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Challenges and Opportunities in Tomato Production Chain and Sustainable Standards

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Abstract
Tomato (*Lycopersicon esculentum*) is an important member of the Solanaceae family. It is mainly used as food and cash crop globally. Tomato also serves as an ornamental plant in some parts of the world. In urban areas, this crop is included in the foodscaping systems where it is grown in hanging baskets, growing pots and aquaponics for aesthetic and food purposes. Tomato production is mainly done for fresh and processing market niches. Most developed countries process a larger portion of tomato than is offered in fresh form. Cultivation of tomato is practiced on the open field and inside greenhouses. Greenhouse production has gained popularity recently. Determinate varieties are produced outdoor while indeterminate ones are produced in greenhouses and tunnels. Due to good adaptability, heirloom tomato varieties are becoming popular especially where farmers practice tomato grafting using the indigenous varieties as rootstocks. High cost of inputs, pest and diseases, postharvest losses and marketing are the major challenges facing tomato production globally. Organic tomato production is an emerging market niche. This is due to the increased consumer awareness, environmental conservation requirements and globalization. Thus, farmers have been making strides towards compliance to organic and other sustainable standards. These standards require adoption of the requisite practices, documentation, verification and certification by a third party. Value addition in tomato is an important aspect in addressing the postharvest challenges, product diversification and ultimately profitability. This review paper is expected to provide the requisite information in tomato value chain to ensure sustainable production of tomato globally.

Keywords: Greenhouse tomato farming, sustainability, pest management, organic standards, processing, innovative technologies.

Introduction

Tomato (*Lycopersicon esculentum,* Miller, 1768), and previously referred to as *Solanum lycopersicon*, Linnaeus, (1753), belongs to the order solanales and family Solanaceae. The family consists about 1500–2000 species making it one of the most diverse family of flowering plants (Sato et al., 2012; Naika et al., 2005). The two main food crops in the solanaceous family with global distribution are potato and tomato. Other members are the nightshades, eggplants, tamarillo, horse nettles and numerous ornamental flowers and fruit plants cultivated for their nutritional benefit (Naika et al., 2005). Tomato is thought to have originated in the South

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American Andes but its use as a food originated in Mexico and spread throughout the world following the Spanish colonization of the Americas (Peralta, 2005; Jacobsen et al., 1994). Tomato is a model species for classical genetic and genomic studies. It has a chromosome number of 2n=2x=24, though incidences of 2n=2x=26 have been reported. The cultivated tomato has about 12 wild relatives. These wild tomatoes have a large genetic diversity, which has contributed greatly to the breeding of modern tomato cultivars. This has resulted in tomato varieties with a polyploidy state and hybrids desired by the market. Thus, many varieties are now widely grown, sometimes inside greenhouses in the cooler climates (Sato et al., 2012). Tomato is mainly propagated from seeds, which are started in the nursery and later transplanted. Intensive agronomic practices such as watering, weeding, pruning, training, pest and disease control are carried out to ensure optimum production (Jones, 2012). The plant typically grows to 1–3 meters in height and has a weak stem that often sprawls over the ground and vines over other plants, if left untrained, it exhibits decumbence. It is perennial in its native habitat, although often grown outdoors in temperate climates as an annual. An average common tomato weighs approximately 100 grams. While tomatoes are botanically and scientifically the berry-type fruits of the tomato plant, they can also be considered a culinary vegetable, causing some confusion. To resolve the confusion, tomato is classified as a vegetable due to its utilization rather than botanical characteristics (Peralta, 2005; Smith, 1994). Among the Solanaceae crops, it ranks second both in production and utilization after potato. The crop is well adapted to tropical and sub-tropical climates where it performs very well at temperatures of between 15 to 30 °C and moderate rainfall of about 1000 mm (Naika et al., 2005).

The tomato industry is one of the most dynamic horticultural sub-sector globally with a lot of research on elite germplasm, cultivation technologies such as production under protected environments and processing (FAOSTAT, 2019). The greatest challenge in tomato production is use of agrochemicals particularly in pest and disease management. Injudicious use of pesticides has resulted in heavy accumulation of chemical residues which is a threat to production of safe tomato in a world where people are conscious about diet, environment and workers' welfare (Karungi et al., 2011). Thus, various mechanisms have been initiated to ensure that the value chain is sustainably managed. These interventions include; production under protected environments to ensure attainment of optimal production conditions (Engindeniz and Tüzel, 2002; Tao et al., 2016). Also, development of regulation standards such as global good agricultural practices (GAP) and good manufacturing practices (GMP) to ensure responsible and ethical production, traceability, chemical use and workers' welfare. Another important standard is the organic standard that discourages use of synthetic pesticides which reduce chemical residues making the fruits safe for consumption and with minimal contaminants. Organic products are also offered at a premium and have a niche market (Gobal organic standard, 2017; Garrido and Luque-Romero, 2014).

Production of organically grown tomato is recently gaining currency globally. Tomato is one of the vegetables produced by application of a lot of pesticides in the world. Production of organic tomatoes will give stakeholders the satisfaction that harmful synthetic chemicals have not been used (Garrido and Luque-Romero, 2014). The chemicals affect the farmer, consumer and environment. Of utmost importance is that the quality and quantity of produced tomato is not affected. This is because tomato is attacked by very many pests and diseases (Karungi et al., 2011). Additionally, being a heavy feeder, the yield and nutritional deficiency disorders in tomato may result when less potent substances are used during production (Jones, 2012; Naida et al., 2005).

Another important standard that is very applicable for tomato production and other horticultural crops is the global good agricultural practices (Global GAP) standard. In line with produce and product safety, international players have documented a list of practices that when observed, will guarantee consumers of their own safety, sustainability of the produce and fairness to both environment and workers involved in the production line. Also, the standards can allow for the traceability from the farm (Garrido and Luque-Romero, 2014). These standards although voluntary, are becoming increasingly important for a producer to access some markets. The global G.A.P that replaced the defunct EurepGAP (European Union Protocol on Good Agricultural Practices) is a set of farm standards dedicated to Good Agricultural Practices (GAP) (Global standard, 2017).

Finally, tomato is marketed in processed and fresh forms. The main bane of the agricultural sector in developing countries is limited value addition that affects the revenue obtained by farmers (Mujuka et al., 2019). For instance, value addition and processing of agricultural produce in Kenya accounts for a paltry 5%. When compared to a developing country such as India, which has a strong and dynamic food processing sector playing a vital role in diversifying the agricultural sector, improving value addition opportunities and creating surplus food for agro-food products. Presently, over 20 percent of fruits and vegetables are processed. Other countries like Brazil account for 30 %, USA (70 %) and Malaysia (82 %) (FAOSTAT; KHDP, 2012).

Tomato production; Challenges and Opportunities

Types of tomato

There exist two main types of tomato cultivars: the determinate and indeterminate (Fig. 1) and bears spherical fruits that range in colour from yellow, orange and crimson. Determinate varieties of tomatoes, also called "bush" tomatoes, are varieties that are bred to grow to a compact height of about 1.2 m. They stop growing when fruit sets on the terminal or top bud and ripen their entire crop at or near the same time that is usually about a month and then die. They may require a limited amount of caging and/or staking for support, should not be pruned or "desuckered" as it severely reduces the crop (Smith, 1994; Jones, 2012). Examples are: Cal. J (Kamongo), Marglobe, Eden, Onyx and some hybrid varieties such as Kilele and Assila (Musyoki et al., 2005). The indeterminate varieties of tomato are also called "vining" tomato. They grow and produce fruit over a long period of time at times over 1 year and can reach heights of up to 3-6 m. The varieties bloom, set new fruit and ripen fruit all at the same time throughout the growing season. They require substantial caging and/or staking for support and pruning and the removal of suckers. Examples are: Anna F1, Chonto F1, Joy F1, Bravo F1, Monicah F1, Tylka F1, Kenom, Monset, Nemonneta among others. These varieties are mainly grown inside greenhouses due to the ideal growing conditions such as temperature, humidity, water utilization efficiency and pest management (Monsatto, 2013; Odame, 2009; Musyoki et al., 2005; Tao et al., 2016).

Global tomato production

The tomato industry is one of the most advanced, globalized and innovative. Agronomic practices, processing, marketing and overall organization of the industry (processed or fresh tomato consumption) vary between countries. The global annual production of tomato has steadily increased over the last few decades and is estimated by FAO at about 123 million tons with a total production area of about 4.5 million ha. The leading tomato producing countries globally are; China, European Union, USA and Turkey (FAOSTAT, 2019).

Fig. 1. Determinate Tomato (A) and Indeterminate Tomato plants (B): Source: Author, 2020.

Global tomato production is expected to continue increasing for both fresh and processed types. However, some dynamics such as proportion between greenhouse tomato and open field tomato are likely to change, with greenhouse produced tomato increasing tremendously. This is because of the near ideal conditions, shortened maturity rate, high productivity per unit area and prolonged production phase (Tao et al., 2016; Engindeniz and Tuzel, 2002). The cost of production continues to be a main challenge in production of tomato particularly in the developed countries which are the leading producers. The developing countries mainly grumble with problems in pest and diseases, erratic production systems and abuse of chemicals (Garrido and Luque-Romero, 2014). Therefore, the current concerns globally are on sustainability of the value chain through reduction of cost of inputs such as; fertilizers, pesticides, energy and water. Issues of safety and environmental safety during production will play a critical role if the crop will continue playing a critical role as one of the most important vegetable globally (FAOSTAT, 2019*;* Kenya Horticulture Competitiveness Project, 2012; Salazar et al., 2014; Seminis, 2007).

Importance and utilization of tomato

Tomato is a major vegetable crop that has achieved tremendous popularity over the last century. It is grown practically in every country of the world in greenhouses, net houses and outdoor fields (Garrido and Luque-Romero, 2014). The plant is versatile and the crop can be divided into two categories; fresh market tomatoes and processing tomatoes. Tomato fruits, aside from being tasty, are healthy as a good source of vitamins A and C. Vitamin A is important for bone growth, cell division and differentiation, for helping in the regulation of immune system and maintaining surface linings of eyes, respiratory, urinary and intestinal tracts. Vitamin C is important in forming collagen, a protein that gives structures to bones, cartilage, muscle and blood vessels. It also helps maintain capillaries, bones and teeth and aids in the absorption of iron (Maria *et al*., 2014). Another important nutritional benefit is the lycopene which is a powerful antioxidant that can help prevent development of many forms of cancer. Cooked tomato and tomato products are the best source of lycopene since it is released from tomato when cooked. A raw tomato has about 20% of the lycopene content found in cooked tomatoes. However, raw or cooked tomatoes are considered the best source for this antioxidant (Dewanto et al., 2002; United State Department of Agriculture, release 28).

Diseases, pests and physiological disorders in tomato

Tomato varieties vary in their resistance to pests and diseases. Modern hybrids focus on improving disease resistance over the heirloom plants. Common tomato diseases include; rots, cankers, mildews, blights and viruses (Agrios, 2005). Other dreaded diseases are wilts caused by bacteria and fungi and anthracnose (Iannotti, 2019, Reddy, 2018 and Tomato Diseases Fact Sheet, 2004). Some of the serious diseases affecting tomato include; Late Blight (Phytopthora infestans); is one of the most serious diseases affecting open field grown tomato caused by a very destructive fungus. The disease occurs under cool and high humidity conditions and spreads rapidly from a hotspot to the entire farm by distribution of the sporangia. It is characterized by rapid drying of leaves, brown streaks develop on the stem and brown dry rot is observed on the fruit. Under severe infection up to 100% loss may occur. The disease is however not common under greenhouse conditions due to the elevated temperature, reduced air movement and absence of moisture on the leaf surface where drip irrigation is used (Shankara et al., 2014; Agrios, 2005; Naika et al., 2005).

Early Blight (Alternaria solani); the disease manifests as stem cankers on seedlings with small irregular dark brown spots on the older leaves leading in partial defoliation of the crop. Infections begin as small brown spots on older leaves that quickly enlarge. The lesions develop a "bulls-eye" pattern of concentric rings that can be seen. The fungus survives on the crop debris thus infected plant materials should be disposed properly to reduce spread (Agrios, 2005; Naika et al., 2005).

Bacterial Cankers (Clavibacter michiganensis) is a seed borne disease whose symptoms are not apparent until the disease is well established. The disease causes up to 90% crop loss. Symptoms include wilting and curling of the leaflets of the lower leaves. Dried, whole leaf curls upwards, turns brown, wither but still remain attached to the stem. If affected, young fruits show slight discoloration of the vascular system, deformation and stunting of fruit and seed abortion (Shankara et al., 2014; Agrios, 2005).

Bacterial Wilt (Ralstonia solanacearum); the disease causes wilting of tomato and potato. In tomato it is mainly seed and soil borne. The disease is most severe under high temperature (25-35^{o}C), humidity (80-95%) and low edaphic pH (<6) conditions. These conditions make the pathogen more aggressive thus devastating the crop. The pathogen is mainly spread from infested to healthy fields by farm equipment, irrigation water and plant-to-plant through the rhizosphere. The latter can be exacerbated when other pests attack the roots in a disease complex web particularly when nematodes injure the root hairs. The pathogen is highly persistent and only antagonistic micro-organisms and environmental factors can affect its survival (Champoiseau et al., 2009; Naika et al., 2005; Agrios, 2005).

Bacterial Speck (*Pseudomonas syringae* pv. *tomato*); the disease is severe in the 3-5 leaf stage. It develops as small, dark lesions with yellow rings on leaves. Superficial, brown and rough spots are also observed on the fruit. The disease retards growth and delays fruit maturity. It is mainly spread by sprinkler irrigation and infection is favored by cool and wet conditions (Shankara et al., 2014; Naika et al., 2005).

Fusarium Wilt (*Fusarium oxysporum sp. lycopersici*); the disease manifests by clearing of veins and chlorosis of lower leaves. There is wilting of leaves and stems sometimes confused with bacterial wilt. The disease also develops into marginal necrosis of leaves and eventual defoliation. The roots become stunted, stems turn brown. The disease becomes severe under warm conditions (Shankara *et al*., 2014; Agrios, 2005).

Fusarium Crown & Root Rot (*Fusarium oxysporum sp. radicis lycopersici*); is a very prevalent disease in young tomato seedlings. The disease is soil borne therefore starts at the base of the stem and move upwards. It results in dark brown colored root rot at soil level, causes the stems to have red-brown vascular discoloration; leaves turn yellow and finally the plant wilts (Shankara et al., 2014).

Powdery Mildew (*Oidium lycopersicum*); the disease makes the leaves to develop irregularly with white superficial mycelium that turns yellow causing desiccation, necrosis and defoliation. Under severe infections there is massive leaf death and defoliation that causes sun scald of fruits. The disease occurs at all stages of crop growth and spread is favoured by wet and hot weather. The disease affects both open field and greenhouse produced tomato (Naika et al., 2005).

Septoria Leaf Spot (*Septoria lycopersici*); is a very destructive disease of tomato foliage. Infection is favoured by warm, dry days and damp nights (85%-100% relative humidity) particularly when such conditions are extended over a long period of time. It is quite rampant in greenhouses experiencing condensation due to poor ventilation or when crops are overwatered late in the evening. It results in numerous small brown water-soaked spots on leaves, petioles and stems with gray or black centers. The leaves also turn yellow and drop. When serious defoliation happens, the fruits suffer sun scalds. The pathogen is spread by wind, water, hands, tools and aphids (Shankara et al., 2014; Naika et al., 2005; Garrido and Luque-Romero, 2014).

Gray Mold (*Botrytis cinerea*); the disease manifests as gray, velvety coating of spores on fruit, stems, leaves and petioles. It thrives at temperatures below 20 °C and high humidity conditions. The disease is serious in greenhouses that experience condensation or where there is overhead watering late in the evening. The spores persist long in plant debris thus proper disposal of infected plant materials is paramount in disease management (Shankara et al., 2014).

Leaf Mold (*Fulvia fulva* syn. *Cladosporium fulvum*); is chlorotic (yellow-green) spots developed on upper surface of older leaves. Under severe infection, the spots merge covering the entire leaf surface. Also, the undersurface may have olive green spores. The disease thrives under poorly ventilated, cool and humid conditions. The spores are spread by air, water, workers and insects. The disease also affects tomato growing under hydroponic system (Agrios, 2005; Barea et al., 2002; Champoiseau et al., 2009; Kailash et al., 2012; Tim et al., 2008; Stefalli et al., 2013).

Tomato is also affected by numerous viruses such as; Tobacco mosaic virus or tomato mosaic virus, Cucumber mosaic virus, Tobacco etch virus, Potato Virus-Y, Potato leaf-roll virus, Tomato spotted wilt virus, Pepper veinal mottle virus, Chilli veinal mottle virus, Tomato yellow leaf curl virus and Tomato Big-Bud mycoplasma. These viruses result in stuntedness, mottling, curling, and chlorosis. Viruses are mainly spread by vectors such as aphids, mealybugs and whiteflies. They are also transmitted by farm implements and other human activities (Naika et al., 2005; Shankara et al., 2014).

Pests

Some common tomato pests are stink worm, cutworm, tomato hornworm, aphids, whiteflies, flea beetles, spider mites, slugs, nematodes, moths and leaf miners including *Tuta absoluta* (Karungi et al., 2011; Reddy, 2018; Agrios, 2005). Tomato plants have evolved over the years specially to survive pest attacks; one way is production of a peptide hormone known as systemin after an insect attack. The hormone activates defensive mechanisms, such as the production of protease inhibitors to slow the growth of insects. Other proteins and compounds have also been produced in tomato plants infected by pathogens such as glucanases, chitinases, catalyses, hydrogen peroxide (Gatahi et al., 2016; Masinde et al., 2009; Mandal et al., 2013). Among the most important pests affecting tomato production include;

Root knot nematodes (*Meloidogyne spp*.); the pests are mainly associated with rhizosphere damage. This is because they are soil borne pests. They are parasitic and attack the soft tissues by puncturing the tissues using their sharp mouth parts. After attacking the roots nematodes gain entry since most are endoparasites causing development of galls in the root tips. These galls and swellings on the roots cause stunting of the plants and eventual death. Diagnosis of these pests is through destructive sampling followed by observing the roots using a dissecting microscope which clearly show these parasites. Nematodes form part of a disease complex by predisposing the plant to other soil borne pathogens such as bacteria and fungi (Jones Antonio et al., 2011; Shankara et al., 2014).

White Fly (*Bemisia tabaci*); are small, white, moth-like flies, which fly from foliage to foliage when plants are disturbed. Nymphs suck plant sap from the underside of the leaf. They transmit plant viruses such as the tomato mosaic viruses (TMV) among others. Attack of tomato plants by white flies makes the plant appear to have distorted and yellow leaves. They also defecate a lot of sap known as the honey dew which turns sooty making the plant to appear blackish. The honey dew also attracts the black ants making the plants heavily colonized by the black ants as they feed on the sweet faecal matter from the flies (Naika et al., 2005; Agrios, 2005).

Spider Mites; are minute reddish arachnids visible by the naked eye. They feed by chewing on the underside of the leaves. These organisms are best observed using a hand lens or magnifying glass during scouting of pests in the field. The mites cause speckling and tarnishing of the leaves turning yellowish to whitish. These mites are either classified as the two-spotted mite (*Tetranychus urticae*) or tomato russet mite (*Aculops lycopersici*). Tomato russet mite also feed on the stems and on fruit. Damage is usually greater in hot and dry weather. Heavy infestation results in webbing of the plant foliage and total chlorophyll loss culminating in plant death (Naika et al., 2005; Garrido and Luque-Romero, 2014).

Thrips; are very tiny, slender insects that feed primarily in flowers and developing fruit. Under heavy infestation, they cause wilting of the soft tissues of tomato plants since they suck sap. Thrips are mainly spotted on the top foliage particularly inside the flowers where they hide thus hard to control. Thrips also transmit the tomato spotted wilt virus (TSWV), causing wilting of the plants. However, not all the species of thrips are vectors of the virus (Biondi et al., 2018; Agrios, 2005).

Caterpillar American boll worm (*Helicoverpa spp*, *Heliothis punctigera*, and *H. armigera)* are the two most common species that damage tomato. The caterpillars bore into fruit and feed on the inner of the fruit releasing plenty of excreta which is noticeable. While Heliothis larva will feed on buds and flowers of tomato plants and bore into the stems, it mainly prefers the fruit. Fruits are damaged when young and rot before they are harvested (Naika et al., 2005; Garrido and Luque-Romero, 2014).

Aphids; these are small grayish insects which suck sap using their pointed mouth parts. These pests multiply very fast and cause significant damage within a short period of time. Aphids attack foliage, flowers, and fruit. The insects are also viral disease vectors. They also create honeydew which attracts sooty mold and black ants (Naika et al., 2005).

Leaf miner (*Tuta absoluta*); is a moth species in the order Lepidoptera and family Gelechiidae. It is commonly known as the tomato leaf miner or South American tomato moth. The larva feeds voraciously on tomato plants, producing large galleries in leaves, burrowing in stalks, and consuming apical buds and green and ripe fruits. The adult moth has a wingspan around one centimeter. The pest is capable of causing a yield loss of 100%. Tomato is the main host plant, but *T. absoluta* also attacks other solanaceous crops such as; potato, eggplant, pepino, pepper, tobacco and nightshades. In favorable weather conditions eight to ten generations can occur in a single year, under such conditions, the pest also exhibit deuterotokous parthenogenesis resulting in very high population (Reddy, 2018; Caparros Megido et al. 2012; Afreen et al., 2017; Agrios, 2005).

Physiological disorders

Finally, tomato fruits exhibit a number of physiological disorders associated with agronomic practices and environmental factors. These disorders are in some instances confused with pest or disease attacks according to the Report on Plant Disease and Physiological Disorders in Tomato, 2014, they include:

Blossom end rot; this is not a pathological disease, but a physiological disorder. The condition is caused by calcium deficiency. The early sign is a water soaked spot near the blossom end of the fruit. The surface of the spot becomes dark, leathery and large. The spot remains dry unless invaded by bacteria or fungi. Other causes of the condition are excessive nitrogen application during the early stages, infrequent irrigation and drought (Margit and Ingrid, 2016).

Fruit cracking; is a condition that occurs when internal fruit expansion is faster than the epidermal expansion which causes the epidermis to split. It is caused by irregular water uptake, high and fluctuating temperature and standing water on the fruit surface (Margit and Ingrid, 2016).

Sun scald also known as the sun burn; occurs when the fruit is exposed to too much sun. This is because very high temperature from the sun impairs development of the red pigment. Thus results in the development of yellow pigment on the fruit shoulder. The yellow pigments are very susceptible to further sun burns. The tissues therefore die fast and turn black. Plant management practices can enhance or prevent the sun scald condition for instance, over pruning can expose the fruit and increase sunscald problems (Delahaut and Stevenson, 2004).

Blotchy ripening and grey wall; the condition mainly occurs in greenhouse grown tomato fruits. The affected fruits ripen unevenly with hard grey to yellow patches. The patches do not turn red but remain grey or yellow. When fruit is cut, the vascular tissues appear brown and rotten. It is common when plants are exposed to environmental stress such as high temperature, deficiency of K and Bo and high nitrogen levels (Delahaut and Stevenson, 2004).

Cat face; is fruit deformation on the blossom end. The affected fruit is abnormally shaped and has a corky brown scar on the blossom end of the fruit. The fruit can also have cavities extending into the flesh. The condition is mainly attributed to disturbance of flowers or flower buds and emergence of a cold season just before flowering. The condition is also associated with heavy thrips infestation and exposure of flowering tomato plants to herbicides (Delahaut and Stevenson, 2004).

Internal white tissue; is a disorder does not have external visual symptoms. The condition manifests when a ripe tomato is cut revealing white and hard areas on the vascular region. Under severe condition the fruit may show white tissue in the center of the fruit. The condition is mainly associated with K deficiency. K is a very important nutrient during tomato fruit ripening and is usually a limiting factor (Delahaut and Stevenson, 2004).

Puffiness; is depicted as tomato fruits with flattened side walls and light weight in relation to their size. When cut the fruit show open cavities between seed gel area and the outer wall. This disorder is caused by poor pollination, extreme temperature variation, high nitrogen levels and poor seed quality (Delahaut and Stevenson, 2004).

Physiological leaf-roll; is a condition common on tomato fruits grown in greenhouses than open field. It starts with upward cupping of the leaf margins and later the leaves roll inwards. Affected leaves are firm and leathery in touch mainly due to hot and dry weather conditions (Delahaut and Stevenson, 2004).

Blossom drop also commonly known as floral abortion; is mainly caused by extreme temperature and humidity variation. It is also caused by poor pollination causing the flowers to drop from the plant without setting fruit. Blossom drop on tomato occurs when night temperatures are below 55 °F or above 75 °F (Delahaut and Stevenson, 2004).

Control of pest and diseases in tomato

Different methods have been employed to manage pest and diseases in tomato. Combinations of these methods have shown tremendous effects in managing the pests to below economic injury level which is envisaged under sustainable tomato production (Afreen et al., 2017). Maintaining pests below economic injury level (EIL) is an important concept in crop production because it is based on the cost/benefit ratio. Economic injury level is defined as the minimum number of pests that can cause yield loss that is equal to the cost of managing that pest. Thus, justifying intervention in controlling such a pest is important. However, under, a good crop management, regular scouting should inform the level at which an intervention can be done just before EIL is reached, this level is known as economic threshold (EC). At this level, the pest density is significant though cannot meet the cost of control, perhaps it is the point of "prevention is better than cure" (Damos and Savopoulou-Soultani, 2012). The EIL, can be modelled mathematically based on 5 primary variables as; $EIL = C/VIDK$, where, C is the cost of management action/ unit area, V is the price of the produce, I is the injury units per pest, D is the damage/ unit of insect injury, and K is the proportionate reduction of injury by the management action. Moreover, the parameters D and I form a linear equation (Fig. 2) and can be obtained from the slope of the yield, or damage function ($Y = a + bx$), where Y = yield loss; $a = 0$, x = number of pests per sampling unit; and b = yield loss/pest, representing the loss per insect, which is equal to $I*D$ or D' (Damos and Savopoulou-Soultani, 2009; Mujuka et al., 2019).

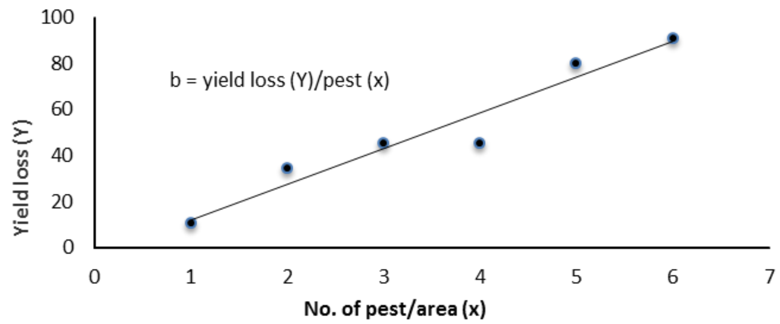

Fig. 2. Crop yield loss (Y) vs no. of pest infestation per unit area (x) (Source: Damos and Savopoulou-Soultani, 2009 with modifications).

For effective pest and disease management, it is paramount for a gardener to conduct scouting. Scouting of pests and diseases plays a critical role in determining the action to take. It entails; observation, identification, monitoring, recording and recommendation (Garrido and Luque-Romero, 2014). The information is recorded on a scouting sheet. Knowledge of pests and diseases specific to a particular plant is important for effective scouting. There are emerging intelligent technologies involved during scouting. Such include use of computed digital assistant devices installed *in situ* while others are used by the scouting staff as they inspect the crops. These devices are able to generate real-time data. Further, they are able to interpret the pest and disease level of damage. Some of these devices are also fitted with environmental monitoring systems and are therefore able to forecast the pest incidences which are very important in effective pest management (Naika et al., 2005; Garrido and Luque-Romero, 2014). Therefore, some of the control strategies include:

Cultural methods; attempts have been made to use different growing methods in order to overcome the pest and diseases in tomato. These methods include; selection of resistant varieties, planting on sites with low pest population by practicing rotation farming, observing good agricultural practices such as; proper spacing by reducing plant to limit pest spread, management of the plant architecture through training and pruning, use of drip irrigation and manipulating the microclimate by growing tomato under protected environment e.g. inside greenhouses. Other methods such as field solarization, rouging and optimal plant nutrition have a major impact in managing pests and diseases in tomato (Muriungi et al., 2014; Snyder, 1995).

Chemical methods; Chemicals are very specific to a particular agent hence the most preferred method of pest management by most tomato farmers. For instance, insects are managed using organophosphates, organochlorides, carbamates or pyrethrene derived insecticides. Also, fungal diseases are controlled using copper or sulphur based fungicides. Further, weeds are managed using herbicides and nematodes controlled using nematicides. Chemicals are also preferred by most farmers due to precision in pest management (Naika et al., 2005; Garrido and Luque-Romero, 2014). However, use of chemicals must be done under safe conditions where care for the person applying the chemical, other people getting in contact with the field or produce and environment is considered. The persons applying the chemical must be dressed in a chemical protecting gear which entails; impermeable apron, nose mask, face shield, gloves and safety boots (Fig. 3). The hygiene standards of the safety gear and knapsack must be maintained at all times to ensure the welfare of the applicator. When a chemical has been applied, the required re-entry and pre-harvest intervals must be observed to protect other people from chemical effects. Finally, safe disposal of the chemical must be observed in order to ensure that environmental hygiene is maintained. Further, chemical applicators and farmers require regular training on chemicals to avoid use of banned chemicals. Other important considerations during application is to utilize the chemicals classified as class IV, III and II by world health organization (WHO) denoted with a green, blue and yellow label strips respectively. It is also important to avoid chemicals classified under class I due to their high toxicity risks and persistence on the environment (SAN standard, 2017).

Fig. 3. Application of chemicals in a greenhouse (Source: Garrido and Luque-Romero, 2014)

It is notable that most chemicals have adverse effects on the environment particularly the biodiversity. Use of some chemicals has been associated with reduced population of some species such as pollinators, some plants, animals and micro-organisms. Moreover, there has also been increased consumer awareness and strictness on phytosanitary issues particularly on use of the banned chemicals (Garrido and Luque-Romero, 2014; Noonari et al., 2015). Use of banned chemicals may result in serious penalties thus must be avoided. In order to ensure compliance to ethical chemical use, some governmental and non-governmental organizations have developed standards that clearly stipulate terms and conditions to be maintained during production. These standards are voluntary for the growers but serves as a guarantee to the consumer or buyer of the produce when certified by a recognized certification body. Some of the relevant standards include; the global GAP, HACCP, ISO and sustainable agriculture. These attempts endevour to ensure responsible use of chemicals in order to enhance productivity and make tomato production a sustainable activity (Noor, 1999; Kyoto Protocol, 2005; GoK UNEP, 2008; Christos et al., 2011; Karungi et al., 2011; SAN standard, 2017).

Biological Methods; Use of living organisms and plant extracts in the control of pest and diseases has been practiced globally. In this case, various living organisms such as parasites, parasitoids, pathogens and botanical extracts have a major role in the control of pests and diseases in tomato. For instance, plant growth regulating rhizobacteria and fungi (PGRB/F) have been observed to play a key role in management of most tomato pathogens. Most soil borne diseases can be managed by use of the micro-organisms which also have a positive effect on soil health. There is a negative correlation between biocontrol agents and soil borne pathogens in plant rhizosphere. Viruses and bacteriophages are also very important biocontrol agents. Some biocontrol agents help in pest and disease management indirectly through induction of systemic resistance (ISR) in tomato plants (Spadaro and Gullun, 2005; Yamada, 2007; Nguyen and Ranamukhaarachchi, 2010; Ding and Liao, 2011; Guo et al., 2011; Glick, 2012).

Other living organisms used in pest management are the predatory mites, entomopathogenic nematodes and other beneficial insects. Use of these organisms in managing pest and diseases require proper application, monitoring and environmental management to ensure effectiveness. Botanical extracts have played an important role in the control of pest and diseases such include; pyrethrum, neem, prosopis extracts, essential oils from most plants and wood ash extracts. These concoctions have been observed to have anti-feedant, repellant and pesticidal effects on most pests attacking crops (Kubata et al., 2005; Garrido and Luque-Romero, 2014).

Innovative strategies; New methods of pest and disease management in crops have been reported. These include; practices that enhance efficacy of chemicals or biochemicals by entrapment using potent compounds such as silica, polythene, chitosan, enzymes and nanomaterials Gatahi et al., 2016; Wazed et al., 2011). Also, use of sticky traps with different colours, chromatic electrocutes, sterile insect techniques and pheromones has been practiced to manage some insect pests (Mandal et al., 2013; Den Otter et al., 1996). Another innovative strategy that has been utilized in other crops is the grafting technique. In this method, resistant heirloom tomato varieties are used as the rootstock while the elite hybrid varieties become the scions. This ensures the unique qualities of each variety/cultivar are united in forming a resistant composite plant. Grafting should be done precisely by a skilled staff to minimize the seedling loss. About 90 % success can be realized when the activity is carried out properly. Grafting mainly helps to overcome the soil borne diseases such as bacterial and fusarium wilts (Damos and Savopoulou-Soultani, 2012; Guan and Hallet, 2016). Further, the rhizosphere can also be treated with beneficial micro-organisms to enable the tomato seedling overcome many other biotic and abiotic stresses within the soil (Fig. 4).

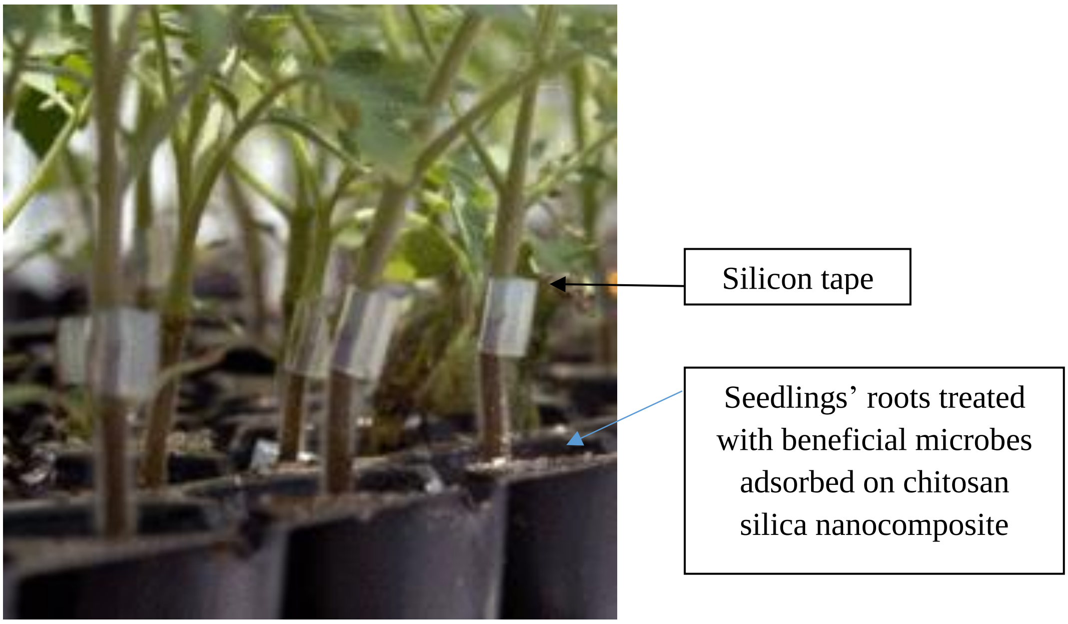

Fig. 4. Grafted tomato seedling treated with beneficial micro-organisms with a nanomaterial delivery media. (source: Guan and Hallet, 2016).

Finally, hydroponic tomato production has become popular recently. This is mainly practiced in soils characterized by endemic soil borne pathogens, poor soil structure and fertility. It entails use of nutrient enriched and well aerated media supported by soilless/inert media such pumice, vermiculite, perlite, sand, charcoal/biochar and fine ballast (Stefalli et al., 2013; Garrido and Luque-Romero, 2014). Numerous nutrient "recipes" are prepared for use in the hydroponic systems (Fig. 5). The macro and micronutrients are well balanced and the optimum pH and electrical conductivity (EC) standardized (Stefalli et al., 2013). Recently, organic hydroponics has become popular. The system uses a solution containing microorganisms. These microbes degrade organic fertilizer into inorganic nutrients (Naika et al., 2005).

Another improvement to address the problem of water logging, a condition that results in huge loss of tomato plants, is use of wet wick system to supply the nutrient to the rhizosphere. Different materials including cotton, sisal, linen, wool and other composite materials have been utilized effectively in capillary water movement (Salazar et al., 2014).

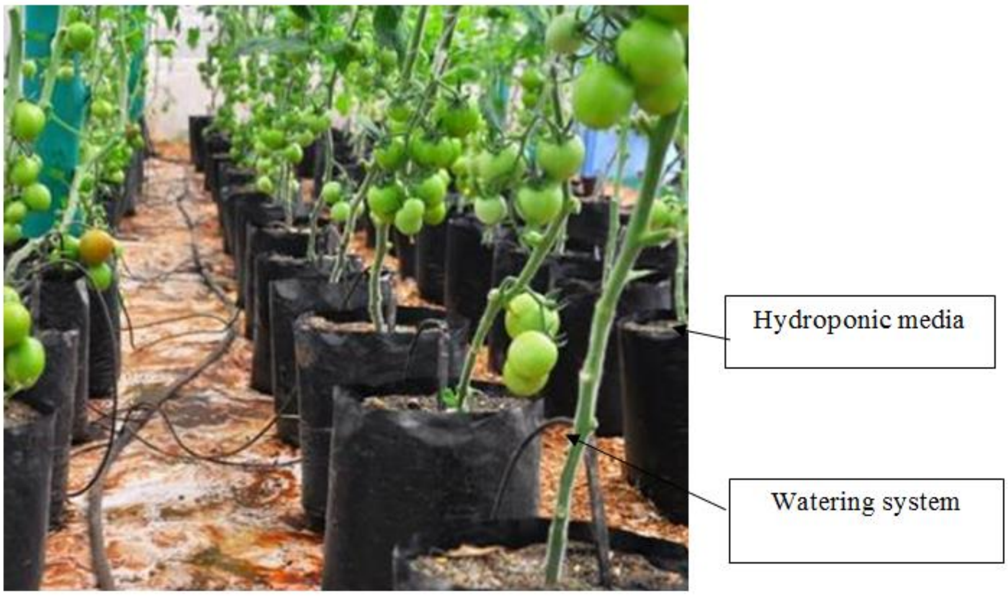

Fig. 5. Tomato plants grown on pumice (Source: Steffalli et al., 2013).

Integrated Pest Management (IPM); is an effective and environmentally sensitive approach to pest management that relies on a combination of harmonious practices. IPM manages pest damage by the most economical means, with the least possible hazard to people, property and the environment. IPM combines the cultural, physical and biological methods. It allows use of chemicals also known as synthetic pesticides as a last resort (Afreen et al., 2017). Under organic systems, only organic pesticides can be used (Damos and Savopoulou-Soultani, 2009; Garrido and Luque-Romero, 2014). Effective pest management can only be achieved through monitoring and correct identification of the pest and disease pathogen. An understanding of the pest lifecycle helps in planning and designing an effective pest management strategy. Monitoring for the presence of pests should start before planting - in surrounding fields, on weeds and in the soil. The presence of pests that live in the soil should be determined by soil sampling and analysis prior to planting. Sticky traps, baits and light traps located in the field or greenhouse helps to monitor the presence of flying insects (Naika et al., 2005; Obradovic et al., 2005; Roda et al., 2015).

Tomato production under controlled environment

Greenhouse production

Greenhouse plant production is the art and science of intensive cultivation of high value crops to optimize on resources. Many types of crops can be grown in the greenhouse viz; vegetables, fruits and flowers (Engindeniz and Tuzel, 2002; Garrido and Luque-Romero, 2014). Due to the decreasing sizes of landholds, climatic changes, need for higher quality and quantity tomato, greenhouse tomato production has been idealized. Greenhouse production creates an ideal production environment that includes optimum relative humidity, temperature and light (Tao et al., 2016). These conditions results in high yields, efficient water utilization, high fruit quality, prolonged production, shortened maturity period, low pest and disease incidences and optimized resource utilization including land, water and labour. This practice has also encouraged production of tomato in urban and peri-urban areas, thus increased food security (Synder, 1995).

Before establishing a greenhouse, the following considerations should be made: type of structure to be raised i.e. metallic/ wooden/ plastic framed structure, available space, cost and affordability, usage i.e. the intended crop. Further, analysis of the site is critical. Aspects such as: insolation, gradient, wind, soil characteristics (structure, nutrients and pathological state) should be also considered. Nutrient test aids in determining the fertilizer program and soil correction program to use for specific crops. Pathological test is important in determining the presence of pathogenic bacteria, fungi and nematodes in the soil. This aids in making an informed management decision including whether to adopt a soilless media system (Noonari et al., 2015; Ali et al., 2017).

Additionally, consideration of market and appropriate timing is necessary particularly for tomato to be sold for fresh consumption. This is necessary to ensure the farmers can get good returns by understanding seasonal variations and demand/ supply. This entails; the time to plant, where farmers are encouraged to grow tomato to coincide with a high demand. This is because greenhouse tomato can do well through the year unlike the open field production. Phased out production can be practiced to ensure round year production. Also, farmers can also be encouraged to make arrangement of their produce prior to production through practices such as acquiring supply contracts, linking up with exporters, processors and local market. This is to ensure the produce meets the customers' expectations (Engindeniz and Tuzel, 2002; Jones, 2012; Ali et al., 2017).

Finally, decision on greenhouse size is paramount. This is mainly determined by farmers' requirements including capital, scale of production, available space and other resources. However, for commercial production, an economic analysis on various sizes must be done to ensure that the farmers can break-even after infesting in a particular unit. For instance, a 15 x 8m greenhouse can accommodate about 400 plants, thus, it can be used as a minimum commercial unit for projections before investing. Some varieties can yield up to 15 kg per plant with a production phase of 6-12 months. Growth rate in greenhouse is faster and the tomato matures within 2½ months (75 days) as opposed to a minimum of 3 months (90-120 days) for the outdoor grown types, this makes greenhouse production an attractive option. However, tomato fruits produced under greenhouse conditions are thought to have a shorter shelf life when exposed to open market conditions after harvesting. This is due to the sudden change in humidity, thus such tomato needs shading and regulated humidity to enhance shelf life. They should be consumed within a short time, stored under modified conditions or processed to reduce losses (Engindeniz and Tüzel, 2002; Seminis-Kenya, 2007; Odame, 2009; Garrido and Luque-Romero, 2014). For effective management of greenhouse a checklist is important to ensure that all aspects are monitored and appropriate action taken. A typical checklist is provided in Table1.

When considering the shape of a greenhouse, a farmer can consider cost, environmental location and aesthetics. Some of the shapes and designs include (Fig. 6 and 7).

Table 1. Greenhouse management checklist

Item	Description
Greenhouse Tunnel	Well ventilated and cladded structure with ultra-violet treated polythene and insect net is ideal. A double door system is recommended to reduce pest incidences. Metallic frame work has a longer lifespan.
Tomato seedlings	High yielding indeterminate seedlings. The seedlings can be inoculated with beneficial microbes and treated with resistance inducing compounds to reduce pest and disease damage with an increased yield.
Plastic Water Tank	Appropriate storage capacity or a sustainable source of water to cover the entire plant growth phase which has different water requirements as the plant develops.
Fertilizer for use	Adequate amounts of nutrients are required because tomato is considered as a heavy feeder. Compost, mineral fertilizers and foliar feed must be applied. This should be suitable for each stage of development. Phosphorous is necessary during planting, nitrogen required at the vegetative stage and potassium boosts flowering and fruiting stage. Micro-nutrients are also important to ensure higher yields.
Pesticide for use	Nematicides, fungicides and insecticides. These chemicals should be used under a structured chemical application plan by aiming at preventing rather than treating the pest and disease effects. An IPM plan where other control strategies such as traps and other deterrents is necessary to reduce chemical application.
Agronomic Training	Greenhouse attendant should be trained. The training should cover all the aspects of tomato production from land preparation, seedling propagation, routine and post-harvest practices.
Visits by an Agronomist	This is very necessary for routine checkup and timely advice which enhances produce quality and quantity hence higher profitability.

(Source: Author, 2020).

Fig. 6. Greenhouse designs for; A - Locally assembled low tunnel greenhouse, B - Propagation House with misters, (Source: Author designs, 2020).

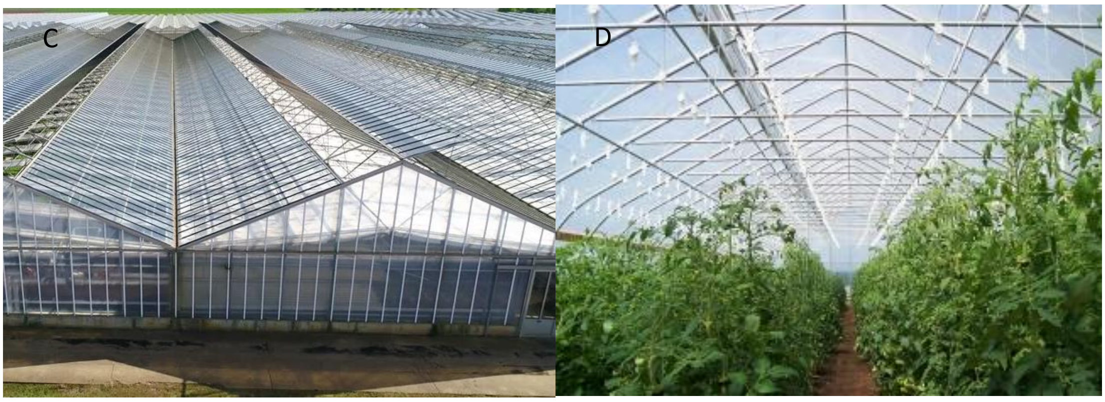

Fig. 7. Greenhouse designs for; C - Extensive multi-arc greenhouse and D High Tunnel - vented and automated greenhouse (Source: Shutterstock.com).

Greenhouse production has become very dynamic recently with some modifications and innovations being done. An interesting technology is the aquaponics system, which is an integrated farming system which constitutes fish and tomato farming. In this set-up water from the fish pond is treated, added more nutrients and used in production of tomato. The system is very ideal in areas with limited space particularly the urban areas since it has higher returns and generates several produce i.e. fish and tomato fruits on the same area. This new farming technology can help to provide employment, food security and occupation even among the youth (Rakocy et al., 2004; Odame, 2009; Jones, 2012; Stefalli et al., 2013). Production of tomato in the greenhouse is a process that involves a myriad of practices. How well the activities are done determines the quality and quantity of produce. According to Tran et al. (2008) and Jones (2012), the practices include:

Nursery Preparation; It's usually advisable to prepare a nursery bed inside the greenhouse so as to benefit from the controlled conditions inside the greenhouse. Propagation can also be done on trays using soilless media to reduce infestation of soil borne pests and pathogens. This also shortens the period of seedling taken to reach transplanting height. The seedlings take about 21 - 30 days to reach transplanting stage. Some of the elite hybrid and indeterminate varieties being propagated for greenhouse production include: Anna, Monset, Arlleta, Bravo, Joy, Tylka and Chonto (http://www. Monsattoafrica.com/pdfs/tomato-anna F1-growers hand book; Odame, 2009; Seminis-Kenya, 2007).

Land Preparation and Planting; Soil analysis should precede production. The soil or the planting media should be well-prepared, thoroughly dug to 1.5 feet deep to loosen the soil. Application of one (1) wheelbarrow of well decomposed manure per square meter. The manure should be thoroughly worked in the soil. The land should then be divided into beds of 1m wide, after which DAP/NPK fertilizers are applied to the surface of each bed by sprinkling sparingly at a rate of 100 g/ M^2. The tomato should be spaced at 50 cm between rows and 40 - 45 cm between plants. Planting can be done in a tandem Zigzag manner to enhance crop density (Naika et al., 2005; Odame, 2009).

Transplanting; Seedlings are transplanted when pencil thick and approximately 15cm long. If taller, it is advisable to bend the seedling horizontally to the ground while transplanting. To encourage more root development, seedlings should be planted two centimeters deep. Overgrown seedlings result in establishment of flowering nodes very high on the stem which reduces the yield (Jones, 2012; Odame, 2009).

Watering; Tomato has a high water demand. A mature tomato crop can use more than 1 gallon of water per plant per day when solar irradiation is high. Greenhouse should be fitted with drip irrigation system and watering should be done in the morning and in the evening. Quality of irrigation and the frequency of watering are very important factors. This is because irregular watering causes fruit cracking and blossom end rot. It is important to avoid wetting the leaves during overhead irrigation to reduce fungal disease development and spread. It is also important to avoid water-logging in tomato fields (Naika et al., 2005).

Control of weeds; Weeds compete unfairly with tomato plants. This competition is for space, nutrients, water and light reduce the yield. Also, weeds harbor some pest and disease pathogens making control of these agents difficult. Regular scouting should be done and observed weeds removed Naika et al., 2005).

Hygiene; A pre-entry chamber should be installed to create the double door system. This helps to reduce exposure to pest and diseases. There should also be provision for chlorinated hand wash at the entrance of the greenhouse and a footbath. Where possible an apron can be provided before one can get into the greenhouse (Jones, 2012; Odame, 2009).

Top dressing and foliar feeding; Top dressing with CAN or Urea is done to enhance plant vigour. Trenches are made between rows and the fertilizer is applied, covered and irrigated. The bed should be aerated (shallow digging) from time to time to avoid compaction (Naika et al., 2005).

Training and Pruning; Crop training can alleviate stress of tomato crops. When the fruits and foliage get into contact with the soil, they are prone to attack from soil borne pathogens. Tomato plants are supported as early as possible to avoid bending. This should be done when the crop is half a foot high. Trellising involves establishment of well anchored posts at 15 feet intervals within the plant row. A rafter or wire is passed along the top of posts and a plastic string used to hold the tomato stem in a vertical direction. Plastic string is recommended and should not be too tight to allow the plant space to expand and avoid injury to the stem. The string is twisted round the plant on a weekly basis, in the afternoon when the cells are flaccid and elastic to avoid breakage of the stem. In the morning, the cells are turgid hence, delicate to bend or train at that time (Odame, 2009; Jones, 2012). Other related activities include; desuckering and defoliation. Desuckering is recommended to be done by hand as soon as the suckers appear; hence frequent surveys' around the greenhouse are necessary. This reduces competition and allows indeterminate varieties develop optimally. While, defoliation is done when there are too many leaves to reduce the canopy cover which may result in high relative humidity hence more prone to diseases. Old leaves should be removed. Once the tomato fruits are formed, the leaves below this truss should be removed (Fig. 8). Finally, truss pruning of leaves around the fruit cluster is done immediately they appear to ensure big sizes of fruits are formed (Naika et al., 2005; Odame, 2009).

Fig. 8. Pruned, trellised and defoliated indeterminate tomato plant (Source: Shutterstock.com).

Pollination; Tomato plants have both male and female reproductive organs on the same flower thus can easily self-pollinate under favorable conditions. Under open field production, wind and insects pollinate tomatoes. In a greenhouse environment, more attention must be paid to the pollination process to ensure maximum fruit set. Under intensive commercial production, pollinators such as bumblebees are introduced or pollination is done using mechanical pollinators. Mechanical pollination is done with a battery powered, hand-held pollinator or by electric vibrating devices. The hand-held pollinators are labor-intensive as workers have to hand pollinate each plant two or three days each week during flowering. Vibration benches work on an automatic timer and do not require much labor after installation, but they are expensive and not cost-effective for smallholder growers (Kueneman, 1995).

Harvesting; the days to maturity varies from cultivar and season. However, most greenhouse tomato matures after 75 days. Each plant yields about 10-15 kg per plant for the production period which is usually 6-12 months depending with the management. Mature plants have about 10 trusses and each truss with 7-8 fruits. A truss appears after every 15-20 cm. As a guideline, tomatoes usually ripen 6–8 weeks from fruit set but this varies with the climate and cultivar. Harvest stage depends on the variety and market destination. For instance, fresh market fruit for local consumers can be picked red, while fruit that will be transported long distances should be harvested at the mature green or breaker stage. Harvest stages in tomato can be classified as:

- Immature Green: where, the fruit color is pale green, and the flesh is hard.
- Mature Green: the fruit is fully grown, the light green color at the blossom end has changed to a yellow-green cast, the seeds are surrounded by locular jelly, and the flesh is hard.
- Breaker: about one quarter of the surface at the blossom end shows some pink color.
- Pink: about three quarters of the surface is pink, and the flesh is firm.
- Full-Ripe: the fruit is nearly all red or pink, and the flesh is still firm.
- Over-Ripe: the fruit is fully colored, and the flesh soft (https://www.monsatoafrica.com; Behera et al., 2019). Ripe tomato fruits (Fig. 9).

Fig. 9. Ripe tomato fruits for Anna (A) and Bravo (B) respectively (Source: Author, 2020)

Sustainable Standards Applicable to Tomato Production

Organic standard

The most important considerations while growing tomato include; variety selection, crop rotation, soil fertility, pest control, and weed control. These considerations are applicable for organic tomato gardening as well (Global organic standard 5.0, 2017; Jones, 2012).

A proper composting process is applied in order to prepare well balanced organic fertilizer for use in production. Addition of compost is also known as feeding the soil while use of inorganic fertilizers can be described as feeding the plant. Plant materials rich in NPK are used during composting. Other nutrients from natural sources such as rock phosphates, nitrates and sulphates can be used as well to enrich the compost. Additionally, potassium and micronutrients from natural sources such as banana peels, sea weeds and plant materials with pesticidal effects can play an important role in the making of compost. Also, use of ash, pyrolysed fine charcoal dust and beneficial microbes including molasses increases mineralization and organic potential of the manure. The compost takes a minimum of 3 months to be ready. Tea compost can be extracted and sprayed on tomato foliage both for nutritional and pest deterrence purposes. Other compost types are the vermiworm and green composts. Further, use of only organic certified pesticides is practiced (Gomez-Brandon et al., 2015; Engindeniz and Tüzel, 2002).

Finally, for tomato produce to be regarded organic, a 3rd party certification audit must be conducted as described below. Before considering adopting organic production system, trainings for the key staff and top management commitment is critical.

Development of an organic standard operating system Plan (OSOSP) is a prerequisite in the process of compliance to organic certification. This is the central document of organic certification. The OSOSP must be completed before any audit activity by a 3rd party is carried. The internal auditor (1st and 2nd party) will inspect the system objectively against the standard or checklist to determine the degree of compliance. Face to face interviews, walk-throughs and document reviews are necessary during this process. An excellent OSOSP includes applicable practices in all sections leaving no unanswered questions in the mind of an operator. It should also provide all the required attachments (maps, land history, process flow charts, material safety data sheets (MSDS) for all materials used, list of all inputs and seeds (Global organic standard 5.0, 2017; EOS, NOP standards).

Preparation of organic certification entails determination of scope from the onset. This is an agreement between the auditor and auditee that should spell out all the stages of production, records and personnel. Some auditors send out pre-inspection forms for the client to conduct internal baseline audits and determine the preparedness. Complete disclosure is very necessary for such an audit to be successful.

The following are some of the important preparation actions in preparation for adoption of organic standard:

Formation of an Implementation Committee; the committee is formally appointed by the chief executive officer within the organization. The committee members are selected from different departments to provide diversity of disciplines for ease of execution of the mandate. The committee is allowed express access to all materials, storage areas, relevant data and documents, processing facilities, farms, and off-farm handling facilities certified within the organization.

Records; documentation plays a critical role in any quality management system. It is very critical to effective planning and implementation of any standard. Audit of records usually takes considerable amount of time thus must be well labeled and organized. Documentation can be done as per the department, criteria and/or veracity of the activity. Organic systems incline more towards use of organic products, environmental conservation, use of best agricultural practices, adoption of sustainable and best manufacturing practices, food and product safety, workers' welfare and societal wellbeing. The records that are relevant to organic certification generally fall into two categories: audit trail and organic integrity.

Basic documents under organic production

a) Organizational structure – clearly shows the role of each staff in the implementation of the standard and general firm management

b) Organic policy statement – an important document that spells management commitment to attainment and maintenance of the standard

c) Organic GAP procedures – cover the entire farm production practices showing how the organic standard is practiced. Is supported by secondary documents that shows the input application, process monitoring and harvest records

d) Organic GMP procedures – cover the entire processing practices if the produce under production is processed

e) Occupational health and safety (OHS) policy and procedures – welfare of the workers is critical since the personnel maintains the integrity of the standard

f) Traceability policy and procedures – important in verification of compliance

g) Training schedules and records – training is a critical part in attaining and maintaining organic standard

h) List of approved inputs – to guide acquisition of only the approved inputs where new materials are to be used. Authority must be sought from the certification body

i) Farmer recruitment checklist – this is necessary where there are out-growers involved in production

j) Risk assessment – it is necessary to conduct a risk assessment to determine the system threats and strategize on possible mitigations

k) Internal Inspection Report – regular monitoring is required to determine the degree of compliance internally. Where there are deviations, appropriate corrective actions must be implemented.

l) Product withdrawal/Recall record and procedure – the document must clearly show how timely communication among the stakeholders will be done

m) Management of suspect product – the document indicates how a suspect produce or produce is segregated until its status is verified

n) Environmental responsibility (ER) policy – since organic standard is related to sustainable environmental use, there must be policies and procedures clearly showing how the environment will be protected and restored

Audit Trail; Entails all records of purchases, movement, sales of inputs, ingredients, intermediates, and final products. These records must be well organized and accessible. A list of all inputs is therefore provided as an Organic Farm Input Report (OFIR). The list must be in a 3-year cycle which is usually a certification cycle. A traceability plan must be documented clearly showing the process of chain of custody and product flow. The processors and handlers must be prepared to track final products back through processing stages and point towards the raw materials. It is important to train all staff involved on this procedure (Global organic standard 5.0, 2017; EOS, NOP standards).

Organic Integrity; Records are used to indicate compliance and implementation plan. These documents are classified as OSOSP, ICS and QMS. Review of documents based on emerging technologies, research findings and validation is always anticipated. The review is also based on audit findings in order to address possible non-compliances.

During the Inspection;

- One should focus on the inspection and reduce distractions as much as possible e.g. from phone and radio calls etc.
- Remain relevant to the objective and scope. The auditor will verify any specific information as per the programme. Documentary and actual evidence depict compliance.
- The auditee should be able to link the connection between all standard operating procedures (OSOSP) with organic standards. Issues of statutory, regulatory, critical and continuous improvement criteria must be well documented and implemented. Previous non-compliances and opportunities for improvement must be satisfactorily addressed within the agreed time frame. Evidence of how the organization prevents potential non-compliances and applies the audit trail must be clearly established. Avoidance of potential risks and hazards must be clearly spelt out in a HACCP plan and/or risk assessment plan (s) e.g. buffers, shared equipment/materials.

After the Inspection; promptly provide all additional information requested, such as additional OSOSP sections, land history documentation, community relations, statutory documents and authorization for various activities the firm is involved in. any activity contravening the country laws automatically becomes a major noncompliance and a threat to existence of the firm.

Certification Body; the firm conducts the 3rd party audits which are independent, objective, periodic and systematic. The auditor from the firm communicates all the findings within the agreed scope before closure of the audit. The auditee is allowed to appeal the decision of the auditor if there is outright in-objectivity in the process of the audit. The final report is submitted to the auditee within the agreed period. In case there is need to use the certifying body logo by the auditee, then this takes place immediately a certificate of compliance is issued by the certifying body and continues to be valid for the specified period of time until either party discontinues the certificate with reasons. Investigative audits can also be done if the audited firm does not provide full disclosure, reneges on an important criterion or product in the market shows inconsistencies (EOS, NOP standards).

Global GAP standard

The standard provides assurance that a produce reaches acceptable levels of safety and quality, has been produced sustainably, respecting the health, safety and welfare of workers, the environment, and animal welfare issues. Failure to provide such reassurance, growers may be denied access to markets. Further, consumers, retailers and governments have placed new demands on farmers and growers to use production techniques that reduce the impact of farming on the environment (land and water), reduce use of chemicals and make efficient use of natural resources, while safeguarding the welfare of both workers and animals. Global GAP standards require proper documentation of all the processes practiced within a farm. Policies and procedures must be done to demonstrate how the grower seeks to observe the statutory, regulatory and prescribed requirements. Procedures on conducting internal inspections, addressing nonconformities and continuous improvement should be well stipulated.

The standard is critical to biodiversity and environmental conservation practices. Thus, procedures and practices within the farm must demonstrate compliance. These practices include; protection of terrestrial and aquatic environments, protection of riparian areas, provision of barriers between farms and natural environments, Inventory of animals/ plants within the locality, avoidance of negative practices such as hunting. Other environmental factors are; practicing good agricultural practices, avoidance of GMO, agro-forestry, compliance to water use laws, proper management of waste water, rain water harvesting, conservatory water use, soil conservation measures, proper waste management, energy conservation and pest management practices. Further, activities that aim at environmental restoration measures including climate smart technologies should be implemented (https://www.globalgap.org). Under, good agricultural practices, the following activities must be practiced;

1. Site selection by taking into consideration the soil type, elevation, fertility and other physico-chemical properties. Activities such as soil analysis and surveying are necessary before production.
2. Land preparation. Should be well done by deep ploughing, harrowing and ridging where necessary. The planting beds must be well established, raised and leveled to permit allow proper root development and human activities such as irrigation, weeding, fertilizer application, pest control, harvesting and transport.
3. Environmental conservation measures. This refers to all the eco-agriculture practices being carried out in the farm.
4. Selection of healthy varieties with high level of pest tolerance, yield and customer appeal.
5. Automation of the fertigation system. This ensures optimum use of fertilizers and water reducing waste of resources, diseases and ensures produce consistency.
6. Proper plants establishment including spacing, planting depth and bed spacing enhance crop development and contributes in pest management
7. Use of organic matter including compost, vermicompost, tea compost, farm yard manure and green manure aid in building the soil bio-physicochemical properties making production sustainable.
8. Documentation. The standard demands identification of the entire process from the farm to the market, this is also referred to as the traceability procedure. All the processes, persons and products used during production are well indicated. The processes must be validated with scientifically proven systems for sustainability and compliance. The criteria for handling certified and non-certified produce must be clearly spelt out. Where the activities take place in multi sites, a systematic procedure must be prepared showing how the produce is produced, harvested, transported, sorted, processed, graded, packaged, labelled and dispatched. The procedure must show an elaborate chain of custody (Tran *et al*., 2008; Jones, 2012; https://www.globalgap.org).

Finally, global GAP standard endeavours to ensure that the workers, community and stakeholders welfare is guaranteed. This is achieved by avoiding discrimination of workers on all accounts, fair remuneration, compliance to the legal working hours, ensuring that workers meet the required age before hiring, providing favourable conditions for personnel development, compliance to good all relevant policies on staff, ensuring safety of workers while at work through provision of protective gear, regular medical tests, trainings and medical cover. Other measures include; ensuring the environment is suitable for work by provision of change rooms, bathrooms, rest rooms, functional toilets and work station ergonomics are adhered to. An important aspect of staff and stakeholders' welfare is communication. There must be an elaborate communication system that demonstrates a two-way interaction. Finally, issues of public participation and community support are playing a critical role in most standards that are concerned with people wellbeing (https://www.globalgap.org).

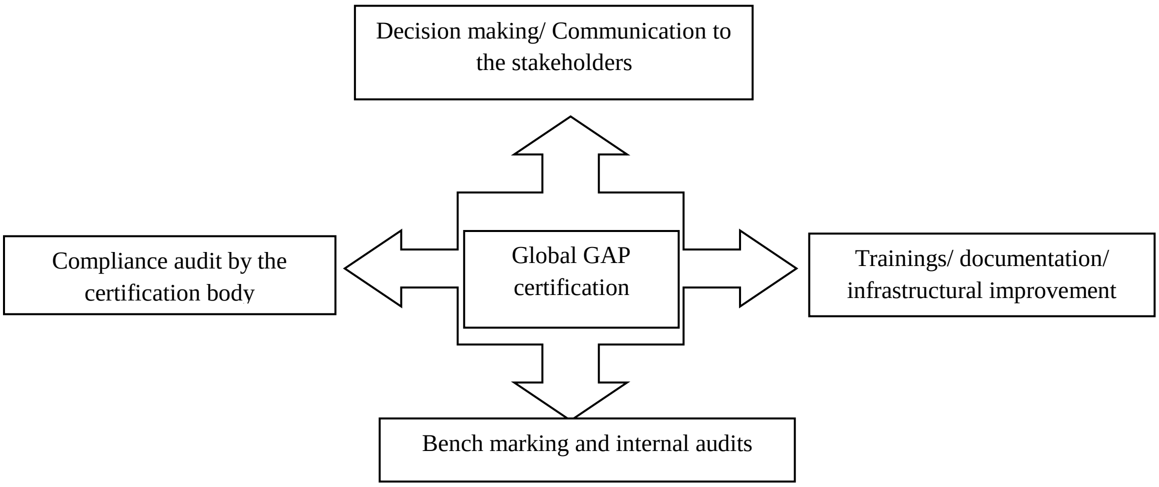

Fig. 10. Steps to follow in global GAP certification (Source: Author, 2020)

Summary of the steps to follow in global GAP certification is presented in Figure 10.

Marketing, processing, packaging and branding

Finally, the process of tomato production ends after marketing of the produce or products. Before marketing, processed tomato requires compliance to good manufacturing practices such as hygiene standards, packaging and branding. The high perishability of the vegetable limits its production, thus attempts to process the produce are likely to encourage production. The main objective of processing is to supply wholesome, safe, nutritious and acceptable food to consumers throughout the year. Tomato and tomato-based foods are considered healthy for the reason that they are low in calories, but possess a rich combination of antioxidants and micronutrients (Toor and Savage, 2006; Behera et al., 2019).

Processing; tomato fruits are thoroughly washed in water and then boiled in steam jacked kettles, before pulping is done in continuous pulper. During pulping, the skin and seeds are separated from the pulp. The extracted pulp is the basic material from which other products are made. The recovery of pulp varies from 40 - 50% depending upon the quality of tomato fruits and technology applied. In juice making, fresh tomato fruits are crushed directly instead of boiling them prior to processing in stainless steel kettles. Whereas, in sauce preparation, the juice is concentrated under vacuum and controlled temperature. Other additives such as; salt, sugar, vinegar, spices, onion etc are added as per requirement. This mixture is boiled under vacuum till it contains minimum 12% tomato solids and 28% total solids. Sauce is then passed through sieve to remove fibrous and other materials. Finally, material is cooled and preservative added before packing (Fig. 11). The process for preparing ketchup remains the same, but there are many spices like ginger, garlic, clove, pepper which are added with salt, sugar, vinegar and class II preservatives (Al-Wandawi et al., 1985; Valencia et al., 2004; Behera et al., 2019).

To prepare tomato paste and puree, the juice is concentrated under vacuum and controlled temperature. Tomato powder can be prepared using different technologies depending on the end use of the product. But the process entails thorough drying to obtain dry material with very low moisture content (Al-Wandawi et al., 1985; Toor and Savage, 2006).

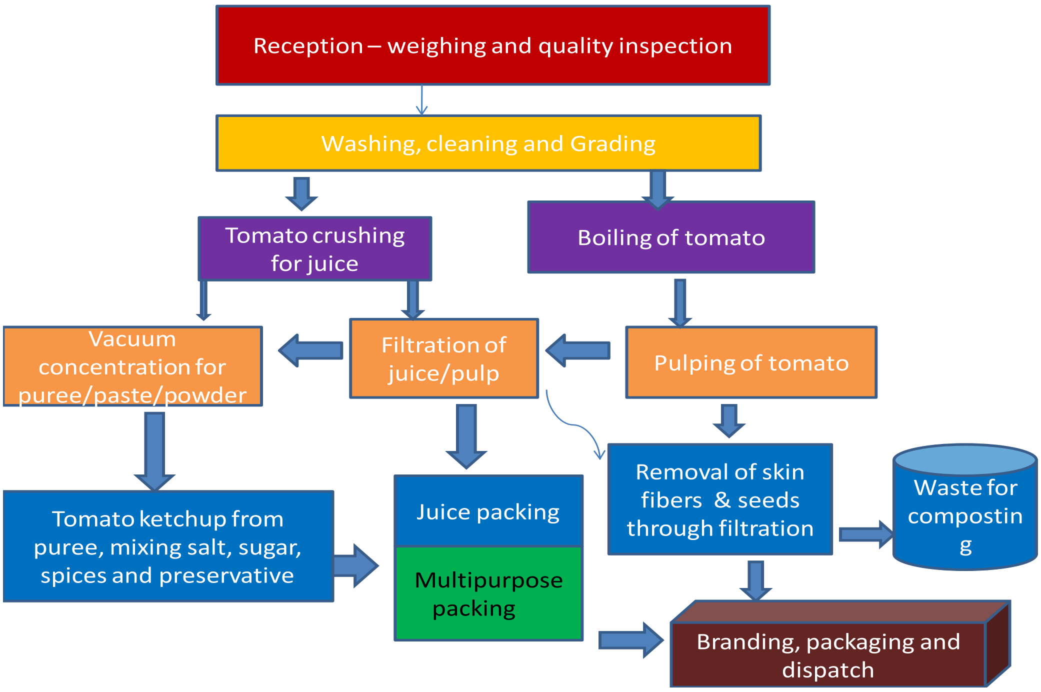

Fig. 11. Tomato Processing Flow Chart (Source: Al-Wandawi et al., 1985).

Process Flow

Reception section; Fresh tomato fruits are received and passed on to the fruit washing and grading section. Washing is done to remove the outer dirt and foreign matter from the fruit skin. Washed tomato fruits are then fed to the inspection cum sorting conveyor where unwanted and the damaged are separated manually (Al-Wandawi et al., 1985; Behera et al., 2019).

Major Equipment: In-feed conveyor, tomato washer, sorting table.

Juice extraction; washed and graded tomato fruits are passed to the fruit juice extraction and processing unit. From fresh tomato, the juice is extracted in juice extraction system. The outer skin, seed and fiber of fruits separated and disposed. Extracted juice is passed to the heat treatment till the critical temperature is attained known as the critical control point (CCP) to ensure quality and hygiene. It is then fine pulped in pulper cum finisher to get the finished juice. This juice then goes for further processing to concentrate it to 12 Brix for tomato puree, 14 Brix for tomato ketchup or 28-30 Brix for tomato paste (Al-Wandawi et al., 1985; Valencia et al., 2004; Behera et al., 2019).

Major Equipment: Tomato Juice Extractor, Receiving Tank, Transfer Pump, Pulp Pre-heater (Shell Tube Heat Exchanger), Pulper cum Finisher, Receiving Tank, Transfer Pump, Pulp Storage cum Balance Tank.

Evaporation; This section mainly entails processes and equipment used for allowing moisture loss from the processed tomato juice. This is aimed at concentrating the juice to the required level.

Major Equipment

1. Effect scrapped surface evaporator for tomato paste

2. Effect forced circulation vacuum vaporator - (Balance Tank, Graduated Flow Control Valve, Feed pump, Calandria, Vapour Separator, Condenser, Concentrate Recirculation Pump, Concentrate discharge Pump, Condensate Pump, Vacuum Pump, Vapour Duct, SS Pipes and Fittings, Seal Water Tank, Steam Supply System, Service Water Line, Control panel).

Packing; glass bottle packing for tomato puree/ketch-up, can cracking for paste/concentrate, e-branding and labeling machine (Dewato et al., 2002; Valencia et al., 2004; Toor and Savage, 2006; Behera et al., 2019; https://www.researchgate.net/publication/49636208).

Conclusions

This paper exposes the entire tomato value chain from propagation, agronomic practices, pest and disease management, harvesting and post-harvest handling. Further, it addresses issues of good manufacturing practices, quality management systems and traceability. It is expected to play a critical role in enhancing production, environmental conservation, global good agricultural practices, organic standards and economic empowerment of the tomato value chain stakeholders.

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Conflict of Interest

There is no conflicting interest in this manuscript.

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