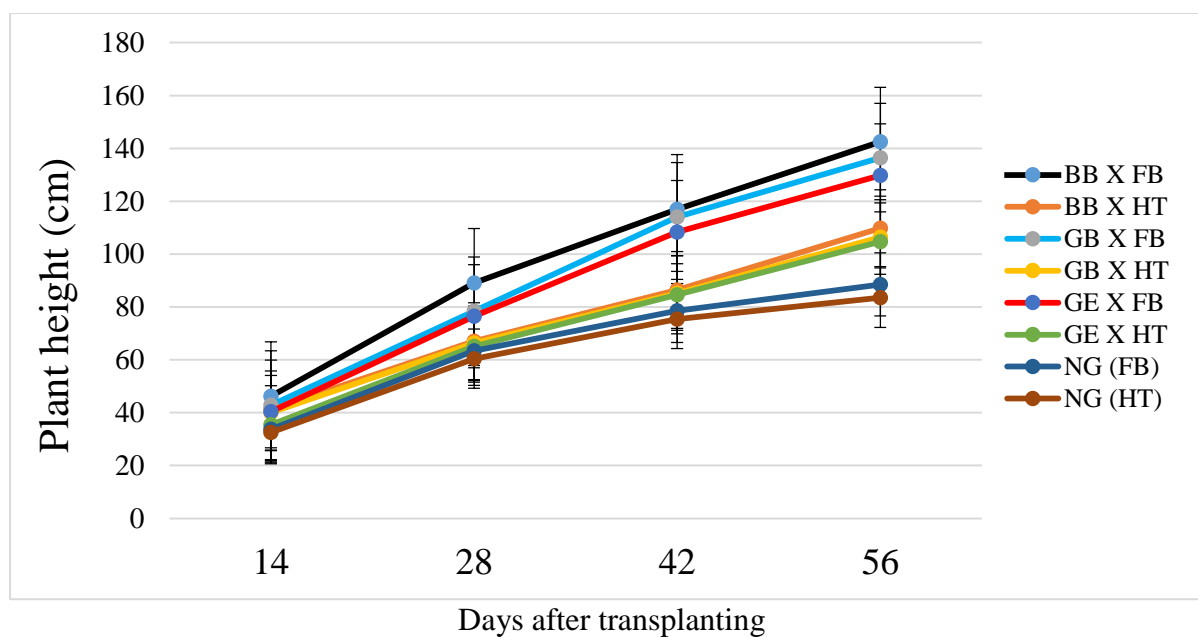


Figure 3 Influence of grafting on the plant height at 14, 28, 42 and 56 days after transplanting

Scion varieties were analysed separately; **FB × BB** and **HT × BB**: ‘Fadæbege’ and ‘Nkansah HT’ grafted onto ‘Black Beauty’ rootstock; **FB × GB** and **HT × GB**: ‘Fadæbegeye’ and ‘Nkansah HT’ grafted onto ‘Gboma’ rootstock; **FB × GE** and **HT × GE**: ‘Fadæbegeye’ and ‘Nkansah HT’ grafted onto ‘Obaapa’ rootstock; **NG (FB)** and **NG (HT)**: Non-grafted ‘Fadæbegeye’ and ‘Nkansah HT’

4.3.2 Stem diameter

The mean stem diameter among grafted treatments varied from 4.02mm – 4.87mm; 5.44mm – 6.17mm; 6.84mm – 7.95mm and 8.84mm- 9.73mm at 14, 28, 42 and 56 DAT respectively (figure 4). Plant growth performance in terms of stem diameter was significantly greater for **FB × BB** (4.87mm, 6.17mm, 7.95mm and 9.73mm) followed by **FB × GB** (4.43mm, 5.96mm, 7.72mm and 9.47mm) and the least mean stem diameter was recorded by **NG(FB)** (4.02mm, 5.60mm, 7.24mm, and 8.95mm) over the growth period (figure 4).

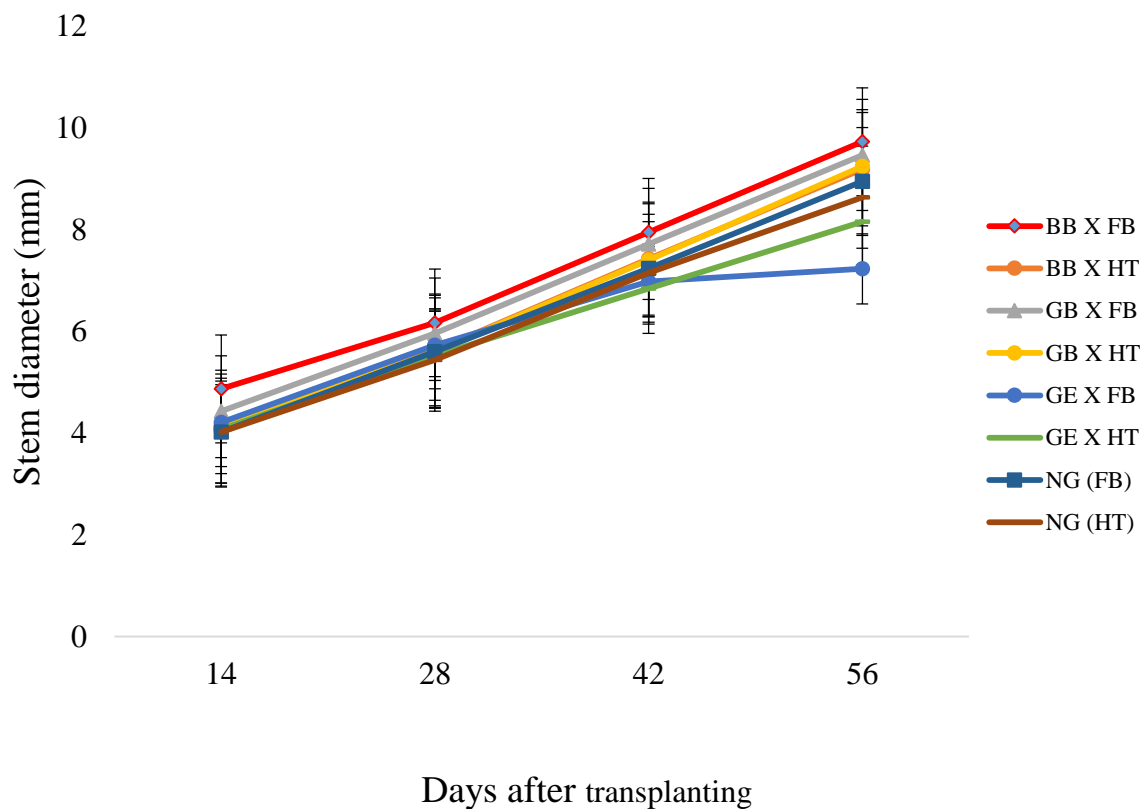


Figure 4 Influence of grafting on the stem diameter at 14, 28, 42 and 56 days after transplanting

Scion varieties were analyzed separately; **FB × BB** and **HT × BB**: ‘Fadεεbege’ and ‘Nkansah HT’ grafted onto ‘Black Beauty’ rootstock; **FB × GB** and **HT × GB**: ‘Fadεεbegeye’ and ‘Nkansah HT’ grafted onto ‘Gboma’ rootstock; **FB × GE** and **HT × GE**: ‘Fadεεbegeye’ and ‘Nkansah HT’ grafted onto ‘Obaapa’ rootstock; **NG (FB)** and **NG (HT)**: Non-grafted ‘Fadεεbegeye’ and ‘Nkansah HT’

4.3.3 Number of leaves

Higher mean number of leaves was observed for **FB × BB** (12, 22, 25, 29) followed **FB × GB** (11, 20, 23, 28) and the least was **NG (FG)** (8, 14, 18, 22) over growth period (figure 3).

Statistically, no significant differences in the leaf number were found for **HT × BB** (10, 18, 20 and 25) and **HT × GB** (10, 18, 20, 24) over the growth period. (Figure 4).

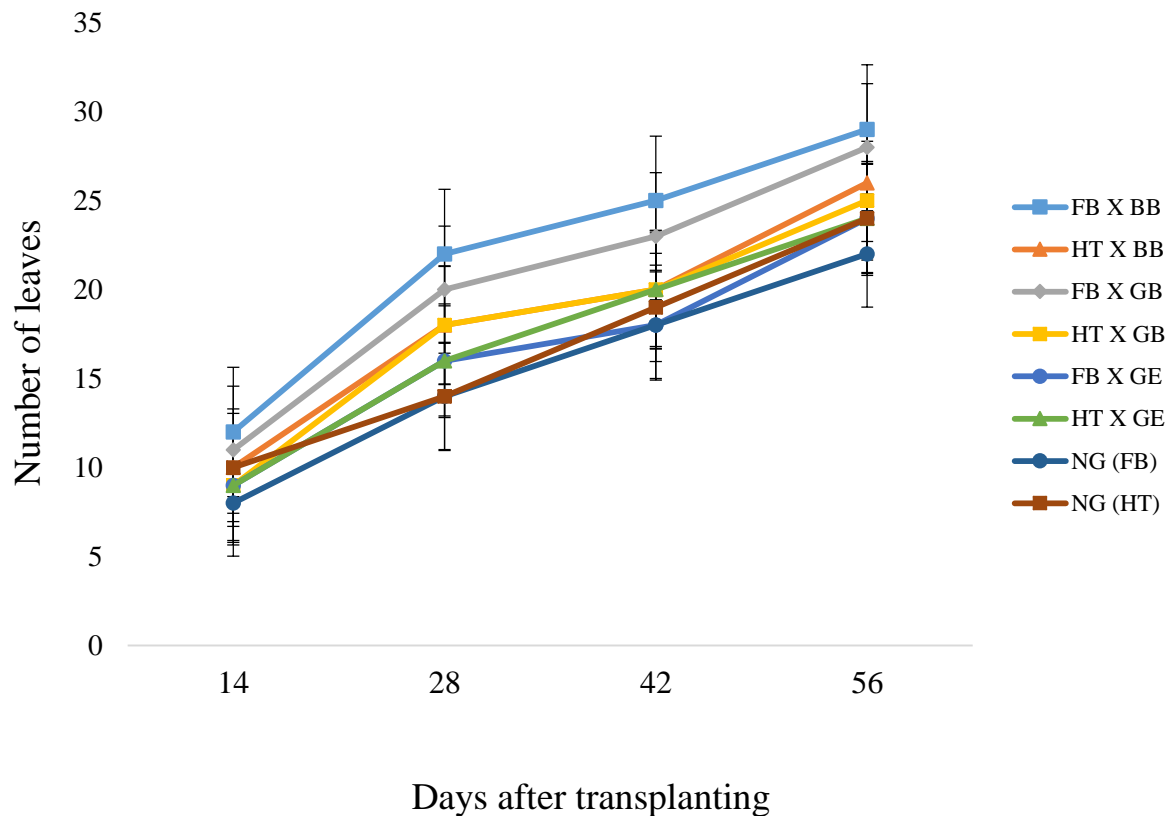


Figure 5 Influence of grafting on the number of leaves at 14, 28, 42 and 56 days after transplanting. Scion varieties were analysed separately; **FB × BB** and **HT × BB**: 'Fadεεbege' and 'Nkansah HT' grafted onto 'Black Beauty' rootstock; **FB X GB** and **HT × GB**: 'Fadεεbegeye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB × GE** and **HT X GE**: 'Fadεεbegeye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock; **NG (FB)** and **NG (HT)**: Non-grafted 'Fadεεbegeye' and 'Nkansah HT'

4.4 Earliness and Reproductive growth

Early flowering was observed for **FB × BB** (21 days) followed by **FB × GB** (22 days) and **GE X FB** (22 days). (Figure 5). Regardless of the early flowering, no significant differences were observed for **FB × BB** (21 days), **FB × GB** (22 days) and **FB × GE** (22 days) (Figure 5). Similarly, no significant difference in days to flowering was observed among **BB × HT** (25 days), **HT × GB** (25 days) and **HT × GE** (25 days) (figure 5). Fruit harvest for **FB × GB** (50 days) was significantly earlier followed by **FB × BB** (51 days), **FB × GE** (51 days) and **NG (FB)** (60 days) (figure 6). No significant differences were observed for days to harvesting between **FB × BB** (51 days) and **FB × GE** (51 days) (figure 6).

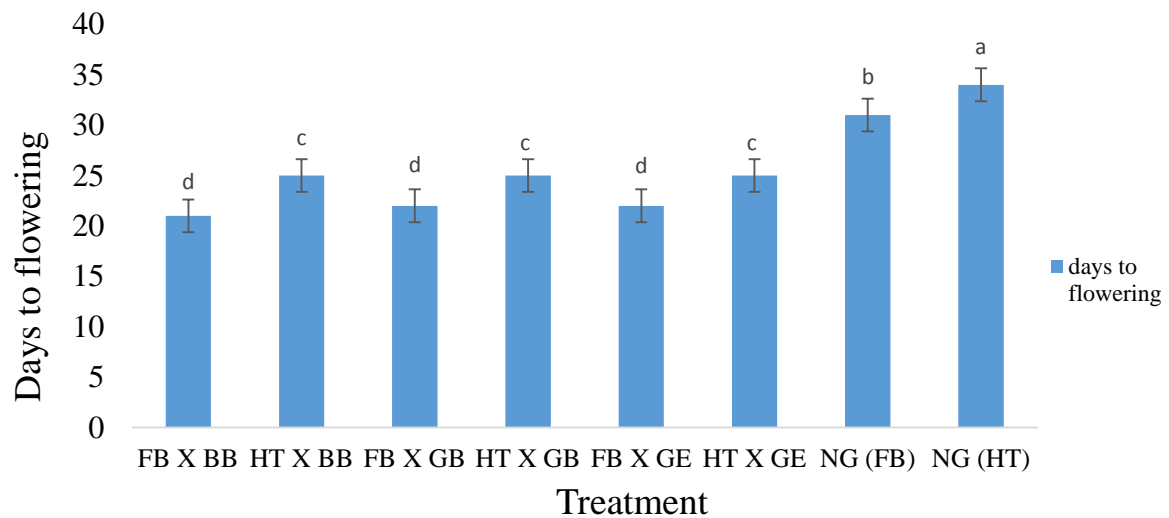


Figure 6 Influence of grafting on days to flowering.

bars within each data marked with the same lowercase letters are not significantly different based on Fisher's LSD ($P=0.05$). Scion varieties were analysed separately; **FB × BB** and **HT × BB**: 'Fadeebege' and 'Nkansah HT' grafted onto 'Black Beauty' rootstock; **FB × GB** and **HT × GB**: 'Fadeebegeye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB × GE** and **HT × GE**: 'Fadeebegeye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock; **NG (FB)** and **NG (HT)**: Non-grafted 'Fadeebegeye' and 'Nkansah HT'

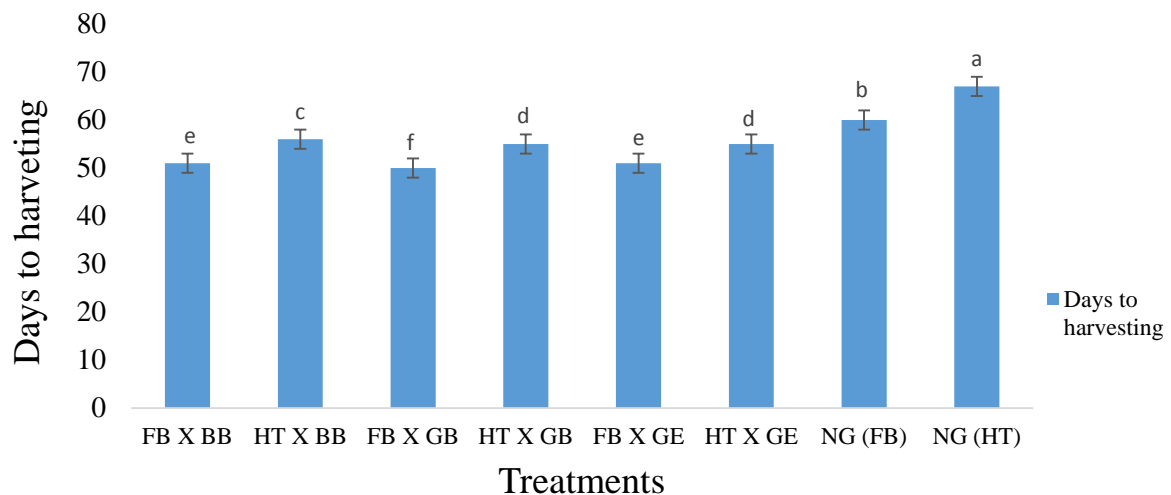


Figure 7 Influence of grafting on days to harvesting.

Bars within each data marked with the same lowercase letters are not significantly different based on Fisher's LSD ($P=0.05$); Scion varieties were analyzed separately; **FB × BB** and **HT × BB**: 'Fadeebege' and 'Nkansah HT' grafted onto 'Black Beauty' rootstock; **FB × GB** and **HT × GB**: 'Fadeebegeye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB × GE** and **HT × GE**: 'Fadeebegeye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock; **NG (FB)** and **NG (HT)**: Non-grafted 'Fadeebegeye' and 'Nkansah HT'

4.5 Yield and yield components

4.5.1 Number of fruit per plant

The mean values for the number of fruit per plant varied significantly ($P=0.05$) among treatment. (Table 4). Higher mean number of fruit per plant was observed for FB × BB (27) followed by HT× BB (25) and the least was NG (FB) (18) (Table 4)

4.5.2 Fruit weight per plant

Mean fruit weight per plant was significantly affected ($P=0.05$) by grafting table. Higher mean fruit weight was observed for FB × BB (352.42g) followed by HT × BB (331.42g) and the least was NG (FB) (224.52g) (Table 4).

4.5.3 Total yield

The total yield was significantly higher for FB × BB (5.18 t/ha) followed by HT × BB (4.86 t/ha) and the least was NG (FB) (3.30 t/ha) (Table 4).

Table 4 Influence of grafting on the yield of scion varieties 'Fadæbægye' (FB) and 'Nkansah HT' (HT) grafted unto 'Black beauty' (BB), 'Gboma' (GB) and 'Obaapa' (GE) rootstocks

Treatment	Number of fruits per plant	Fruit weight per plant (g)	Total yield (t/ha)
FB × BB	27 ^a	352.42 ^a	5.18 ^a
HT × BB	25 ^b	331.42 ^b	4.86 ^b
FB × GB	24 ^c	286.75 ^c	4.21 ^e
HT × GB	24 ^c	298.75 ^d	4.39 ^d
FB × GE	20 ^f	311.47 ^e	4.59 ^c
HT × GE	22 ^e	278.95 ^f	4.06 ^f
NG (FB)	18 ^g	224.52 ^g	3.30 ^h
NG (HT)	23 ^d	268.32 ^h	3.94 ^g

Mean values within a column marked with the same lowercase letters are not significantly different based on Fisher's LSD ($P=0.05$); Scion varieties were analysed separately; **FB × BB** and **HT × BB**: 'Fadæbege' and 'Nkansah HT' grafted onto 'Black Beauty' rootstock; **FB × GB** and **HT × GB**: 'Fadæbægye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB × GE** and **HT × GE**: 'Fadæbægye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock; **NG (FB)** and **NG (HT)**: Non- grafted 'Fadæbægye' and 'Nkansah HT'

4.6 Fruit quality attributes

4.6.1 Soluble solids content (Brix)

The mean brix values varied among treatments. Higher mean value in brix was observed for FB X BB (9.27) followed by FB × GB (8.25) and the least was NG (HT) (3.98) (Table 5). Statistically, no significant differences were found in brix for FB × GE (5.23) and NG (FB) (5.24) (Table 5).

4.6.2 Titrable acidity (TA)

Titration acidity (TA) was significantly higher for FB × BB (0.55) followed by FB × GB (0.52) and the least was HT X GE (0.34) (Table 5). The mean pH values varied among treatment. Higher mean values for pH were observed were for FB × BB (4.35) and FB × GE (4.35) followed by FB × GB (4.34) and the least was NG (HT) (Table 5)

4.6.3 TSS : TA ratio

The TSS : TA ratio was significantly higher for FB × BB (16.85) followed by FB ×GB (15.86) and the least was NG (HT) (9.45) (Table 5).

4.6.4 Vitamin C

Higher mean value in vitamin C was observed for FB × BB (30.02 mg/100ml) followed by HT × BB (28.37 mg/100ml) and the least was NG (HT) (24.56 mg/100ml) (Table 6).

4.6.5 Lycopene

Higher mean value in lycopene content was observed for FB × BB (24.35 mg/100ml) followed by HT× BB (23.75 mg/100ml) and the least was NG (HT) (20.45 mg/100ml) (Table 6).

4.6.6 Firmness

Fruit firmness was significantly higher for HT × GB (0.41 kg) followed by HT × BB (0.38 kg) and the least was observed for NG (FB) (0.25 kg) (Table 4B). Statistically, no significant differences were observed among HT X BB (0.38 kg) and NG (HT) (0.38 kg). (Table 6)

4.6.7 Shelf life

Fruit shelf life was significantly higher for GB × HT (46 days) followed by HT × BB (43 days) and the least was FB × GE (23) (Table 6).

Table 5 The influence of grafting on the fruit quality attributes^y of scion varieties ‘Fadεεbεgye’ (FB) and ‘Nkansah HT’ (HT) grafted unto ‘Black beauty’ (BB), ‘Gboma’ (GB) and ‘Obaapa’ (GE) rootstocks

Treatment	Soluble solids content (°Brix)	Titration acidity (% citric acid)	pH	TSS: TA
FB × BB	9.27 ^a	0.55 ^a	4.35 ^a	16.85 ^a
HT × BB	4.43 ^d	0.35 ^f	4.30 ^{cd}	12.65 ^e
FB × GB	8.25 ^b	0.52 ^b	4.34 ^b	15.86 ^b
HT × GB	4.20 ^f	0.38 ^e	4.29 ^d	11.05 ^f
FB × GE	5.23 ^c	0.37 ^e	4.35 ^a	14.13 ^c
HT × GE	4.33 ^e	0.34 ^f	4.30 ^{cd}	12.73 ^d
NG (FB)	5.24 ^c	0.51 ^b	4.33 ^b	110.27 ^g
NG (HT)	3.98 ^g	0.42 ^e	4.25 ^e	9.45 ^h

Mean values within a column marked with the same lowercase letters are not significantly different based on Fisher’s LSD (P=0.05). **FB × BB** and **HT × BB**: ‘Fadεεbεgye’ and ‘Nkansah HT’ grafted onto ‘Black Beauty’ rootstock; **FB X GB** and **HT × GB**: ‘Fadεεbεgye’ and ‘Nkansah HT’ grafted onto

'Gboma' rootstock; **FB** × **GE** and **HT** × **GE**: 'Fadecbegye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock;
NG (FB) and **NG (HT)**: Non- grafted 'Fadecbegye' and 'Nkansah HT'

Table 6 Influence of grafting on fruit quality attributes^y of scion varieties 'Fadæbægye' (FB) and 'Nkansah HT' (HT) grafted unto 'Black Beauty' (BB), 'Gboma' (GB) and 'Obaapa' (GE) rootstocks.

Treatment	Vitamin C ^z	Lycopene ^x	firmness	shelf life
	(Mg AA/100ml of juice)	(Mg/100ml of juice)	(Kg)	(Days)
FB × BB	30.02 ^a	24.35 ^a	0.23 ^f	25 ^f
HT × BB	28.37 ^b	23.75 ^a	0.38 ^b	43 ^b
FB × GB	27.57 ^c	21.90 ^{bc}	0.28 ^{cd}	27 ^e
HT × GB	25.11 ^g	20.73 ^d	0.41 ^a	46 ^a
FB × GE	25.97 ^e	22.63 ^b	0.26 ^{ed}	23 ^h
HT × GE	26.77 ^d	22.25 ^b	0.30 ^c	38 ^d
NG (FB)	25.23 ^f	21.22 ^{cd}	0.25 ^{ef}	24 ^g
NG (HT)	24.56 ^h	20.45 ^d	0.38 ^b	41 ^c

Mean values within a column marked with the same lowercase letters are not significantly different based on Fisher's LSD (P=0.05). **FB × BB** and **H × BB**: 'Fadæbægye' and 'Nkansah HT' grafted onto 'Black Beauty' rootstock; **FB × GB** and **HT × GB**: 'Fadæbægye' and 'Nkansah HT' grafted onto 'Gboma' rootstock; **FB × GE** and **HT × GE**: 'Fadæbægye' and 'Nkansah HT' grafted onto 'Obaapa' rootstock; **NG (FB)** and **NG (HT)**: Non-grafted 'Fadæbægye' and 'Nkansah HT'. ^yQuality attribute measured from ten randomly selected fruit per treatment with four replications. Scion varieties were analysed separately; ^zVitamin C content reported as mg of ascorbic acid per 100ml of fruit juice; ^x Lycopene content reported as mg per 100ml of fruit juice.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Seed germination and Graft success

Herbaceous grafting has shown to be an efficient resource of increasing crop productivity, enhancing resistance to soil-borne diseases, improving resistance to environmental stress and fruit quality in fruit vegetable crops (King *et al.*, 2010,). Without a glitch, rootstocks can be used to increase yield and improve quality of the produce. This can be done by grafting onto rootstocks that have resistance or tolerance to soil-borne pathogens, environmental stress or can impact a high degree of vigour to the scion (Lee and Oda, 2003). In this study, the effect of grafting the scion have revealed that, significant improvement can be achieved by using this technique in sustainable tomato production, in Ghana. Although a lot of benefits have been gained from using rootstock grafts, there are challenges in the grafting process. Efficient production of grafted plants calls for good germination rates, good germination periods and uniformity of the rootstock and scions, high rates of successful graft and field establishment (greenhouse or open field) after transplanting (Ibrahim *et al.*, 2001). The uniformity of the rootstock and scion depends on seed germination which is affected by seed quality. Seed quality of the rootstock and scion is very important, as it affects seedling development, uniformity of growth and diameter of the stem (Morejon, 2013). Likewise, the survival rate of grafted seedlings is inversely proportional to the difference between scion and rootstock diameters. Lack of uniformity creates incompetence and difficulties in the grafting process (Oda *et al.*, 1993). In addition, growth rate and germination period differ from variety to variety and from season to season (AVRDC, 2003). It is therefore important for the grafter to regulate and plan the dates according to prevailing conditions. Planning is very important for vegetable grafting although very difficult to manage under uncontrolled environmental

conditions. Planning and Scheduling is also not easy because the timing of germination is always not well known. Moreover, for some rootstocks the germination rate and uniformity may be poor and it might be obligatory to use a lot of seeds than plants to graft. Proper planning is possible only if seed characteristics and plantlets requirements are well known. In this way, the appropriate grafting, at the same time for the scion and rootstock may be achieved (Leonardi and Romano, 2004). The success of grafting also depends on the union of the grafts (rootstock and scion) and compatibility of the rootstock and scion. Tomatoes is grafted by the cleft or tube method. The use of cleft in this study resulted in graft success rate > 80% in all graft combinations. The result indicated that, this procedure was effective with these rootstock-scion combinations. The lower success observed for ‘Obaapa’ (GE) rootstock may points out that irrespective of the genetic proximity of tomatoes to eggplants some graft incompatibility might exist (Furini and Wunder, 2004). Besides, vigour may be the reason for the lower success rate (Gisbert *et al.*, 2011).

5.2 Plant growth attributes

Quite a handful of reports and reviews have documented the interaction of rootstock and scion in different crops (Leonardi and Giuffrida, 2006). In this study, it was observed that the source of rootstock used can significantly influence the plant growth, earliness yield and fruit quality attributes. Plant growth attributes, plant height, stem diameter, number of leaves, were significantly increased in grafted plants compared to non-grafted plants. The increase in these plant growth attributes are consistent with existing literature which reports similar effects for additional grafted tomato combinations as well as grafted peppers (Leonardi and Giuffrida, 2006; Mohammed *et al.*, 2009; Nkansah *et al.*, 2013). Interaction between the scion and grafting were not present for any plant growth parameters indicating that the type of rootstock stimulates growth of the scion. In addition, ‘Fadεεbεgye’ (FB) and ‘Nkansah HT’ (HT) scion grafted onto ‘Black Beauty’ (BB) and ‘Gboma’ (GB) demonstrated greater gains in plant

height, stem diameter, number of leaves, compared to ‘Fadecbeɔgye’ and ‘Nkansah HT’ grafted onto ‘Obaapa’ (GE) rootstock and non-grafted controls. This indicates that, rootstock variety may play a key role in the extent to which grafted plant respond in terms of plant growth.

5.3 Earliness and reproductive growth

In the absence of incompatibility problems and environmental stress, grafted plants may develop faster contributing to earliness (Gisbert *et al.*, 2011). In this study, earliness was observed in the most vigorous rootstock ‘Black Beauty’ and ‘Gboma’. This was characterized by early flowering and early harvesting in plants grafted onto ‘Black Beauty’ and ‘Gboma’ rootstocks. In addition, earliness observed in ‘Obaapa’ rootstock could be the influence of grafting. This result also indicates that, the influences of grafting and rootstock selection are important in conferring earliness in the scion. However, the earliness could also be influenced by scion selection. Increased earliness have also been reported for tomato grafted onto eggplant rootstock (Ibrahim *et al.*, 2001); for eggplant grafted onto tomato hybrid rootstock (Khan *et al.*, 2006); for eggplant grafted onto eggplant rootstocks (Gisbert *et al.*, 2011) and for watermelon grafted onto bottle gourd (Sakata *et al.*, 2007). Early harvest may be more important for the farmer (either in the greenhouse or in the open field) to capture higher market prices (Barret, 2011; Alexopoulos *et al.*, 2007).

5.4 Yield and yield components

It was also found out that grafted plants with ‘Black Beauty’ rootstock had higher fruit number and total yield compared to grafted plants with ‘Gboma’ and ‘Obaapa’ rootstocks and non-controls. ‘Black Beauty’ rootstocks demonstrated encouraging benefits for agronomic performance in grafted tomato. This indicates that grafting tomatoes on suitable rootstocks have positive effect for yield. The results agree with Barret, (2011), Ibrahim *et al.*, (2001), Marsic and Osvald, (2004) and Nkansah *et al.*, (2013) who observed similar result in grafted

and non-grafted tomato plants. These reasons suggest that higher yields of fruits from grafted plants might have been the influence of the vigorous roots of the rootstock, which enhanced the uptake of water and minerals (Lee and Oda, 2003). Correspondingly, observations on earliness and yield are consistent with Raigon *et al.*, (2008), Munez-falcau *et al.*, (2008) and Nkansah *et al.*, (2013) who found out that, plants with the highest yield entered much earlier into production.

5.5 Fruit quality attributes

Fruit quality traits are important for the marketability of fruits. These traits can be significantly be influenced by grafting (Alexopoulos *et al.*, 2007; Lopez-Galarza *et al.*, 2004; Proietti *et al.*, 2008).

5.5.1 Soluble solids content (Brix)

The TSS (brix) is one of the most important quality parameters processing tomatoes and in the fresh market production, due to its important contribution of sugars to the organoleptic quality of tomatoes (Manashi, 2011). It represents the potential sweetness of the produce. In this study, the brix was significantly increased in grafted plants with BB. This suggests that, the significant increase in brix for grafted plants with 'Black Beauty' rootstock may perhaps be due to the influence of influence of grafting and rootstock. However, this result disagrees with Nkansah *et al.*, 2013 who reported that grafting did not affect brix. In addition, the result are consistent with existing literature which report similar effects (Flores *et al.*, 2010; Ibrahim *et al.*, 2001; Martinez-Ballesta *et al.*, 2008 Mohammed *et al.*, 2009). Higher TSS is very vital for the processing industry since tomatoes with high TSS improves processing efficiency (Johnson *et al.*, 2005; Favati *et al.*, 2009). Besides, higher brix content may be attributed to greater light intensity in crop environment, better uptake of water and nutrients and greater photosynthetic activity.

5.5.2 Titrable Acidity (TA)

The TA is also an important quality attribute that affects the organoleptic property of tomatoes. High TA values are required for very good flavour and it is mainly because of the citric acids and the malic acids (Adedeji, 2006). In this study, the TA was significantly improved for plants grafted onto 'Black Beauty' and 'Gboma' rootstocks, This result agrees with Ibrahim *et al.*,(2001), Flores *et al.*, (2010) and Turhan *et al.*, (2011) who observed similar effects in grafted plants compared to non-grafted plants. TA in tomato fruits not only improves its palatability but also plays an important role in the maintenance of acid-base balance in the body. The TA influences the flavour (taste), color, stability consistency and keeping quality of the fruit. Manashi, (2011).

5.5.3 PH

The pH of food is an indication of its resistance to microbial attack (Manashi, 2011). Similarly a pH value between 2.5-5.5 tends to prolong shelf life of fresh fruit and inhibit the multiplication of microorganism (Manashi, 2011). In this study, the pH varied from 4.25 to 4.35 among treatments. Although the treatments were within the desired optimum pH range, plants grafted onto 'Black Beauty' rootstock were significantly different. This suggests that grafting significantly affected the pH of the tomato fruits. This result agrees with Khah *et al.*, (2006) who reported similar effects in grafted plants compared to non-grafted plants. However, this result disagrees with other researchers who reported that grafting did not affect the pH (Nkansah *et al.*, 2013; Barret, 2011).

5.5.4 TSS:TA

The TSS:TA ratio is very important to the fresh market production due to the significant contribution of acids and sugars to the overall flavour and nutritional quality (Manashi, 2011). In addition, flavour is related to both acids and sugars. A high sugar concentration with relatively high acid gives the best tomato flavour. This study demonstrated that, the

TSS:TA ratio was significantly different for grafted plants on ‘black beauty’ rootstocks. Irrespective of the high TSS:TA ratio observed in other treatments, grafted plants with black ‘beauty’ rootstock were significantly higher. These results suggest that grafting onto the appropriate rootstock can enhance the TSS:TA significantly in tomato fruits. The results are consistent with existing literature which reports similar effects (Ibrahim *et al.*, 2001; Turhan *et al.*, 2011; Mohammed *et al.*, 2009).

5.5.5 Vitamin C

Vitamin C and lycopene plays an important role in human health and mainly found in fruit and vegetables. Vitamin C aids in the prevention of scurvy and maintenance of skin and blood vessels (Lee and Kader, 2000). This study brought to bare, the significant increase in vitamin C content for grafted plants with ‘Black Beauty’ rootstock compared to other grafted plants and non-grafted plants. The results agrees with current literature which reports similar effects (Ibrahim *et al.*, 2001; Mohammed *et al.*, 2009; Turhan *et al.*, 2011 Balliu and Vuksani, 2008; Fernandez-Garcia *et al.* 2004b). This result also confirms that, grafting can be used to enhance the nutritional quality of tomatoes, especially for vitamin C when grafted onto carefully selected and appropriate rootstocks. The need to evaluate extensively the effect of grafting on the nutritional qualities demands critical attention.

5.6.6 Lycopene

Lycopene is an important health related compound found in fruits and vegetables. Lycopene aid in the prevention of cancer related diseases (Lee and Kader, 2000). This study indicated that, plant grafted onto ‘black beauty’ had significantly, higher lycopene content compared to non-grafted plants. The result is in consistent with Gerster, (1997) and Fernandez-Garcia *et al.*, (2004b), who found out that, grafted plant had significantly higher lycopene content compared to non-grafted plants. However, this result disagrees with other researchers who

reported that grafting did not affect the lycopene content in grafted tomato plant (Barret, 2011; Khah *et al.*, 2006).

5.6.7 Firmness

Textural traits are very important in determining consumer acceptability. Firmness is one of the typical attribute used to describe the texture of fruits. Grafting can influence the firmness significantly (Rouphael *et al.*, 2010). There are several reports on changes in firmness brought about by grafting (Rouphael *et al.*, 2010). These findings are often contradictory perhaps, due to the multitude of experimental settings and the complexity of the process involved (Rouphael *et al.*, 2010). Moreover, hormonal signals in the rootstock-scion interaction may alter the cell wall metabolism with potential consequences on fruit texture. In this present study, fruit firmness was significantly higher in ‘Black Beauty’ grafted plants. Although other studies have found no significant differences in fruit firmness (Barret, 2011; Khah *et al.*, 2006), this result agrees with El-Wani *et al.*, (2014) who found out that grafting tomato hybrid ‘TM 100 F1 Sakata’ on the tomato rootstock hybrid ‘*S.lycopericum* cv RX 01660449’ improves the firmness of grafted tomato plant significantly. The results also agrees with Nkansah *et al.*, (2013) who observed that, grafting onto African eggplant improved the firmness significantly. The influence of rootstock on fruit firmness of grafted tomatoes may be related to alterations in cellular, cell turgor, the chemical and mechanical properties of the cell walls as a result of increasing synthesis of endogenous hormones and changing water relationships and nutritional status of the scion (Rouphael *et al.*, 2010).

5.5.8 Shelf life

Tomatoes' being a climacteric fruit has relatively short postharvest life since many processes affecting quality take place after harvest (Zapata *et al.*, 2008). The main factor associated with tomato postharvest life, particularly in tropical regions where the temperature is high is increased respiration which results in faster ripening and deterioration of fruit quality. In Ghana the aggregate postharvest losses from farm gate to consumers in tomatoes range from 20% - 50% (MOFA, 2010). Among all available strategies for minimizing postharvest losses, grafting onto rootstocks that have the ability to extend or increase the postharvest life may be encouraging. This study revealed that 'Black Beauty' and 'Gboma' grafted plants had significantly increased shelf life compared to 'Obaapa' grafted plant and non-grafted control plants. This result also indicates that, rootstock may have a significant influence on the shelf life of tomatoes. The results agree with Nkansah *et al.*, (2013) who observed that, grafting onto African eggplant extended the postharvest life of tomatoes significantly. It is remarkable to note that, tomato fruit which were firm, had significantly extended shelf life. This suggests that fruit that are firmer tend to have prolonged shelf life. Investigations may be done in addition to breeding programmes to produce rootstocks that can improve quality and shelf life particularly under biotic and abiotic stress.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From this study, the use of ‘Black Beauty’ and ‘Gboma’ rootstocks for grafting exhibited good vigour, high yield and fruit quality attributes as well as extended the shelf life of tomatoes. The scion-rootstock combinations that had positive impact on growth, yield, fruit quality and shelf life were FB x BB and HT x GB. These benefits can be of value to farmers and the tomato industry. In addition, it may be a ground-breaking method that can offer farmers new profit-making opportunities, greater production stability, higher fruit quality with longer shelf life and increased yields. Higher yields, good fruit quality and extended shelf life consequently means higher profits for farmers. However, farmers are less likely to adopt this technique if fruit quality and shelf life are poorly affected at the expense of yield and disease resistance. Finally, farmers interested in using grafted plant need to be aware that scion-rootstock interaction is not fully understood. It is therefore prudent that different grafting combinations are assessed under different locations and under specific conditions before selecting the suitable rootstock and integrating this technology on a bigger scale.

6.2 Recommendations

From this study, ‘Black Beauty’ has shown to be potential rootstock that can be used especially, for the production of tomatoes in Ghana. I therefore recommended that

1. Economic feasibility studies should be done on grafted plant production to assess the cost and benefits of grafted plant production in Ghana.
2. Successful adoption of grafting by farmers, especially in Ghana, requires simple effective techniques that can work successfully within limited the propagation facilities. Research is

therefore required to evaluate different healing chamber designs on graft survival under different environmental conditions. In addition, locally available materials such as plastic straw (for drinking) being used to hold the graft union must be evaluated and their effects determined on grafted seedlings.

3. Future research should be conducted in major production regions with multiple rootstocks. This will help farmers to select the most appropriate rootstock for their production systems and reduce the risk of economic losses.

REFERENCES

- Abdelhaq, H. (2004). Integrated production and protection in greenhouse crops: Institut Agronomique et Veterinaire Hassan II.
- Abdelmageed, A.H.A., Gruda, N. and Geyer, B. (2004). Effect of temperature and grafting on the growth and development of tomato plants under controlled conditions. *Rural poverty reduction through research for development and transformation conference*, Deutscher Tropentag, Berlin, Germany, October 5-7
- Abdelmageed, A.H.A. and Gruda, N. (2009). Influence of Grafting on Growth, Development and some Physiological Parameters of Tomatoes under Controlled Heat Stress Conditions. *Eur. Journ. Of Hort. Sci.* 74(1):16-20.
- Acquaah, G. (2007). *Principles of Plant Genetics and Breeding*. Blackwell publishing ltd, 350 main street, Malden, MA 02148-5020, USA. Pg. 124-126
- Adams, S.R., Cockshull, K.E. and Cave, C.R.J. (2001). Effect of temperature on the growth and development of tomato fruits. *Ann. Bot.* 88, 869–877.
- Adedeji O, Taiwo K. A, Akanbi C T and Ajani R. (2006). Physicochemical properties of four tomato cultivars grown in Nigeria. *Journ. of Food Pro. and Pres.* 30:79-86
- Aherne, S.A., Jiwan, M.A. Daly, T., and O'Brien N.M. (2009). Geographical location has greater impact on carotenoid content and bio accessibility from tomatoes than variety. *Plant foods for Hum. Nutr.* 64 (4):250-256.
- Ahn, S.J., Im, Y.J., Chung, G.C., Cho, B.H. and Suh, S.R. (1999). Physiological responses of grafted-cucumber leaves and rootstock roots affected by low root temperature. *Sci. Hortic.* 81, 397–408.

- Alai, S.M.R. (2014). Evaluating the graft success between (*S. macrocarpon*) and two *S. lycopersicon* (tomato) varieties (Petomech and Roma) using the splice graft method. Bsc. Thesis, University of Ghana
- Alan, O., Z. and Nen, Y. (2007). Effect of grafting on watermelon plant growth, yield and quality. *J. Agron.* 6, 362–365.
- Albacete, A., Martinez-Andujar, C., Ghanem, M.E., Acosta, M., Sanchez-Bravo, J., Asins, M.J., Cuartero, J., Lutts, S., Dodd and I.C., Perez-Alfocea, F. (2009). Rootstock-mediated changes in xylem ionic and hormonal status are correlated with delayed leaf senescence, and increased leaf area and crop productivity in salinized tomato. *Plant Cell Environ.* 32, 928–938.
- Allen, D.J. and Ort, D.R. (2001). Impacts of chilling temperatures on photosynthesis in warm-climate plants. *Trends Plant Sci.* 6, 36–42.
- Alexopoulos AA, Kondylis A. and Passam HC. (2007). Fruit yield and quality of watermelon in relation to grafting. *J Food Agric & Environ* 2007; 5(1):178-179
- Andrews, P.K. and Marquez C.S. (1993). Graft incompatibility. *Hort. rev.* 15:183- 232.
- Arao, T., Takeda, H. and Nishihara E. (2008). Reduction of cadmium translocation from roots to Shoots in eggplant (*Solanum melongena*) by grafting onto *Solanum torvum* rootstock. *Soil Sci. Plant Nutr.* 54, 555–559.
- Ashita, E. (1927). Grafting of watermelons (in Japanese). Korea (Cho sun) *Agr.Nwsl.* 1:9.
- Atherton J. G. and Rudich J. (1986). The Tomato Crop. Chapman and Hall Ltd., London
- AVRDC, (2003). Guide. Grafting tomatoes for production in the hot-wet season. Asian Vegetable Research and Development Center, Publ. No#03-551, Shan hua, Tainan, Taiwan, 6 pp. (www.avrdc.org/fileadmin/pdfs/grafting_tomatoes.pdf).

- AVRDC, (2009). Guide. Grafting sweet peppers for production in the hot-wet season. Asian Vegetable Research and Development Center, Publ.-No 09-722-e, Shanhua, Tainan, Taiwan, 8 pp. (www.libnts.avrdc.org.tw/fulltext/pdf/FLYER/f0002.pdf).
- Balliu, A. and Vuksani, G. (2008). Grafting Effects on Tomato Growth Rate, Yield and Fruit Quality under Saline Irrigation Water. p. 1161-1166. In: S.M.G.S.M.A.S.E. De Pascale (ed). *Proceedings of the International Symposium on High Technology for Greenhouse System Management, Vols 1 and 2*.
- Barret, C. E. (2011). Organic production of grafted heirloom tomatoes: nematode management, fruit quality and economics. Msc. Thesis, University of Florida. <http://ufl.ufdc.edu>
- Bazzano, L.A., He, J., Ogden, G., Vupputuri, S., Loria, C., Meyers, L., Meyers, L., and Whelton, P.K. (2002). Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first national health and nutrition examination survey epidemiologic follow-up study. *Am. J. Clin. Nutr.* 76, 93–99.
- Beecher, B. R. (2009). *Nutrient content of tomatoes and tomato products*. National Center for Biotechnology Information, U.S. National Library of Medicine. (url)<http://www.ncbi.nlm.nih.gov/pubmed/9605204>. 09/11/2010. 9:25pm GMT. Accessed: December 30, 2013. 12:23pm GMT.
- Bekele, D.A. and Geleta, G.S. (2015). Iodometric determination of ascorbic acid (vitamin C) content of some fruits consumed in Jimma town community in Ethiopia. *Res. J. Chem.Sci.* Vol. **5(1)**, 60-63,

- Besri, M. (2001). New developments of alternatives to methyl bromide for the control of tomato soil-borne pathogens in covered cultivation in a developing country, Morocco in *2001 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions*, San Diego, California, USA. November 5-8, 2001
- Besri, M. (2003). Tomato grafting as an alternative to methyl bromide in Morocco, 2003 *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions*. San Diego, CA USA. November 3-6, 2003
- Black, L.L., D.L. Wu, J.F. Wang, T. Kalb, D. Abbass, and J.H. Chen. (2003). Grafting tomatoes for production in the hot-wet season. *Asian Vegetable Research & Development Center. AVRDC Publication (03-551):6*.
- Bletsos, F., Thanassouloupoulos, C. and Roupakias, D. (2003). Effect of grafting on growth, yield, And Verticillium wilt of eggplant. *Hort. Sci.* 38, 183–186.
- Bletso, F.A. 2005. Use of grafting and calcium cyanamide as alternatives to methyl bromide soil fumigation and their effects on growth, yield, quality and Fusarium wilt control in melon. *J. Phytopathol.* 153(3):155-161.
- Bloom, A. J., Zwieniecki, M. A., Passioura, J. B., Randall, L.B., Holbrook, N.M., St. and Clair, D. A. (2004). Water relations under root chilling in a sensitive and tolerant tomato species. *Plant Cell Environ.* 27, 971–979
- Bradley, J. A. (1968). Tomato grafting to control root diseases. *New Zea. Journ. of Agri.* 116:26-27.
- Branthome, F. (2010). Trends in tomato products consumption compared to total tomato consumption. The world Processing Tomato Council (WPTC).

- Brown, P., Lumpkin, T., Barber, S., Hardie, E., Kraft, K., Luedeling, K., Rosenstock, T., Tabaj, K., Clay, D., Luther, G., Marcotte, P., Paul, R., Weller, S., Youssefi, F., and Demment, M. (2005). Global Horticulture Assessment. Gent-Oostakker, Belgium.
- Bulder, H.A.M., den Nijs, A.P.M., Speek, E.J., van Hasselt, P.R., and Kuiper, P.J.C. (1991). The effect of low root temperature on growth and lipid composition of low temperature tolerant rootstock genotypes for cucumber. *J. Plant Physiol.* 138, 661–666
- Caliman, F.R.S., Da Silva, D. J. H., Stringeta, P.C., Fontes, P.C.R., Moreira, G.R., and Montovan, E.C (2010) Quality of tomatoes under protected environment and field conditions, *Idesia (Arica)* 28: 75-82
- Cheng Z., Wang, P., Zhou, Y., Ji, Y., Liang, P., Wan, Z., Hao, J. (2012). Effects of Different Resistant Rootstocks on Yield and Quality of Grafted Tomato and Control Effects of *Meloidogyne incognita*. *Journal of Horticulture and Landscape*, Vol, 1(20): 83-87
- Chung, H.D. (1995). Studies on the occurrence causes and prevention of fermentation in melon fruit, *Cucumis melo* L. var. *makuwa* Mak. cv. Geumssaragieuncheon. Res. Rep. Kyungpuk Provincial RDA, Korea.
- Clearwater, M.J., Lowe, R.G., Hofstee, B.J., Barclay, C., Mandemaker, A.J., and Blattmann, P. (2004). Hydraulic conductance and rootstock effects in grafted vines of kiwifruit. *J. Exp. Bot.* 55, 1371–1381
- Colla, G., Roupael, Y., Cardarelli, M., Massa, D., Salerno, A. and Rea, E. (2006a). Yield, fruit quality and mineral composition of grafted melon plants grown under saline conditions. *J. Hortic. Sci. Biotechnol.* 81, 146–152..

- Colla, G., Roupshael, Y., Cardarelli, M. and Rea, E. (2006b). Effect of salinity on yield, fruit quality, leaf gas exchange, and mineral composition of grafted watermelon plants. *Hort. Science* 41, 622–627.
- Colla, G., Suarez, C.M.C., Cardarelli, M. and Roupshael, Y. (2010a). Improving nitrogen use efficiency in melon by grafting. *Hort Science* 45, 559–565
- Colla, G., Roupshael, Y., Cardarelli, M., Salerno, A., Rea, E., (2010b). The effectiveness of grafting to improve alkalinity tolerance in watermelon. *Environ. Exp. Bot.* 68, 283–291.
- Copes, D.L. and M.D. Oliver, M.D. (1970). Relationship between Douglas - Fir Graft compatibility and Wood Specific Gravity. *J. For.* 68(11):726-728.
- Crino, P., Lo Bianco, C., Roupshael, Y., Colla, G., Saccardo, F. and Paratore, A. (2007). Evaluation of rootstock resistance to fusarium wilt and gummy stem blight and effect on yield and quality of a grafted ‘Inodorus’ melon. *Hort. Science* 42, 521–525.
- Cuartero, J., Bolarin, M., Asins, C. and Moreno V. (2006). Increasing salt tolerance in the tomato. *Journal of Experimental Botany* 57:1045-1058.
- Davis, A.R., Perkins-Veazie, .P, Hassell, R., Levi, A., King, S.R., and Zhang, X. (2008a). Grafting effects on vegetable quality. *Hort Science* 43(6):1670-1672.
- Davis, A.R., Perkins-Veazie, P., Sakata, Y., Lopez-Galarza, S., Maroto, J.V., Lee, S., Huh, Y., Sun, Z., Miguel, A., King, S.R., Cohen, R., and J. Lee., (2008b). Cucurbit grafting. *Crit. Rev. Plant Sci.* 27(1):50-74.
- Di Gioia F., Serio F., Buttaro D., Ayala O., Santamaria P. (2010). Vegetative growth, yield, and fruit quality of ‘Cuore di Bue’, an heirloom tomato, as influenced by rootstock. *J. Hortic. Sci. Biotec.* 85(6), 232-236

- Dorais, M., Papadopoulos, A.P. and Gosselin, A. (2001). Greenhouse tomato fruit quality. *Hortic Rev.* 26, 239–319.
- Edelstein, M. and Ben-Hur, M. (2007). Preventing contamination of supply chains by using grafted plants under irrigation with marginal water. In: Wilson, J. (Ed.) 2007, *Proceedings of the International Symposium on Water Resources Management. Honolulu, Hawaii, USA*, pp. 150–154.
- Edelstein, M., Ben-Hur, M., Cohen, R., Burger, Y. and Ravina, I., (2005). Boron and salinity effects on grafted and non-grafted melon plants. *Plant Soil* 269, 273–284.
- Edelstein, M., Ben-Hur, M., (2006). Use of grafted vegetables to minimize chemical usage and damage to plant growth and yield quality under irrigation with marginal water. *Acta Hortic.* 699, 159–167.
- Edelstein, M., Ben-Hur, M., and Z. Plaut. (2007). Response of grafted and non-grafted melon plants to effluent and boron under greenhouse conditions. p. 325-328. In: D.I. Leskovar (ed) 2007. *Proceedings of the IVth International Symposium on Seed, Transplant and Stand Establishment of Horticultural Crops: Translating Seed and Seedling Physiology into Technology. Hawaii, USA*, pp. 123–125.
- El-wanis, .A., Mona, A., Atress, S.H. and Salmon, S.R. (2014). Effect of grafting on the growth, yield, quality and storability of tomatoes (*S. lycopersicon*) grown in NFT system under plastic house conditions. *Middle East J. Appl. Sci.*, 4(2): 157-165, 2014
- Estan, M. T., Martinez-Rodriguez, .M. M., Perez-Alfocea F., Flowers, T. J. and Bolarin, .M. C. (2005). Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. *Journ. of Expt. Bot.* 56:703-712.
- FAOSTAT, F.A.O. (2013). F. A. O. statistical data base. <http://www.fao.org>. Accessed:

February 15, 2015

- Favati F, Lovelli S, Galgano F, Miccolis V, Di Tommaso T. and Candido V. (2009).
Processing tomato quality as affected by irrigation scheduling. *Sci Hort.* 122:562-571
- Fernandez-Garcia, N., Martinez, V. and Carvajal, M. (2004a). Effect of salinity on growth, mineral composition, and water relations of grafted tomato plants. *J. Plant Nutr. Soil Sci.* 167, 616–622.
- Fernandez-Garcia, N., Martinez, V., Cerda, A., and Carvajal, M. (2004b). Fruit quality of grafted tomato plants grown under saline conditions. *J. Hortic. Sci. Biotechnol.* 79, 995–1001.
- Flores, F.B., Sanchez-Bel, P., Estan, M.T., Martinez-Rodriguez, M.M., Moyano, E., Morales, B., Campos, J.F., Garcia-Abellan, J.O., Egea, M.I., Fernández-Garcia, N., Romojaro, F., Bolarin, M.C. (2010). The effectiveness of grafting to improve tomato fruit quality. *Sci. Hortic.* 125, 211–217.
- Furini, A., Wunder, J. (2004). Analysis of eggplant (*Solanum melongena*) related germplasm: morphological and AFLP data contribute to phylogenetic interpretations and germplasm utilization. *Theor. Appl. Genet.* 108, 197–208.
- Gao, .Q.H., Xu, X.F. and Wang, Y.W. (2006). Effect of grafting on cold tolerance in eggplant seedlings. *Acta Hort.* 771: 781-789
- Garcia-Sanchez, F., Syvertsen, J.P., Gimeno, V., Botia, P. and Perez-Perez, J.G. (2007). Responses to flooding and drought stress by two citrus rootstock seedlings with different water-use efficiency. *Biol. Plant.* 130, 532–542.
- Gerster, H. (1997). The potential role of lycopene for human health. *J. Am. Coll. Nutr.* 16,109–126.

- Giannakou, I. O., and Karpouzas D. G. (2003). Evaluation of chemical and integrated strategies as alternatives to methyl bromide for the control of root-knot nematodes in Greece. *Pest Management Science* 59:883-892.
- Gisbert, C., Prohensa, J., Raigon, M.D., Stommel, J. R., Nuez, F. (2011). Eggplant relatives as sources of variation for developing new rootstocks: Effects of grafting on eggplant yield and fruit apparent quality and composition. *Sci. Hortic.* 128 (2011) 14– 22
- Greaves, J.A. (1996). Improving suboptimal temperature tolerance in maize: the search for variation. *J. Exp. Bot.* 47, 307–323.
- Grimault, V., and Prior, .P. (1994). Grafting tomato cultivars resistant or susceptible to bacterial wilt - analysis of resistance mechanisms. *Journal of Phytopathology-PhytopathologischeZeitschrift*141:330-334.
- Grubinger, V. (2007). Grafting greenhouse tomatoes. University of Vermont Extension Website. <<http://uvm.edu/vtvegandberry/factsheets/graftingGHtomato/html>>
- Grubben, G.H., Denton, O.A. (2004). *Vegetables*, PROTA (CTA, PROTA)
(URL) <http://publications.cta.int/en/publications/publication/1229/>
- Gruda, N. (2005). Impact of environmental factors on product quality of greenhouse vegetables for fresh consumption. *Crit. Rev. Plant Sci.* 24, 227–247.
- Hartmann, H.T., Kester, D.E., Davies, F.T., and Geneve, R.L. (2002). *Plant propagation and principles*. 7th ed. Prentice Hall, Upper Saddle River, NJ.
- Hartmann H.T., Kester, D.E., Davies, F.T., and Geneve, R.L. (2011). *Plant Propagation: Principles and Practices*. Eight edition. New York: Prentice Hall
- He, Z.L., Yang, X.E. and Stoffella, P.J. (2005). Trace elements in agroecosystems and impacts on the environment. *J. Trace Elem. Med. Biol.* 19, 125–140.
- He, Y., Zhu, Z., Yang, J., Ni, X., Zhu, D. (2009). Grafting increases the salt tolerance of tomato by improvement of photosynthesis and enhancement of antioxidant enzymes

- activity. *Environ. Exp. Bot.* 66, 270–278.
- Horna, D., Timpo, S., Al-Hassan R.M., Smale, M., Falck-Zepeda, J (2007). Vegetable production and Pesticide use in Ghana; Would GM varieties have an impact at the farm level? AAAE conference proceedings 2007; 473-477.
- Hu, C.M., Zhu, Y.L., Yang, L.F., Chen, S.F., Hyang, Y.M. (2009). Comparison of photosynthetic characteristics of grafted and own-root seedling of cucumber under low temperature circumstances. *Acta Bot. Boreali-Occident.Sin.* 26, 247–253.
- Huang, Y., Tang, R., Cao, Q., Bie, Z. (2009). Improving the fruit yield and quality of cucumber by grafting onto the salt tolerant rootstock under NaCl stress. *Sci. Hortic.* 122, 26–31.
- Huang, Y., Bie, Z., He, S., Hua, B., Zhen, A., and Liu, Z. (2010). Improving cucumber tolerance to major nutrients induced salinity by grafting onto *Cucurbita ficifolia*. *Environ. Exp. Bot.* 69, 32–38.
- Huitron-Ramirez, M.V., Ricardez-Salinas, M., and Camacho-Ferre, F. (2009). Influence of grafted watermelon plant density on yield and quality in soil infested with melon necrotic spot virus. *Hort. Science* 44, 1838–1841
- Ibrahim, M., Munira, M.K., Kabir, M.S., Islam, A.K.M.S., and Miah, M.M.U. (2001). Seed germination and graft compatibility of wild rootstock as tomato. *Journ. of Bio. Sci.* 1:701-703.
- Ibrahim A, Wahb-Allah .M., Abdel-Razzak, .H., and Alsadon A. (2014). Growth, Yield, Quality and water use efficiency of grafted tomato plants grown in greenhouse under different irrigation Levels. *Life Sci J.* 11(2):118-126]. (ISSN: 1097-8135).
- Ioannou, N. (2001). Integrating soil solarisation with grafting on resistant rootstocks for management of soil-borne pathogens of eggplant. *Journ. of Hort. Sci. & Biotech.* 76:396-401.

- Johnson, S.J. and C.A. Miles. (2011). Effect of Healing Chamber Design on the Survival of Grafted Eggplant, Tomato, and Watermelon. *Hort. technology* 21(6):752-758.
- Johnstone P. R., Hartz .T.K., Le Strange .M., Nunez, .J.J. and Miyao EM. (2005). Managing fruit soluble solids with late-season deficit irrigation in drip-irrigated processing tomato production. *Hort. Sci*; 40:1857-1861
- Kato, C., Ohshima, N., Kamada, H. and Satoh, S. (2001). Enhancement of the inhibitory activity for greening in xylem sap of squash root with waterlogging. *Plant Physiol. Biochem.* 39, 513–519.
- Kawaguchi, M., Taji, A., Backhouse, D., and Oda, M. (2008). Anatomy and physiology of graft In compatibility in solanaceous plants. *J. Hortic. Sci. Biotechnol.* 83, 581–588.
- Kays, S.J., (1999). Pre-harvest factors affecting appearance. *Postharvest Biol. Technol.* 15,233–247.
- Khah, E.M., Kakava, E.M.A., Chachalis, D., and Goulas, C. (2006). Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in greenhouse and open field. *J. Appl. Hortic.* 8, 3–7
- King, S.R., Davis, .A.R. Zhang, .X. and Crosby, .K. (2010). Genetics, breeding and selection of rootstocks for Solanaceae and Cucurbitaceae. *Sci. hortic.* 127(2):106-111.
- Kleinhenz D. M., Monicah Waiganjo, J. M.E., and Sally A. M. (2013) Tomato grafting guide: a quick guide to splice and Cleft Graft Method. Retrieved from http://hortersp.ucdavis.edu/main/Deliverables/Kleinhenz/tomato_grafting_guide.pdf on 20/10/2014.
- Krumbein, A. and Auerswald, H., (1998). Characterization of aroma volatiles in tomatoes by

- sensory analyses. *Food* 42, 395–399.
- Krumbein, A., Peters, P., Bruckner, B. (2004). Flavour compounds and a quantitative descriptive analysis of tomatoes (*Lycopersicon esculentum* Mill.) of different cultivars in short term storage. *Postharvest Biol. Technol.* 32, 15–28.
- Kubota, C., McClure, M.A., Kokalis-Burelle, N., Bausher, M.G., and Ross kopf, E.N. (2008). Vegetable grafting: History, use, and current technology status in North America. *Hort. Science* 43(6):1664-1669.
- Kumar, G. N. M. (2011). Propagation of Plants by Grafting and Budding. A Pacific Northwest Extension Publication. PNW496.
- Lee, J. (2003). Advances in Vegetable Grafting. *Chron. Hortic.* 43:13-19.
- Lee, J., Kubota, C., Tsao, S.J., Bie, Z., Echevarria, P.H., Morra, L., and M. Oda. (2010). Current status of vegetable grafting: diffusion, grafting techniques, automation. *Sci. Hortic* 127(2):93-105.
- Lee, J.M. (1994). Cultivation of grafted vegetables I: current status, grafting methods and benefits. *Hort. Science* 29, 235–239.
- Lee, J.M., Bang, H.J., Ham, H.S., (1999). Quality of cucumber fruit as affected by rootstock. *Acta. Hortic.* 483, 117–123.
- Lee, J.M. and Oda, M. (2003). Grafting of herbaceous vegetable and ornamental crops. *Hortic. Rev.* 28, 61–124.
- Lee, S.K. and Kader, .A. A. (2000). Pre-harvest and postharvest factors influencing vitamin C content of horticultural crops. *Journal of Postharvest Biology and Technology*, 20, 207-220.
- Leonardi, C., and Giuffrida, F., (2006). Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks. *Eur. J. Hortic. Sci.* 71, 97–101.

- Leonardi, C. and Romano, D. (2004). Recent issues on vegetable grafting. *Acta Hort.* 631: 163-174
- Liao, C.T. and Lin, C.H. (1996). Photosynthetic response of grafted bitter melon seedling to flood stress. *Environ. Exp. Bot.* 36, 167–172.
- Liu, H.Y., Zhu, Z.J., Diao, M., and Guo, Z.P. (2006). Characteristic of the sugar metabolism in leaves and fruits of grafted watermelon during fruit development. *Plant Physiol. Commun.* 42, 835–840.
- Lopez-Galarza, S., San Bautista, A., Perez, D.M., Miguel, A., Baixauli, C., Pascal, B., Maroto, J.V., and Guardiola, J.L. (2004). Effects of grafting and cytokinin-induced fruit setting on colour and sugar-content traits in glasshouse-grown triploid watermelon. *J. Hortic. Sci. Biotechnol.* 79, 971–976
- Louws, F., Rivard, .C. L. and Kubota, .C. (2010). Grafting fruiting vegetables to manage soil-borne pathogens, foliar pathogens, arthropods and weeds. *Sci. Hort.* 127:127-146.
- Manashi, D.P. (2011). Physiochemical properties of five different tomato cultivars of Meghalaya, India and their suitability in food processing. *As. J. food Ag-Ind.* 4 (3), 187-203
- Marsic N. K., and Osvald J. (2004). The influence of grafting on yield of two tomato cultivars (*S. Lycopersicum* Mill.) grown in a plastic house. *Acta Agric Slov* 2004; 83(2):243-249
- Martinez-Ballesta, M.C., Lopez-Perez, L., Hernandez, M., Lopez-Berenguer, C., Fernandez-Garcia, N. and Carvajal, M., (2008). *Agricultural practices for enhanced human health. Phytochem. Rev.* 7, 251–260.
- Masterson, .S.A. (2013). Propagation and utilisation of grafted tomatoes in the Great Plains. M. of Hort. Thesis, University of Alabama. <http://krex>

- Matsuzoe, N. Aida, H., Hanada, K., Ali, M., Okubo, H. and Fujieda, K. (1996). Fruit quality of tomato plants grafted on *Solanum* rootstocks. *J. Jpn. Soc. Hortic. Sci.* 65, 73–80.
- Matsuzoe, N., Nakamura, H., Okubo, H., and K. Fujieda. (1993). Growth and yield of tomato plants grafted on *Solanum* rootstocks. *Journ. of the Jap. Soc. for Hort. Sci.* 61:847-855.
- Matsuzoe, N., H. Okubo, and K. Fujieda. (1993). Resistance of tomato plants grafted on *Solanum* rootstocks to bacterial wilt and root-knot nematode. *Journ. of the Jap. Soc. for Hort. Sci.* 61:865-872.
- Mattheis, J.P. and Fellman, J.K. (1999). Pre-harvest factors influencing flavor of fresh fruit and vegetables. *Postharvest Biol. Technol.* 15, 227–232.
- McAvoy, T. Paret L.M., Freeman, J., Rideout, S., Olson, S.M. (2011). Grafting for management of bacterial wilt and root-knot nematode in tomato (URL): www.grafting2011.com. Accessed December 30th, 2013.
- Miguel, A., Maroto, J.V., San Bautista, A., Baixauli, C., Cebolla, V., Pascual, B., Lopez-Galarza, S. and Guardiola, J.L. (2004). The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methyl bromide for control of *Fusarium* wilt. *Sci. Hortic.* 103, 9–17.
- MOFA, (2010). Production of crops in Ghana. <http://mofa.gov.gh/site> Accessed December 30th, 2014
- Mohammed, S.M.T., Humidan, .M. Boras, .M. and Abdallah, .O.A. (2009). Effect of Grafting Tomato on Different Rootstocks on Growth and Productivity under Glasshouse Conditions. *As. J. of Agric. Research* 3(2):47-54.
- Morra L. and Bilotto M. (2009). Mercato in fortissima ascesa per i portainnesti orticoli. *L'Informatore Agrario.* 1: 51-54.
- Morejon, N.H. (2013). Genetic and environmental factors affecting improvement of

- rootstocks for tomato. M. of Hort. Thesis, Ohio State University.
- Mortvedt, J.J., Cox, F.R., Shuman, L.M. and Welch, R.M. (1991). *Micronutrients in Agriculture*, 2nd ed. SSSA Book Ser. 4, SSSA, Madison, W
- Mudge, K., Janick, J., Scofield S, and Goldschmidt, E.E. (2009). A history of grafting. *Hort. Rev.* 35: 437-493.
- Munez-Falcau, J.E., Prohens, J., Rodriguez-Burruezo, A. and Nuez, F. (2008). Potential of local varieties and their hybrids for the improvement of eggplant production in the open field and greenhouse cultivation. *J. Food Agric. Environ.* 6, 83–88.
- Nkansah, G.O., Ahwereng, A.K., Amoatey, C., and Ayarna, A.W. (2013). Grafting unto African eggplant enhances growth, yield and fruit quality of tomatoes in tropical forest ecozones. *Journ. of appl. Hort.*, 2013, vol. 15, issue 1, pages 16-20.
- Obeng-Ofori, D., Danquah, E.Y., and Ofori Anim, J. (2007). *Vegetable and spice crop production indgh West Africa*. The city publishers' limited.pp 53
- O'Connell, S. (2008). Grafted Tomato Performance in Organic Production Systems: Nutrient Uptake, Plant Growth, and Fruit Yield. *M. of Hort. thesis*, North Carolina St. Univ., Raleigh, NC.
- Oda, M., Tsuji, K. and Sasaki, H. (1993). Effect of hypocotyl morphology on survival rate and growth of cucumber seedling grafted on *Cucurbita* spp. *Jap. Agric. Res. Quart.* 26(4):259-263.
- Oda, M. (1999). Grafting of vegetable to improve greenhouse production. *Acta Hort.* 759:175-180
- Oda, M. (2002). Grafting of vegetable crops. *Sci. Rep. Agr. & Biol. Sci.* Osaka Pref. Univ. 54:49-72.
- Oda, M. (2007).Vegetable grafting in Japan. *Proc. XXVII IHC on Global Hort.: Diversity and Harmony* (ed. J. Janick). *Acta Hort* 759: 175-180.

- Okimura, M., Matso, S., Arai, K. and Okitsu, S. (1986). Influence of soil temperature on the growth of fruit vegetable grafted on different stocks. *Bull. Veg. Ornam. Crops Res. Stn. Jpn.* C9, 43–58
- Palada, M.C. and Wu, D.L. (2008). Evaluation of chili rootstocks for grafted sweet pepper production during the hot-wet and hot-dry seasons in Taiwan. *Acta Hort.* 767, 167–174.
- Passam, H.C., Stylianoy, M. and Kotsiras, A. (2005). Performance of eggplant grafted on tomato and eggplant rootstocks. *Eur. J. Hortic. Sci.* 70, 130–134.
- Pavlou, G. C., Vakalounakis, .D. J. and Ligoxigakis, .E. K. (2002). Control of root and stem rot of cucumber, caused by *Fusarium oxysporum* f. *radicis-cucumerinum*, by grafting onto resistant rootstocks. *Plant Disease* 86:379-382.
- Plants with Phytochemicals. Property of Top Cultures and Protected by Belgian and International copyright laws. <http://www.phytochemicals.info/plants/tomato.php>. Tuesday, July 28, 2015, 9:44PM GMT.
- Peregrine, W. T. H., and K. Binahmad. (1982). Grafting - a simple technique for overcoming bacterial wilt in tomato. *Tropical Pest Manag.* 28:71-76.
- Pervez, M.A., Ayub, .C.M., Khan, .H.A., Shalid, .M.A. and Ashraf, I. (2009). The effect of drought on growth yield and seed quality of tomatoes (*S. lycopersicum*). *Pak. J. Agri. Sci. Vol. 46(3)* 22-26
- Petran, A.J. (2013). Interspecific grafting of tomato (*solanum lycopersicum*) onto wild eggplant (*Solanum Torvum*) for increase environmental tolerances. Msc. Thesis, University of Minnesota. <http://umn.edu>.
- Pogonyi, A., Pek, Z., Helyes, L. and Lugasi, A. (2005). Effect of grafting on the tomato's yield, quality and main fruit components in spring forcing. *Acta Alim.* 34, 453–462.
- Proietti, S., Roupael, Y., Colla, G., Cardarelli, M., De Agazio, M., Zacchini, M., Moscatello,

- S. and Battistelli, A. (2008). Fruit quality of mini-watermelon as affected by grafting and irrigation regimes. *J. Sci. Food Agric.* 88, 1107–1114.
- Pulgar, G., Villora, G., Moreno, D.A., Romero, L., 2000. Improving the mineral nutrition in grafted watermelon plants: nitrogen metabolism. *Biol. Plant.* 43, 607–609.
- Qi, H.-Y., Liu, Y.-F., Li, D. and Li, T.L. (2006). Effects of grafting on nutrient absorption, hormone content in xylem exudation and yield of melon (*Cucumismelo* L.). *Plant Physiol. Commun.* 42, 199–202.
- Qian, Q.Q., Liu, H.Y. and Zhu, Z.J. (2004). Studies on sugar metabolism and related enzymes activity during watermelon fruit development as influenced by grafting. *J. Zhejiang Univ.* 30, 285–289.
- Rahman, M.A., Rashid, M.A., Salam, M.A., Masud, M.A.T., A.S.M.H. Masum, A.S.M.H., and Hossain, M.M. (2002). Performance of some grafted eggplant genotypes on wild *Solanum* root stocks against root-knot nematode. *Journal of Biological Sciences* 2:446-448
- Raigon, M.D., Prohens, J., Munoz-Falcon, J.E. and Nuez, F. (2008). Comparison of eggplant landraces and commercial varieties for fruit content of phenolics, minerals, dry matter and protein. *J. Food Comp. Anal.* 21, 370–376.
- Relf, D., McDaniel, A. and Morse, R. (2009). Tomatoes. Virginia Cooperative Extension Publication 426-381.
- Rice, R.P. (1993). *Fruits and Vegetable Production in Africa*. The Macmillan press Ltd. London p233.
- Rivard, C., and Louws, F. J. (2006). Grafting for disease resistance in heirloom tomatoes. NC Coop. Ext. Serv. AG-675

- Rivard, C.L. and Louws, F.J. (2008). Grafting to manage soil-borne diseases in heirloom tomato production. *Hort. science* 43, 2104-2111
- Rivero, R. M., Ruiz, J. M. and Romero, L. (2003a). Role of grafting in horticultural plants grown under stress conditions. *Food, Agric., & Environ.* 1:70-74.
- Rivero, R.M., Ruiz, J.M., Sanchez, E., Romero, L., (2003b). Does grafting provide resistance to tomato rootstocks against root-knot nematode? *Journ. of Bio. Sci.* 2:446-448
- Rivero, R.M., Ruiz, J.M., and Romero, L., (2004). Iron metabolism in tomato and watermelon plants: influence of grafting. *J. Plant Nutr.* 27, 2221–2234.
- Robinson, J. Z. E. and Kolavalli, S. L. (2010). The Case of Tomato in Ghana – Marketing. (International Food Policy Research Institute - IFPRI). (Online) <http://www.ifpri.org/publication/case-tomato-ghana-marketing>. 09/11/2010. 09:44am Accessed: March 9, 2015.
- Rost, L. T. (1996). Tomato anatomy. Leaf anatomy. Univ. of California Davis. (URL) <http://www.pld.ucdavis.edu/labs/rost/tomato/Reproductive/flranat.html>. Accessed: 2011. 11:39 GMT.
- Rouphael, Y., Cardarelli, M., Colla, G. and Rea, E. (2008a). Yield, mineral composition, water relations, and water use efficiency of grafted mini-watermelon plants under deficit irrigation. *Hort. Sci.* 43, 730–736.
- Rouphael, Y., Cardarelli, M., Rea, E., and Colla, G. (2008b). Grafting of cucumber as a means to minimize copper toxicity. *Environ. Exp. Bot.* 63, 49–58.
- Rouphael, Y., Schwarz, D., Krumbein, A., and Colla, G. (2010). Impact of grafting on product quality of fruit vegetables. *Scientia Horticulturae* 127 (2010) 172–179
- Ruiz, J.M., Blasco, R. Rivero, M. and Romero, L (2005). Nicotine free and salt tolerant tobacco plants, obtained by grafting onto salinity-resistant rootstocks of tomato. *Physio. Plantarum* 124:465-475

- Ruiz, J.M., Belakbir, A., Lopez-Cantarero, I., and Romero, L. (1997). Leaf-macronutrient content and yield in grafted melon plants. A model to evaluate the influence of rootstock genotype. *Sci. Hortic.* 71, 227–234.
- Sakata, Y., Ohara, T. and Sugiyama, M. (2007). The history and present state of the grafting of cucurbitaceous vegetables in Japan. 3rd proceedings on Cucurbits (Ed. R. McConcie and G. Rogers). *Acta Hort.* 731, ISHS.
- Salam, M.A., Masum, A.S.M.H., Chowdhury, S.S., Dhar, M., Saddeque, A. and Islam, M.R. (2002). Growth and yield of watermelon as influenced by grafting. *J. Biol. Sci.* 2, 298–299.
- Salehi, R., Kashi, A., Lee, J.-M., Babalar, M., Delshad, M., Lee, .S.G. and Huh, Y.C. (2010). Leaf gas exchanges and mineral ion composition in xylem sap of Iranian melon affected by rootstocks and training methods. *Hort. Science* 45, 766–770.
- Sams, C.E. (1999). Pre-harvest factors affecting postharvest texture. *Postharvest Biol. Technol.* 15, 249–254.
- Sanchez-Rodriguez, E., J. Manuel Ruiz, F. Ferreres, and D.A. Moreno. (2012). Phenolic Metabolism in Grafted versus Non-grafted Cherry Tomatoes under the Influence of Water Stress. *J. Agric. Food Chem.* 59(16):8839-8846.
- Santamaria, P. (2006). Nitrate in vegetables: toxicity, content, intake and EC regulation. *J. Sci. Food Agric.* 86, 10–17.
- Santa-Cruz, A., Martinez-Rodriguez, M.M., Perez-Alfocea, F., Romero-Aranda, .R., and . Bolarin, .M.C. (2002). The rootstock effect on the tomato salinity response depends on the shoot genotype. *Plant Sci.* 162(5):825-831.
- Satisha, J., Prakash, G.S., Bhatt, R.M. and Kumar, P. (2007). Physiological mechanisms

- of water use efficiency in grape rootstocks under drought conditions. *Int. J. Agric. Res.* 2, 159–164
- Savvas, D., Colla, G., Roupael, Y. and Schwarz, D. (2010). Amelioration of heavy metal and nutrient stress in fruit vegetables by grafting. *Sci. Hort.* 127, 156–161.
- Savvas, D., Papastavrou, D., Ntatsi, G., Ropokis, A., Olympios, C., Hartmann, H. and Schwarz, D. (2009). Interactive effects of grafting and Mn-supply level on growth, yield and nutrient uptake by tomato. *Hort. Science* 44, 1978–1982.
- Schreiner, M. (2005). Vegetable crop management strategies to increase the quantity of Phyto-chemicals. *Eur. J. Nutr.* 44, 85–94.
- Schwarz, D., Roupael, Y., Colla, G. and Vanema, J.K. (2010). Grafting as tool to improve tolerance of fruit vegetable to abiotic stresses: thermal stress, water stress, and organic pollutants. *Sci. Hort.* 127: 162-171
- Shibuya, T., Tokuda, A., Terakura, R., Shimizu-Maruo, K., Sugiwaki, H., Kitaya, Y. and Kiyota, M. (2007). Short-term bottom-heat treatment during low-air-temperature storage improves rooting in squash (*Cucurbita moschata* Duch.) cuttings used for rootstock of cucumber (*Cucumis sativus* L.). *J. Jpn. Soc. Hort. Sci.* 76 (2), 139–143.
- Simonne, E., Hutchinson, C., De Valerio, J., Hochmuth, R., Treadwell, D., Wright, A., Santos, B., Whidden, A., McAvoy, G., Zhao, X., Olczyk, T., Gazula, A. and Ozores-Hampton, M. (2010). Current knowledge, gaps, and future needs for keeping water and nutrients in the root zone of vegetables grown in Florida. *Hort. Tech.* 20, 143–152.
- Tambo, J.A. and Gbemu, T. (2010). *Resource-use Efficiency in Tomato Production in the*

- Dangme West District, Ghana*. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Tropentag, ETH Zurich, Switzerland, 2010
- Taussig, C., Izard, D. and Ernout, H. (1996). Melon greffe: comment le conduire. *PHM* 368, 36–39.
- Tikoo, S. K., Mathai, .P. J., and Kishan, R. (1979). Successful graft culture of tomato in bacterial wilt sick soils. *Curr. Sci.* 48:259-260.
- Tresky, S, and Walz, E. (1997). Testing solutions for control of bacterial wilt in tomatoes. *Organic Farming Research Foundation Bulletin* 4:8-9.
- Tsaballa A., Athanasiadis C., Pasentsis K., Ganopoulos I., Nianiou-Obeidat I., Tsaftaris A. (2013). Molecular studies of inheritable grafting induced changes in pepper (*Capsicum annuum*) fruit shape. *Sci. Hort.*149: 2-8.
- Tsouvaltzis, P.I., Siomos, A.S. and Dogras, K.C. (2004). The effect of the two tomatoes grafting on the performance, earliness and fruit quality. In: *Proceedings of 21st Pan-Hellenic Congress of the Greek Society for Horticultural Science*, Ioannina, Greece, 8–10 October 2003. vol. 11, pp. 51–55.
- Tsrer, L., and Nachmias, .A. (1995). Significance of the root system in Verticillium wilt tolerance in potato and resistance in tomato. *Isr. Journ. of Plant Sci.* 43:315-323.
- Turhan A., Ozmen, N., Serbeci, M.S. and Seniz, V. (2011). Effects of grafting on different rootstocks on tomato fruit yield and quality. *Hort. Sci. (Prague)*, 38: 142–149.
- Upstone, M. E. (1968). Effects of methyl bromide fumigation and grafting on yield and root diseases of tomatoes. *Plant. Path.* 17:103-&.
- Van der Hoeven, R. S., Ronning, C., Giovannoni, J. J., Martin, G. and Tanksley, S. D. (2002) Deductions about the number, organization, and evolution of genes in the tomato genome based on analysis of a large expressed sequence tag collection and

- selective genomic sequencing. *The Plant Cell* 14, pp. 1441–1456.
- Van der Ploeg, A. and Heuvelink, E. (2005). Influence of sub-optimal temperature on tomato growth and yield: a review. *J. Hortic. Sci. Biotech.* 80, 652–659.
- Venema, J.H., Dijk, B.E., Bax, J.M., van Hasselt, P.R. and Elzenga, J.T.M. (2008). Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a high-altitude accession of *Solanum habrochaites* improves suboptimal-temperature tolerance. *Environ. Exp. Bot.* 63, 359–3
- Venema, J.H., Linger, P., van Heusden, A.W., van Hasselt, P.R. and Bruggemann, W. (2005). The inheritance of chilling tolerance in tomato (*Lycopersicon* spp.). *Plant Biol.* 7, 118–130
- Voutsela, S., Garip Y., Spyridon, A., Petropoulos, T., and Khan, I.M. (2012). The effect of grafting of five different rootstocks on plant growth and yield of tomato plants cultivated outdoors and indoors under salinity stress; *African Journal of Agricultural Research* Vol. 7(41), pp. 53-57, 29 October, 2012.
- Wang, S., Yang, R., Cheng, J., and Zhao, J.(2007). Effect of rootstocks on the tolerance to high temperature of eggplants under solar greenhouse during summer season. *Hort.* 761, 357–360.
- Wang, W., Vinocur, B. and Altman, A. (2003). Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta* 218, 1–14.
- Xu, C.Q., Li, T.L. and Qi, H.Y. (2006a). Effects of grafting on development, carbohydrate content, and sucrose metabolizing enzymes activities of muskmelon fruit. *Acta Hortic.Sinica* 33, 773–778.

- Xu, C.Q., Li, T.L., Qi, H.Y. and Wang, H. (2005). Effects of grafting on growth and development, yield, and quality of muskmelon. *China Veg.* 6, 12–14.
- Xu, C.Q., Li, T.L., Qi, H.Y. and Wang, H. (2006b). Effects of grafting on development and sugar content of muskmelon fruit. *J. Shenyang Agric. Univ.* 37,
- Yao, F.J., Huang, D.F., Zhang, H.M. and Liu, Y.Q. (2003). Effects of rootstocks on growth and fruit quality of grafted watermelon. *J. Shanghai Jiao tong Univ. (Agricultural Science)* 21, 289–294.
- Yetisir, H., Caliskan, M.E., Soylu, S. and Sakar, M. (2006). Some physiological and growth responses of watermelon [*Citrullus lanatus* (Thunb.) Matsum and Nakai] grafted onto *Lagenaria siceraria* to flooding. *Environ. Exp. Bot.* 58, 1–8.
- Yetisir, H., Kurt, S., Sari, N. and Tok, F.M. (2007). Rootstock potential of Turkish *Lagenaria Siceraria* germplasms for watermelon: plant growth, graft compatibility, and resistance to fusarium. *Turkish J. Agric. For.* 31, 381–388.
- Yetisir, H., and Sari, N. (2003). Effect of different rootstock on plant growth, yield and quality of watermelon. *Aust. J. Exp. Agric.* 43, 1269–1274.
- Yetisir, H., Sari, N. and Yucel, S. (2003). Rootstock resistance to Fusarium wilt and effect on watermelon fruit yield and quality. *Phytoparasitica* 31, 163–169.
- Zhou, Y.H., Huang, L.F., Zhang, Y., Shi, K., Yu, J.Q. and Noguees, S., (2007). Chill-induced decrease in capacity of RuBP carboxylation and associated H₂O₂ accumulation in cucumber leaves are alleviated by grafting onto Figleaf Gourd. *Ann. Bot.* 100, 839–848
- Zhu, J., Bie, Z., Huang, Y. and Han, X. (2008). Effect of grafting on the growth and ion concentrations of cucumber seedlings under NaCl stress. *Soil Sci. Plant Nutr.* 54, 895–902.

APPENDICES

Appendix 1: Anova for plant height at 14 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	2.0370	0.6790	2.31	
Treatment	7	626.4127	89.4875	304.85	<.001
Residual	21	6.1645	0.2935		
total	31	634.6141			

Appendix 2: Anova for plant height at 28 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.8896	0.2965	0.92	
Treatment	7	2606.8866	372.4124	1160.11	<.001
Residual	21	6.7413	0.3210		
total	31	2614.5176			

Appendix 3: Anova for plant height at 42 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.5688	0.1896	1.2	
Treatment	7	7770.1039	1110.0148	6555.45	<.001
Residual	21	3.5559	0.1693		
total	31	7774.2285			

Appendix 4: Anova for plant height 56 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	3.971	1.324	1.24	
Treatment	7	13190.486	1884.355	1761.42	<.001
Residual	21	22.466	1.070		
total	31	13216.923			

Appendix 5: Anova for stem diameter 14 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0015250	0.0005083	0.67	
Treatment	7	2.4268500	0.3466929	454.32	<.001
Residual	21	0.0160250	0.0007631		
total	31	2.4444000			

Appendix 6: Anova for stem diameter at 28 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0004625	0.0001542	0.19	
Treatment	7	1.6521375	0.2360196	283.43	<.001
Residual	21	0.0174875	0.0008327		
total	31	1.6700875			

Appendix 7: Anova for stem diameter at 42 days after transplanting

Source of variation	df	ss	ms	Vr	Fpr
Block	3	0.019784	0.006595	1.15	
Treatment	7	3.779897	0.539985	93.92	<.001
Residual	21	0.120741	0.005750		
total	31	3.920422			

Appendix 8: Anova for stem diameter at 56 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0021094	0.0007031	1.57	
Treatment	7	18.3278969	2.6182710	5839.62	<.001
Residual	21	0.0094156	0.0004484		
total	31	18.3394219			

Appendix 9: Anova for leaf number at 14 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.11358	0.03786	2.67	
Treatment	7	44.70265	6.38609	449.51	<.001
Residual	21	0.29834	0.01421		
total	31	45.11457			

Appendix 10: Anova for leaf number at 28 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.1997	0.0666	0.50	
Treatment	7	194.7846	27.8264	208.04	<.001
Residual	21	2.8088	0.1338		
total	31	197.7930			

Appendix 11: Anova for leaf number at 42 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.21281	0.07094	1.36	
Treatment	7	165.75864	23.67981	454.54	<.001
Residual	21	1.09304	0.05205		
total	31	167.06449			

Appendix 12: Anova for leaf number at 56 days after transplanting

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.27718	0.09239	0.94	
Treatment	7	153.31522	21.90217	222.37	<.001
Residual	21	2.06834	0.09849		
total	31	155.66075			

Appendix 13: Anova for days to flowering

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.4837	0.1612	0.59	
Treatment	7	616.1388	88.0198	319.45	<.001
Residual	21	5.7863	0.2755		
total	31	622.4088			

Appendix 14: Anova for days to harvesting

Source of variation	df	ss	ms	vr	Fpr
Block	3	2.725E-03	9.083E-04	14.96	
Treatment	7	8.831E+02	1.262E+02	2.078E+06	<.001
Residual	21	1.275E-03	6.071E-05		
total	31	8.831E+02			

Appendix 15: Anova for graft success

Source of variation	df	ss	ms	vr	Fpr
Treatment	6	42.278	8.456	1.18	0.374
Residual	14	86.000	7.167		
Total	20	128.278			

Appendix 18: Anova for fruit number

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.46625	0.15542	8.62	
Treatment	7	318.65375	45.52196	2523.99	<.001
Residual	21	0.37875	0.01804		
total	31	319.49875			

Appendix 19: Anova for fruit weight

Source of variation	df	ss	ms	vr	Fpr
Block	3	1.3434	0.4478	1.78	
Treatment	7	44175.1097	6310.7300	25127.75	<.001
Residual	21	5.2741	0.2511		
total	31	44181.7272			

Appendix 20: Anova for total yield

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0015125	0.0005042	1.15	
Treatment	7	9.0609875	1.2944268	2958.69	<.001
Residual	21	0.0091875	0.000437		
total	31	9.0716875			

Appendix 21: Anova for Soluble solids content (brix)

Source of variation	df	ss	ms	vr	Fpr
Block	3	1.344E-04	4.479E-05	0.39	
Treatment	7	1.33E+02	1.619E+01	1.393E+05	<.001
Residual	21	2.441E-03	1.1662E-04		
total	31	1.133E+02			

Appendix 22: Anova for Titrable acidity

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.00018437	0.00006146	1.04	
Treatment	7	0.20277188	0.02896741	490.33	<.001
Residual	21	0.00124063	0.00005908		
total	31	0.20419688			

Appendix 23: Anova for PH

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0023125	0.0007708	3.65	
Treatment	7	0.0329375	0.0047054	22.27	<.001
Residual	21	0.0044735	0.0002113		
Total	31	0.0396875			

Appendix 24: Anova for TSS:TA

Source of variation	df	ss	ms	vr	Fpr
Block	3	4.750E-04	1.583E-04	4.93	
Treatment	7	1.928E+02	2.755E+01	8.570E+05	<.001
Residual	21	6.750E-04	3.214E-05		
total	31	1.928E+02			

Appendix 25: Anova for vitamin C

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.0049344	0.0016448	1.80	
Treatment	7	97.3703469	13.9100496	15181.99	<.001
Residual	21	0.0192406	0.0009162		
total	31	973945219			

Appendix 26: Anova for lycopene

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.2159	0.0720	0.16	
Treatment	7	53.8171	7.6882	17.42	<.001
Residual	21	9.2669	0.4413		
total	31	63.3000			

Appendix 27: Anova for firmness

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.00005937	0.00001979	0.62	
Treatment	7	0.13172187	0.01881741	593.68	<.001
Residual	21	0.00066562	0.00003170		
total	31	0.1324487			

Appendix 28: Anova for shelf life

Source of variation	df	ss	ms	vr	Fpr
Block	3	0.11368	0.03789	0.57	
Treatment	7	2596.93560	370.99080	5565.96	<.001
Residual	21	1.39972	0.06665		
total	31	2598.44900			