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Research Article

Grafted Tomatoes: A Potential Innovation for Bacterial Wilt Disease Management, Improved Yield, Food Security and Nutrition in Uganda

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Abstract

Limited availability and consumption of high-nutrient fresh foods has led to malnutrition which is a serious developmental concern in Uganda, as a result of inadequate access to quality foods such as vegetables, lack of awareness of appropriate food and nutrition requirements; and unhealthy lifestyles and food behaviour. This has resulted in 29% stunting of children below five years, 11% underweight and 3.4% wasted which, in turn affects agricultural labor leading to abject poverty. Accessibility of essential foods such as tomatoes is considered a necessary behavioral change in the nutritional status of Ugandans. Although on their own, tomatoes might not make a complete meal, you often will not enjoy a meal without tomatoes as they make our food tasty and are a dietary item for nearly every household. They have numerous health benefits for a well-balanced diet and a key source of essential nutrients including vitamin A, C and E, with approximately 20 mg of vitamin C per 100 grams. Bacterial wilt (*Ralstonia solanacearum*) is the biggest challenge facing the tomato growers in Uganda. Although the disease targets primarily tomatoes, it is also a problem for potatoes, peppers, eggplant and other crops as well as weeds in the Solanaceous family, which act as natural alternate hosts. Almost all the commercial tomato varieties highly demanded by consumers in Uganda and the regional markets are susceptible to bacterial wilt. As an intervention from a consortium of partners, rootstock varieties resistant to the bacterial wilt disease were introduced from the Netherlands and evaluated for compatibility with highly demanded commercial varieties, in Uganda. Results clearly demonstrated that our method of grafting (splice method), was the most effective and suitable for Uganda, with survival and recovery of plants in most cases reaching over 80%. All seedlings were able to grow normally, after hardening both in greenhouses, on-station and on-farmers' fields. Among the rootstocks, E15M00025 performed best in graft recovery and also in yield and resistance to bacterial wilt. This line was also highly compatible with other lines including Anja F1 as a scion. As for scions, Anja F1 again performed best followed by Morelia F1 and then Randah F1 (E15A.60035) F1.

Keywords: *Grafting; bacterial wilt, humid chamber, tomatoes.*

Introduction

The origin of plant grafting is often attributed to Chinese horticulturalists; though the specific date is still disputed. Records suggest that, grafting was being utilized in China for fruit trees by 1500 BC (Hartman *et al*., 2002). Both Aristotle (384-322 BC) and his successor Theophrastus (371- 287 BC) wrote about the issue of graft compatibility, a

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continued challenge for modern horticulturalists (Sarah a. Masterson, 2013).

Grafting or graftage is a horticultural technique whereby tissues of plants are joined so as to continue their growth together. The upper part of the combined plant is called the scion while the lower part is called the rootstock. The success of this joining requires that the vascular tissue grow together and such joining is called inosculation. Vegetable grafting, however, has a much briefer and somewhat less poetic history.

Related in theory to woody grafting, the basic process of vegetable grafting employs a hybridized rootstock resistant to soil-borne diseases and a scion of a less-resistant variety that produces desirable fruit traits (Grubinger 2007). Herbaceous grafting was developed in Asia during the early 1920s to combat soil-borne disease in melons (Ashita 1927; Lee 1994), and it has since garnered popularity in regions with intensive land use and small agricultural areas (Hartmann and Kester, 1975). Overall, herbaceous grafting has an increasing presence in worldwide cultivation practices.

Techniques of successful grafting

Successful grafting only requires that a vascular connection take place between the grafted tissues. For successful grafting to take place, the vascular cambium tissues of the rootstock and scion plants must be placed in contact with each other and kept alive until the graft has "taken off", usually a period of a few days in vegetables and weeks in fruit trees. Research conducted in *Arabidopsis thaliana* hypocotyls have shown that the connection of phloem takes place after 3 days of initial grafting, whereas the connection of xylem can take up to 7 days (Melnyk *et al*., 2015). Joints formed by grafting are not as strong as naturally formed joints, so a physical weak point often still occurs at the graft because only the newly formed tissues inosculate with each other. The existing structural tissue (or wood) of the stock plant does not fuse. During grafting, the vascular cambium of the scion and stock should be tightly pressed together and oriented in the direction of normal growth. Proper alignment and pressure encourages the tissues to join quickly, allowing nutrients and water to transfer from the rootstock to the scion. Because grafting involves the joining of vascular tissues between the scion and rootstock, plants lacking vascular cambium, such as monocots, cannot normally be grafted. The grafting is completed at a time when the scion and root-stock are capable of producing callus and other wound-response tissues. Generally, grafting is performed when the scion is dormant, as premature budding can drain the grafting site of moisture before the grafting union is properly established. Temperature greatly affects the physiological stage of plants. If the temperature is too warm, premature budding may result and, high temperatures can slow or halt callus formation.

Importance of grafting in other countries.

Grafting and budding are horticultural techniques used to join parts from two or more plants so that they appear to grow as a single plant. In grafting, the upper part (scion) of one plant grows on the root system (rootstock) of another plant, usually of the same species or family. In the budding process, a bud is taken from one plant and grown on another. While grafting trees has many advantages, including retaining of desirable characteristics of the parent plants, and enhancing disease resistance and cold hardiness, there are some disadvantages as well. The grafted plants are more expensive because of the costs of rootstock seeds, and the labour required for the grafting and for raising the grafted seedlings.

In European countries, grafted transplant production has steadily grown with Spain leading the helm (129.8 million annually), and Italy and France (47.1 million and 28 million, respectively) following (Lee *et al*., 2010; Morra and Bilotto, 2009).

In the Mediterranean area, where land use is very intensive and continuous cropping is in common practice, vegetable grafting is considered an innovative technique with an increasing demand by farmers. Viewing recent data concerning the Mediterranean area by Leonardi and Romano (2004) it was reported that Spain is the most important country for the spreading of vegetable grafting with tomato and watermelon, accounting for 40 and 52% of the total of 154 million respectively.

Tomato (*Lycopersicon esculentum* Mill.) is a crop of high importance in many countries; and according to FAO (1998), in Greece, 1.8 million MT were produced. In the Mediterranean area, where land use is very intensive and continuous cropping is in common practice, vegetable grafting is considered an innovative technique with an increasing demand by farmers.

Tomato grafting became popular in the 1960s as a way to reduce certain diseases caused by soil-borne plant pathogens such as *Ralstonia solanacearum*. Currently, however, grafting is used to offer not only protection from certain diseases, but also tolerance to abiotic stress like flooding, drought, and salinity especially when the rootstock is resistant to the underlying constraints.

Some contradictions on grafting

However, there are also some contradictory results about the fruit quality traits and how grafting affects them. For example Traka-Mavrona *et al*., (2000) reported that the solutes associated with fruit quality are translocated in the scion through the xylem, whereas Lee (1994) states that quality traits e.g. fruit shape, skin colour, skin or rind smoothness, flesh texture and colour, soluble solids concentration etc. are influenced by the rootstock. However, other researchers showed that grafting did not affect fruit quality (Leoni *et al*., 1990; Romano and Paratore, 2001).

Many researchers found interaction between rootstock and scion which led to vigorous root system and higher absorption of water and minerals resulting in improving fruit yield and quality (Lee, 1994; Oda, 1995; Bersi, 2002) from lower plant population (Yetisir and Sari, 2003). Also grafting on suitable rootstock improves the resistance to salt stress (Romero *et al*., 1997), resistance to low root temperatures and heat stress (Rivero *et al*., 2003), synthesis of endogenous hormones and production of aerial parts resistance to soil-borne diseases (Bersi, 2002; Augustin *et al*., 2002) and also involved in the utilization and metabolism of macronutrients (Ruiz *et al*., 1996; Ruiz and Romero, 1999). Since grafting is considered an important technique for the sustainable production of fruit bearing vegetables in Korea, Japan and some European countries (Lee, 1994; Oda, 1995), the cultivation of grafted fruit-bearing vegetables has increased greatly nowadays.

To address challenges of Bacterial Wilt Disease (BWD) in Uganda, the National Crop Resources Research Institute (NaCRRI), Solidaridad Eastern and Central Africa Expertise Centre (SECAEC) and other consortium partners such as the House of Seeds Representing Enza Zaden Export, Makerere University Kampala, and AgriProFocus, Uganda) implemented a three years project, “Improved Resilience through Sustainable Production of Grafted Tomatoes in Uganda (IRESO)”, aimed at developing and promoting BWD resistant tomato seedlings as a more sustainable option to manage Bacterial wilt disease and to contribute to safe and quality tomatoes for consumers, through reduced application of a broad spectrum of synthetic pesticides. The project activities were implemented with support from NWO – WOTRO Science for Global Development applied research fund cycle 3 from the people of the Republic of The Netherlands. The Food & Business Knowledge Platform has published the research progress and milestones of our IRESO project. The overall objective of the project was to improve income, nutrition and bacterial wilt resilience through mobilization, commercialization and capacity building in sustainable production of grafted tomato.

Materials and methods

The research was conducted at the National Crops Resources Research Institute (NaCRRI) one of the Principal Research Institutes of the National Agricultural Research Organization (NARO), at Namulonge, in Wakiso district which is about sixteen kilometers north of Kampala and situated on latitude 0° 32′ north, longitude 32°37′ east, at an altitude of 1150-1155 m above sea level. The annual mean day temperature ranges from 24 to 30°C. The area experiences an average annual rainfall of 1000 to 1450 mm per year with a bimodal distribution pattern. The soil types are acidic Ferrallisols with a pH ranging from 6.5 to 7.0. The vegetation is tropical wet and mild dry climate with slight humid conditions (65% relative humidity) which are suitable for tomato growing.

The on station (NaCRRI) conditions comprised of a greenhouse measuring 15m by 9m (with concrete floor), with a height of 4.5 meters and covered by a rainproof low density ultra violet reinforced polythene sheet all over and an outside field previously infected with *Ralstonia solanacearum,* the causal agent for bacterial wilt disease (BWD). A locally constructed humid chamber of 9 x 2 metres was installed inside the greenhouse at the extreme end, and the flour spread with a 3 cm thick layer of sterilized lake sand. It was then covered allover with a waterproof polythene sheet supported by wooden poles, which was immersed in sand at all sides, to prevent air circulation in and out of the chamber. In addition, a non-replicated performance trial was established at two farmers' fields; one at Wakiso, Kiira municipality in Kimwanyi village (Urban Green Ecofarm) and another at Sekanyonyi village, Mityana district. Grafted tomato seedlings were planted in infected plots of these non-replicated trials, which had previously failed to support tomato production due to bacterial wilt disease. The farmers were allowed to practice their known farm management practices apart from trying to manage any observed bacterial wild disease incidences.

Grafting protocols

The grafting method adopted was the splice method. The essence was to use the soil adaptable and bacterial wilt disease resistant lines as rootstocks and the lines with desired characteristics such as high yielding and consumer acceptability attributes as a scion. Prior to this, healthy plants for scions and rootstocks were raised in a clean environment, as the first step to obtain robust planting materials. Information available indicate that grafting on suitable rootstock improves the resistance to salt stress (Romero *et al*., 1997), soil-borne diseases (Bersi, 2002; Augustin *et al*., 2002), low root temperatures (Bulder *et al*., 1991) and heat stress (Rivero *et al*., 2003), synthesis of endogenous hormones and production of aerial parts and improved utilization and metabolism of macronutrients (Ruiz *et al*., 1996; Ruiz and Romero, 1999).

Optimal conditions for seed germination and growth for both rootstock and scion plants were provided (Wenjing and Hallett, 2016). For example, tomato's ideal germination temperature is around 85°F (29.4^{0}C). Care was taken not to graft plants that showed disease symptoms or were severely stressed during germination or early growth. Since germination and growth rates vary among varieties, it was often found necessary to plant the rootstocks and scions at different dates depending on the varieties used, to achieve similar stem diameters at time of grafting.

In cases where differences in size of the rootstock and scion occurred, the grafting points were aligned on one side so that the cambial (cambium) layers of both were well in touch together on either side.

In all, tomato seedlings of 3-4 weeks with 4-6 true leaves were used. Healthy plants with straight long internodes above the cotyledonous leaves, were selected. Several grafting materials such as razor blades, clips and trays were prepared thoroughly by cleansing in disinfectants (Jik or sodium hypochlorite– 0.03%) and this was largely done in a cool environment. The grafting point for each plant was positioned at least 15cm above the ground to avoid the union getting into contact with the soil, especially for plants destined for field growth. A smooth single, sloping cut, with a sharp razor blade, at approximately 30^0 was made first on the root stock, followed by the scion respectively. The cut surfaces were immediately slightly pressed against one another and fastened together with a light polythene strip (tape), tubes or clip. Tubes or clips are not common on the Uganda market, but we obtained them from the House of Seeds (one of our partners), to enable us evaluate them against the light polythene strips which Ugandan farmers are used to and are common on the local market. Whereas the tube is inserted at the grafting point of the rootstock and scion, the plastic strip is wrapped tightly at the same point to ensure minimum water loss from the site. We also compared two grafting methods, the splice and the wedge methods. Thereafter, the grafted seedlings were transferred to the humidity chamber, with relative humidity of about 90%, for 5-8 days depending on the weather conditions; the cooler the conditions, the fewer days required. Humidity was enhanced by wetting the sand on the floor, with clean tap water and leaving the water to evaporate and then tightly closing the entrance of the chamber. Under humid chamber conditions, the plants were exposed by opening the lid for 30 minutes after every three days for purposes of acclimatizing the seedlings, and later closed. After 5-8 days in the chamber, the plants were removed and transferred to the open shade within the greenhouse where constant watering and all other management practices such as fertility management, pest and disease management were imposed. On the 10th day after hardening off, seedlings were ready for field transplantation. When it was felt satisfactory that the graft site was firm, the tying polythene strip (tape) or clip that fastened the joint at the grafting point was removed before the seedlings were transplanted in soil.

On-station and on-farm establishment

The field plot at NaCRRI was an infected garden previously infected with bacterial wilt pathogen (BW), for regular inoculation as source of *Ralstonia solanacearum*. Inoculum pressure was maintained in soil plots and enhanced by constantly planting susceptible tomatoes in these plots and these regularly showed bacterial wilt symptoms as a confirmatory proof of the pathogen in soil. In this regard, the experiment (both in greenhouse and outside plots) was a completely randomized design (CRD) of three rootstocks (E2900018, E15M00025 and MT 56) and two scions (Moleria F1 and then Randah F1 (E15A.60035) with each treatment replicated ten times. The two rootstocks E290018 and E1500025 were acquired from one of the Consortium partners (The House of Seeds, the exclusive distributor in Uganda for the vegetable breeder Enza Zaden based in the Netherlands). MT56, which is available locally was included as a local check. However, we later received another tomato line, Anja F1 also from House of Seeds, which was used as both a rootstock and scion (with all the previous lines) in a non-replicated plot, but not combined with the original performance trial. Its greenhouse and field performance at one of our farmers in Wakiso (Urban Green Ecofarm), was constantly observed and recorded. On station performance data was collected through regular observations and recordings of BW disease incidence, plant growth or and fruit yield. At the farmer's field in Sekanyonyi, Mityana district, grafted plants of E1500025 as a scion and Asilla F1 as a scion, were planted in a bacterial wilt infected plot of approximately one acre in size, in a non-replicated trial. Asilla F1 is the most preferred commercial tomato variety in Uganda but susceptible to bacterial wilt disease. The rootstock and scion combination was therefore largely demanded by the farmer after his visit at NaCRRI, for he had been frustrated with bacterial wilt damage on his farm. One part of this farmer's field was planted with Asilla F1, non-grafted plants for comparison purposes. Management was done at farmers' known agricultural practices. We allowed this management practice in order to satisfy the farmer's interests.

On-farm performance data was collected on farmers' fields at Kimwanyi village (Urban Green Ecofarm) Kiira municipality, Wakiso district and Sekanyonyi village, Mityana district. The farmers were allowed to practice their known farm management practices apart from trying to manage any observed bacterial wilt disease incidences. Farmers' perceptions as well as observations of BW disease incidence, plant growth and fruit yield were documented.

Results and discussions

Best performing root stocks for grafting

It was clearly demonstrated that our method of grafting (splice, method, Table 2), was quite effective and suitable for Uganda, with survival and recovery of plants in most cases reaching an average of 74.3%. While (Table 1), tape rapping technique (70.9%) performed better than plastic tubes (50.4%) and clips performed poorly at an average of 46.7%. Furthermore, this method has been demonstrated and adopted by farmers in other parts of the country where the project has been operating such as Wakiso, Mpigi, Mukono, Luweero and Kabale districts. All seedlings were able to grow normally, after hardening both in greenhouses, on-station and on-farm field trials.

Table 1. Survival rate by the method used for grafting scion and the rootstock

Variety (scion)	Rootstock	Survival rate out of 100 (in %)		
		Tape rapping	Plastic tube	Clips
Randah F1	E2900018	67	53	48
Moleria F1	E1500025	89	70	49
Anja F1	MT 56	51	43	14
Randah F1	E1500025	78	66	69
Moleria F1	E2900018	71	61	27
Anja F1	E1500025	88	68	62
Randah F1	MT 56	61	42	51
Anja F1	E2900018	77	51	44
Moleria F1	MT56	56	37	56
Mean		**70.9**	**54.6**	**46.7**

Table 2. The most suitable method for tomato grafting

Variety (scion)	Rootstock	Survival rate per grafting method out of 100 (%)	
		Splice	Wedge
Randah F1	E2900018	78	61
Moleria F1	E1500025	91	71
Anja F1	MT 56	62	55
Randah F1	E1500025	81	58
Moleria F1	E2900018	79	70
Anja F1	E1500025	75	69
Randah	MT 56	64	42
Anja F1	E2900018	80	68
Moleria	MT56	59	31
Mean		**74.3**	**58.3**

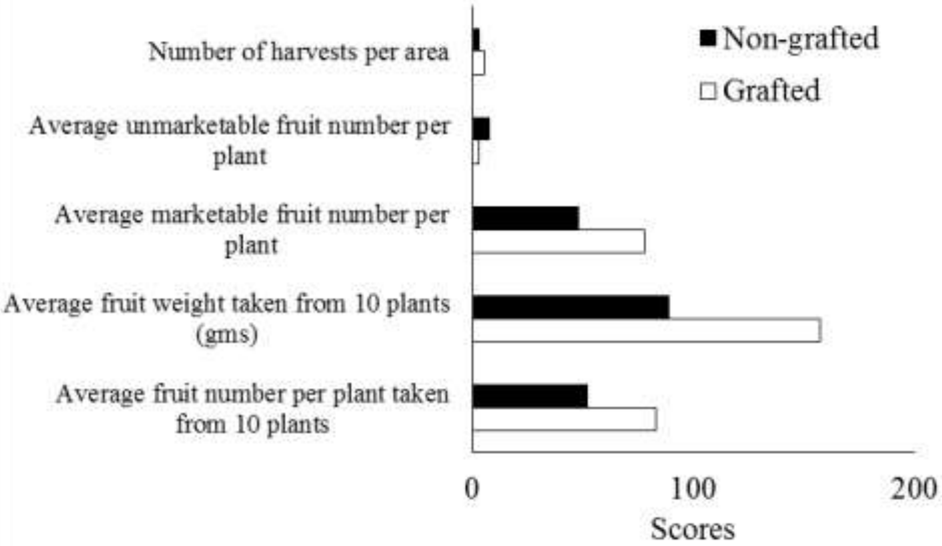

Figure 1. On-farm performance of one of the commercial varieties (Asila F1) when grafted on E1500025

NB: Marketable fruit = rind not deformed and medium to large size with high consumer appeal

Our observations showed that, the "post-graft" healing environment and acclimatization process are essential to the graft success. Neglecting post-grafting care would likely result in failed grafts. Depending on the plants' growth stage at the time they are grafted, plants should be ready to grow in normal greenhouse conditions, at 5 to 10 days after grafting.

We determined that among rootstocks, E15M00025 performed best in graft recovery (Table 1), giving results of above 70% in plant recovery and in yield and resistance to bacterial wilt in greenhouse and on station trials and in greenhouse inoculation trials using *Ralstonia solanacearum* pathogen (Solome Namutebi, unpublished). The fruit yield per plant was also shown to be higher with E15M00025 grafts as rootstocks, in one of the non-replicated trials on farm, reaching to 157 fruits compared to non-grafted plants (Figure 1). This line was also highly compatible with other lines including Anja F1 as a scion and when grafted together with Anja F1, resulted into exceptionally high yields at one of our farmer in Wakiso, Kiira municipality in Kimwanyi village (Urban Green Ecofarm), where the farmer excitedly reported of getting on average 130 large fruits (≈13.0kgs) from one plant. These claims have been corroborated by myself and other project members. Rootstock E290016 followed in grafting success followed by MT56. As for scions, Anja F1 performed best followed by Morelia F1 and then Randah F1 (E15A.60035) (Table 2)

E15M00025 performed best in yield and fruit quality in terms of size and consumer appeal, and was also resistance to bacterial wilt disease at on station and greenhouse inoculation trials (Solome Namutebi, unpublished). This was also reflected in grafted tomato on-farm trials carried out on farmers' fields in Wakiso and Mityana districts where E15M00025 rootstock' superior performance was highly visible compared to conventionally raised seedlings (Figure 1). This line was highly compatible with another line called Anja F1 as a scion, and when grafted together with Anja F1, the results were exceptionally high, especially at one of our farmers in Wakiso, Kiira municipality in Kimwanyi village (Urban Green Ecofarm).

This suggests that grafting tomatoes could be a highly advantageous technology for both greenhouse and field growers in Uganda. Grafting is a beneficial option in terms of yield for growers, but growers interested in on-farm grafting (as opposed to purchasing grafted plants) may discover some challenges in adopting the skills for grafting and propagation. Therefore, a simplified technique that requires less intensive management is critical for adoption of grafting technology for tomato growers.

Discussions and Conclusion

According to the data obtained so far, we confirmed that tomato grafting is a viable and potentially profitable practice for farmers in Uganda. Previous reports by other workers, demonstrated that profitable yield increases may occur in grafted vegetable crops, when few biotic stressors are present (Ruiz and Romero, 1999; Yetisir and Sari, 2003). Our study suggests that grafting with inter-specific hybrid rootstocks, E15M00025, E290016, MT 56 with scions such as Moleria F1 and then Randah (E15A.60035) F1, increased fruit yield and was quite evident both in the greenhouse and on farmer's fields. Both rootstocks conferred a significant increase in yield compared to the non-grafted plants.

It has been further reported by some workers that, in tomatoes, grafting usually leads to increased fruit yields of more than 50% due to larger fruit size (Pogonyi *et al*., 2005; Augustin, *et al*., 2002). This increase in output vigor is linked to heightened rootstock growth, thereby affecting water uptake and nutrient content (Leonardi and Giuffrida, 2006; Fernandez-Garcia *et al*., 2002). It is well documented that growers graft high-value crops such as tomatoes to increase overall vigor, yield, tolerance to abiotic stress and disease resistance (Lee, 1994, 2003, 2007; Paroussi *et al*., 2007; Rivard and Louws, 2008, Lee *et al*., 2010). However, the original and primary function of grafting was to combat soil-borne diseases such as Bacterial wilt (*Ralstonia solanacearum*), with significant yield gain associated with grafted plants (Louws *et al*., 2010; Marsic and Osvald, 2004).

Some historic account of vegetable grafting has been provided by Jung-Myung Lee *et al*. (2010). Vegetable production with grafted seedlings originated in Japan and Korea as a remedy for serious crop losses caused by infection of soil-borne diseases aggravated by successive cropping. This practice is now rapidly spreading and expanding over the world and has been safely adapted for the production of organic as well as environmentally friendly produce thereby, minimizing uptake of undesirable agrochemical residues, as a result of reduced chemical pesticides to control soil pests and diseases. In this regard the number and size of commercial vegetable seedling producers has increased markedly across the world, reflecting the increase in farmers' preferences for grafted seedlings of high-quality and better performance. In addition to the widely recognized advantages of disease tolerance and high crop yields, grafting technology is also highly effective in ameliorating crop losses caused by adverse environmental conditions such as low soil temperature and high soil salts, especially under protected cultivations where successive cropping or continuous farming is routinely practiced. Over the years, water melon and tomato are the 2 major vegetables for grafting and worldwide distribution. Introduction of excellent rootstocks possessing multiple disease resistance and efficient grafting machines including grafting robots will greatly encourage the extended use of grafted vegetables over the world.

Despite some negative drawbacks like high additional costs for rootstock seeds, labor required for the grafting and raising grafted seedlings, lack of experience and technique for grafting and cultivation of grafted plants, and incidence of possible physiological disorders associated with grafting, there are also, enormous benefits from using grafted seedlings. These include income increase by high yield and offseason growing, lower input of fertilizers and irrigation water due to the wide root systems of the rootstocks, considerable saving in agrochemicals due to high resistance of the rootstocks to soil diseases, extension of the harvest period, efficient maintenance of popular cultivars against diseases and other physiological disorders, no need for long-term crop rotations, overcoming problems due to saline soils and thermal stress, ease of producing organically grown vegetables. Partial or full take of these benefits will depend upon various factors such as farm size and degree of mechanization, cultivation practices such as crop rotation and transplanting, technology level, understanding the full benefits and risks of grafted seedlings, and the uses of protected cultivation and hydroponics.

Effective tomato grafting has just been adopted in Ugandan tomato production and research agenda. Considering the challenges involved in this technology, we consider that the results obtained from this investigation so far, was a considerable success. Apart from succeeding in developing the protocols and procedures of grafting, we were also able to generate planting materials for greenhouse, on station and on farm trials and in addition conducting training of trainers in more than five districts who are now trainers, including young plant raisers of grafted tomato and other fruit and vegetable seedlings to enhance the dissemination of the technology to deepen further to the wider public. Because of this, the demand for grafted tomato planting materials has recently shot up in the country.

In Uganda, among the highlighted constraints to tomato production, bacterial wilt caused by *Ralstonia solanacearum*, ranks as the top most constraint that has inhibited many willing farmers to cultivate even the most commercial varieties in the country. The most common traditional treatment for some of the soil-borne diseases is the application of broad-spectrum pesticides, such as appropriate fumigants. However, this method is not of benefit when used to control bacterial wilt disease. Although farmers may successfully disinfest the aforementioned diseases, the implications of a broad-spectrum soil acting fumigants are vast and cause for international re-evaluation of disease management practices.

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References

1. Ashita, E. "Grafting of watermelons (in Japanese)." *Korea (Chosun) Agr. Nwsl*. 1.9 (1927).
2. Augustin, B., Graf, V., Laun, N. "Einfluss der Temperatur auf die Effizienz von Tomatenveredlungen gegenüber Wurzelgallenälchen (Meloidogyne arenaria) und der Korkwurzelkrankheit (Pyrenochaeta lycopersici) Temperature influencing efficiency of grafted tomato cultivars against root-knot nematode (Meloidogyne arenaria) and corky root (Pyrenochaeta lycopersici)." *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz/Journal of Plant Diseases and Protection* 109. 4 (2002): 371-383.
3. Besri, M. "Tomato grafting as an alternative to methyl bromide in Morocco." *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions November* 3-6, (2003).
4. Fernandez-Garcia, N., V. Martinez, A. Cerda, and M. Carvajal. "Water and nutrient uptake of grafted tomato plants grown under saline conditions." *Journal of Plant Physiology* 159.8 (2002): 899-905.
5. Grubinger, V. "Grafting greenhouse tomatoes." University of Vermont ExtensionWebsite. <http://uvm.edu/vtvegandberry/factsheets/graftingGHtomato/html>.
6. Hartman, H.T., Kester, D.E., Davies, F.T. and Geneve, R. "Plant propagation, principles and practices." *7th ed. Prentice Hall,*

Upper Saddle River, N.J. Horticultural reviews 28 (2002): 61–124.

7. Jung-Myung, L., Kubota, C., Tsao, S. J., Bie, Z., Echevarria, P. H., Morra, L., and Oda, M. "Current status of vegetable grafting: Diffusion, grafting techniques, automation." *Scientia Horticulturae* 127.2 (2010): 93-105.
8. Jung-Myung, L. "Cultivation of grafted vegetables I. Current status, grafting methods, and benefits." *HortScience* 29.4 (1994): 235-239.
9. Jung-Myung, L. "Advances in vegetable grafting. Chron." *Horticult.* 43 (2003):13-19.
10. Jung-Myung, L. and Oda, M. "Grafting of herbaceous vegetable and ornamental crops." *Hortic. Rev.* 28 (2003): 61-124.
11. Leonardi, C. and Romano, D. "Recent issues on vegetable grafting." *XXVI International Horticultural Congress: Issues and Advances in Transplant Production and Stand Establishment Research 631*. (2004) 163-174.
12. Leonardi, C., and Giuffrida, F. "Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks." *European Journal of Horticultural Science* 71.3 (2006): 97 - 101.
13. Leoni, S., Grudina, R., Cadinu, M., Madeddu, B., and Carletti, M. G. "The influence of four rootstocks on some melon hybrids and a cultivar in greenhouse." *II International Symposium on Protected Cultivation of Vegetables in Mild Winter Climates* 287.1989 (1990) 127-134.
14. Louws, F. J., Rivard, C. L., and Kubota, C. "Grafting fruiting vegetables to manage soilborne pathogens, foliar pathogens, arthropods and weeds." *Scientia Horticulturae* 127.2 (2010): 127-146.
15. Melnyk, C. W., Schuster, C., Leyser, O., & Meyerowitz, E. M. "A developmental framework for graft formation and vascular reconnection in Arabidopsis thaliana." *Current Biology* 25.10 (2015): 1306-1318.
16. Morra, L., and Bilotto, M. "Mercato in fortissima ascesa per i portainnesti orticoli." *L'Informatore Agrario* 1.2009 (2009): 51-54.
17. Oda, M. "New grafting methods for fruit-bearing vegetables in Japan." *Japan Agricultural Research Quarterly* 29 (1995):187-194.
18. Rivero, R. M., Ruiz, J. M., & Romero, L. "Role of grafting in horticultural plants under stress conditions." *Journal of food agriculture and environment* 1 (2003a): 70-74.
19. Rivero, R. M., Ruiz, J. M., and Romero, L. "Can grafting in tomato plants strengthen resistance to thermal stress?." *Journal of the Science of Food and Agriculture* 83.13 (2003b): 1315-1319.
20. omano, D., and Paratore, A. "Effects of grafting on tomato and eggplant." *V International Symposium on Protected Cultivation in Mild Winter Climates: Current Trends for Suistainable Technologies 559*. (2000): 149-153.
21. Romero, L., Belakbir, A., Ragala, L., & Ruiz, J. M. "Response of plant yield and leaf pigments to saline conditions: effectiveness of different rootstocks in melon plants (Cucumis melo L.)." *Soil Science and Plant Nutrition* 43.4 (1997): 855-862.
22. Manuel, R. J., Belakbir, A., & Romero, L. . "Foliar level of phosphorus and its bioindicators in Cucumis melo grafted plants. A possible effect of rootstocks." *Journal of Plant Physiology* 149.3-4 (1996): 400-404.
23. Manuel, R. J., & Romero, L. . "Nitrogen efficiency and metabolism in grafted melon plants." *Scientia Horticulturae* 81.2 (1999): 113-123.
24. Sarah A. M. "Propagation and utilization of grafted tomatoes in the Great Plains." *MASTER OF SCIENCE thesis; submitted in partial fulfillment of the requirements for the degree. College of Agriculture KANSAS STATE UNIVERSITY Manhattan, Kansas, 2013*
25. Traka-Mavrona, E., Koutsika-Sotiriou, M., & Pritsa, T. . "Response of squash (Cucurbita spp.) as rootstock for melon (Cucumis melo L.)." *Scientia Horticulturae* 83.3-4 (2000): 353-362.
26. Yetisir, H., and Sari, N. "Effect of different rootstock on plant growth, yield and quality of watermelon." *Australian journal of experimental agriculture* 43.10 (2003): 1269-1274.

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