EFFECTS OF AGRONET COVER AND COMPANION PLANTING WITH BASIL (*Ocimum basilicum* L.) ON WHITEFLY (*Bemisia tabaci* Gennadius) INFESTATION, YIELD AND QUALITY OF TOMATO (*Solanum lycopersicum* L.)

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the award of Master of Science Degree in Horticulture of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented before in this or any institution for any award of a degree.

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Recommendation

This thesis has been submitted with our approval as supervisors according to the Egerton university regulations.

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DEDICATION

I humbly dedicate this work to my beloved family, friends and employer whom I owe a lot for the success. May God bless you in a mighty way.

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a major vegetable crops, and is ranked second at 14% of total value of exotic vegetables produced in Kenya after potato with a value of 55%. It is predominantly grown by small to medium scale growers in open fields. However, open field tomato production faces many challenges including weather extremes, diseases and insect pests. The whitefly (*Bemisia tabaci* Gennadius), is one of the major pests of tomato capable of causing up to 80% loss in yield. To address the whitefly problem, most growers indiscriminately use synthetic insecticides. This however, is known to impact negatively on the environment, human and other natural pest management systems. The main objective of this study was to determine the effectiveness of agronet covers and companion planting with aromatic basil (*Ocimum basilicum* L.) as an alternate whitefly management strategy on tomato; and how the use of these treatments would impact on yield and quality of the crop. The study consisted of two trials of open field tomato production experiments at the Horticulture Research and Training Field, Egerton University, Njoro (Kenya); each followed by a tomato quality determination experiment in the laboratory. A Randomized Complete Block Design (RCBD) with six treatments replicated five times was used for the open field tomato experiment. Completely Randomized Design (CRD) with six treatments replicated three times for the quality determination experiment. Data collected included tomato plant growth and yield parameters, whitefly infestation and quality aspects of tomato fruit. Data collected was subjected to Analysis of Variance (ANOVA) at $P \leq 0.05$ level of significance and means separated using Tukey's honestly significant difference (Tukey's HSD) test at the same probability level. Results obtained showed that, agronet cover and companion planting with basil resulted in significant reduction in whitefly population, improved growth, yield and postharvest quality of tomato compared to the control treatments. Better reduction in whitefly population and increase in growth, yield and postharvest quality of tomato obtained when the two treatments were used in combination. Among the tomato-basil planting arrangement, planting a row of basil in-between adjacent rows of tomato proved more beneficial compared with basil was surrounding tomato plants from outside. Findings of the study demonstrate the potential of using agronet covers and/or companion planting as part of an integrated pest management strategy in tomato production leading to environmentally safe and affordable tomato culture while maintaining high yield and quality of the produce.

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LIST OF ABBREVIATIONS AND ACRONMYS

ANOVA	Analysis of Variance
CCIs	Chlorophyll Concentration Index Units
CRD	Completely Randomized Design
DAT	Days After Transplanting
DAS	Days After Storage
EU	European Union
EFN	Eco-Friendly Nets
FAO	Food and Agriculture Organization of the United Nations
FRC	Floating Row Covers
HCDA	Horticultural Crops Development Authority
KALRO	Kenya Agricultural and Livestock Research Organization
KEPHIS	Kenya Plant Health Inspectorate Services
KHCP	Kenya Horticultural Crops Programme
Ksh	Kenya shillings
MOARD	Ministry Of Agriculture and Rural Development
PRP	Pest Repellent Plants
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
WAT	Weeks After Transplanting
VOC	Volatile Organic Compounds

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Vegetable production can be adopted as a strategy for improving livelihood and employment needs of many people in developing countries (McCulloch and Ota, 2002). In Kenya, vegetable production is a booming business driven by rapid population growth and urbanization which has led to an increase in demand for fresh produce. Further, export of fresh vegetables earns the country about Ksh.21.4 billion in foreign exchange (HCDA, 2013). In the year 2012, total vegetable production in Kenya was 380,000 million tons with a value of Ksh.95 billion which accounted for 48% of the domestic value of horticulture (HCDA, 2013) up from ksh.85 billion realized in 2011.

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops in Kenya. It is ranked second at 14% of total percent share by value of exotic vegetables produced in the country after potato with a value of 55% (HCDA, 2013). The crop is commonly grown for both fresh domestic and export market (MOARD, 2003); with an increasing demand for processing (Mungai *et al*., 2000). In the year 2012, tomato contributed approximately Ksh.12.8 billion of the annual export earnings from fresh vegetables (HCDA, 2013). Besides foreign exchange earnings, tomato is an important condiment in most diets and a cheap source of vitamins such as vitamin A, C and E and minerals that are important for protecting the human body against diseases (Taylor, 1987). The tomato fruit contains large quantities of water, calcium and niacin all of which are of great importance in the metabolic activities of the human body. The fruit has also been documented to have medicinal value as a gentle stimulant for kidneys, intestinal and liver disorders as well as washing toxins that contaminate the body system (Wamache, 2005).

In Kenya, tomato production covers an area of about 18,612 ha (HCDA, 2013). Average yields per unit area of land especially in the open fields is between 8 to 12 tha^{-1} (Mungai *et al*., 2000; Lanny, 2001) against the world average of 75 tha^{-1} (FAO, 2010). The crop is predominantly grown by smallholder and medium-scale commercial growers as an important cash crop with a strong year-round demand (KHCP, 2012). Successful open field production of the crop is, however, hampered by both biotic and abiotic stresses that affect the crop from seedling stage all through to maturity. Among the abiotic constraints are fluctuating moisture regimes, excessive solar radiation, temperature, relative humidity, and light (Dumas *et al*., 2003; Caliman *et al*., 2010). Common production biotic constraints reported in the country include diseases (Varela *et al*., 2003) and insect pests; among them the whitefly (*Bemisia tabaci* Gennadius) (Franca *et al*., 2000; Haji *et al*., 2002).

The whitefly which belongs to the order Hemiptera and family Aleyrodidae is a multivoltine, highly prolific polyphagus and invasive pest found almost all over the world. It has devastating effects on a wide range of horticultural crops that could undermine the European Union (EU) based export business (Kedera and Kuria, 2003). It is one of the pests responsible for rejection of Kenya's fresh produce in the EU market (KEPHIS, 2006). On tomato, the whitefly has been associated with both direct and indirect damages. Whitefly feed directly on the tomato crop by withdrawing sap from the phloem, resulting in leaf and fruit spotting, weakening of plants and irregular fruit ripening (Muigai *et al*., 2002). Sooty moulds growing on honey dew secreted by the pest further reduce the photosynthetic potential of the crop which in turn affects the eventual yield and postharvest quality of fruits. In addition, the whitefly has also been associated with transmission of viral diseases which also negatively impact on crop yield (Polston and Anderson, 1997; Mansoor *et al*., 2003).

Although pesticides are to some extent available for the control of most insect pests of tomato, the whitefly has been found to exhibit resistance to modern insecticides (Horowitz *et al*., 2005; Ma *et al*., 2007). Moreover, most of the pesticides are quite expensive for small scale farmers (who account for the majority of tomato growers) to afford, besides being harmful to the user, environment and other non-target insects (Weinberger and Lumpkin, 2005). Further, no amicable solution exists for the abiotic constraints to open field tomato production. Concerted efforts on greenhouse production of the crop have been advocated to solve some of these problems but, its adoption has been slow, especially in developing countries such as Kenya due to the high costs involved in purchase and installation of the structures. As a result, most farmers still grow their tomato in the open fields, despite the many challenges (HCDA, 2006).

The use of net covers in offering physical and/or visual barriers has proved successful in protecting different crops from weather extremes and insect pests. Use of such technology has served as a means of reducing or even preventing the often indiscriminate insecticide applications by small scale growers and at the same time improving yield and quality of crops (Taleker *et al*., 2003). For instance, insect proof nettings have been reported to offer good protection to young plants against the aphid *Lipaphis erysimi* (Martin *et al*., 2006; Gogo *et al*., 2012) and a wide range of vegetable insect pests (Chen *et al*., 1998). Besides, net covers have been known to protect agricultural crops from excessive solar radiation and other environmental hazards thus enhancing plant microclimate for better crop performance. Pek and Heyles (2004) recorded better regulation of air temperature, reduced crop stresses and better crop performance with the use of netting technology compared to open field production of vegetable crops.

Companion planting which refers to the practice of establishing two or more plant species in close proximity for cultural benefits such as suppression of insect pests and weeds (Kuepper and Dodson, 2001) has been a component of most traditional farming systems. A number of plants have been planted together with vegetables in a garden setting to serve as companion crops. For example, intercropping mustard (*Brassica juncea* L.Cern) as a companion crop for collards (*Brassica oleraceae* var. *acephala* de Condole) has been used successfully to repel the whitefly (Legaspi *et al*., 2011), while tomato has successfully been used as a repellent for the diamondback moth on cabbage (*Brassica oleraceae* var. *capitata*) (Buranday and Raros 1975; Sivapragasam *et al.,* 1982).

Experience from many parts of the world has shown the benefits of cultivating aromatic plants in companion with other crops due to the variety of volatile oils contained in such plants that are well known for their insecticidal, antifeedant, repellent and oviposition deterrent effects on insect pests (Song *et al*., 2010). Essential oil of marjoram (*Origanum majorana* L.) and rosemary (*Rosmarinum officinalis* L.) have shown feeding and oviposition deterrence against onion thrips. Repellant effects have also been reported for mint (*Mentha logifolia*) on common maize weevil (*Sitophilus zeamais*) (Odeyemi *et al*., 2008) and for basil (*Ocimum basilicum* L.) against mosquitoes (Azhari *et al*., 2009) and flea beetle on Pechay (*Brassica perkinensis*) (Roxas, 2009). Apart from the direct effects on insect pests, companion planting has also been found to increase the abundance of beneficial insects (Schader *et al*., 2005) which lead to reduced need for pesticide use. In addition to pest suppression or control, other associated benefits of companion cropping are reduced risk of crop failure and improved total crop yield per unit area (Litsinger and Moody, 1976; Okigbo and Greenland, 1976) thus improving income for the growers.

1.2 Statement of the Problem

Tomato production is a major income earner for many small to medium scale growers who form the bulk of farmers producing vegetable crops in Kenya for both domestic and export markets. Tomato production is currently threatened by insect pests some of which have been declared to be of great economic importance and feature in the European Union (EU) list of quarantine pests. The whitefly is one of such devastating pests causing huge losses in terms of yield and market value of tomato in the country as well as vectoring several viral diseases. Although pesticides are available for control of this pest, they are too expensive for smallholder farmers to afford. Moreover, repeated use of chemical pesticides has been documented to result in increased pesticide residues in the soil, water and harvested produce, killing of non-target beneficial insects and the consequent development of resistance to pesticides by the pest. Worldwide development of new biotypes of whitefly is likely to result in more resistance to pesticides leading to even more severe crop losses and/or excessive use of pesticides which may force many small scale farmers out of tomato production. Although screen nets and companion cropping have been used successfully as alternative pest management strategies in other parts of the world, their potential benefit in controlling whitefly in local tomato grower fields remain unexploited.

1.3 Objectives of the Study

1.3.1 General Objective

To contribute to improved tomato yield and quality by providing alternative cropping and pest management systems that are environmentally friendly and relatively affordable to small and medium scale tomato growers.

1.3.2 Specific Objectives

The specific objectives of the study were to determine the effects of:

i. Agronet cover on whitefly infestation, growth, yield and postharvest quality of tomato.
ii. Basil on whitefly infestation, growth, yield and postharvest quality of tomato.
iii. Companion planting design on whitefly infestation, growth, yield and postharvest quality of tomato.
iv. Combined use of agronet cover and basil planting arrangement on whitefly infestation, growth, yield and postharvest quality of tomato.

1.4 Research Hypotheses

The following hypotheses were tested:

i. The use of agronet cover reduces whitefly infestation, and improves growth, yield and postharvest quality of tomato.
ii. Use of basil reduces whitefly infestation, and improves growth, yield and postharvest quality of tomato.
iii. Companion planting design influences whitefly infestation, and improves growth, yield and postharvest quality of tomato.
iv. Combined use of agronet cover and companion planting with basil reduces whitefly infestation, and improves growth, yield and postharvest quality of tomato.

1.5 Justification of the Study

Tomato is one of the most susceptible crops to insect herbivory hence demanding a heavy load of insecticides for pest management. This factor remains to be one of the major economic and ecological problems affecting farmers, crops and their living environment. For instance, efforts to control whitefly by use of chemical pesticides have so far proved difficult and complex due to its rapid rate of development and reproduction, wide range of hosts and also its ability to develop high resistance to many insecticides available in the market. This complex nature of the whitefly has thus forced many growers to intensify their indiscriminate use of synthetic pesticides. The demand for "healthy products" by consumers coupled with the high cost of chemical pesticides and other environmental hazards calls for an integrated approach that mostly focuses on prevention and reliance on cultural and biological control. This approach would aim at increasing production of safe vegetables through the use of non- chemical based strategies for managing insect pests. Protecting vegetables like tomato by companion planting or the use of agronet covers could reduce or even prevent indiscriminate pesticide applications by small-scale farmers in the tropics where whitefly is prevalent and thus protect growers, consumers and the environment from hazardous chemicals. Besides, agronet covers are relatively affordable and easy to use by both skilled and unskilled farming communities compared to the use of greenhouses which is capital intensive and require skilled personnel to install and maintain. The advantages of such an approach would be protection of human health by reducing pesticide sprays, reducing environmental pollution from pesticide residues and increasing crop yield and quality. Further, the use of agronet covers could improve or modify plant growth environmental factors such as light, humidity, air movement and temperature as well as insect pest exclusion all of which have been shown to have direct positive impact on the eventual yield and quality of crops leading to increased income for the growers.

On the other hand, use of aromatic plants as a cultural insect pests control measure has been recommended for its supposed pest repellent qualities hence discouraging pest establishment, or indirectly through attracting natural enemies that kill the pest. The ideal companion plant can also be harvested to provide direct economic returns to the farmer besides an array of other benefits including reduced disease incidence and improved crop yield and quality. It is anticipated that such a practice would reduce over dependence on pesticides in the mitigation of tomato pests particularly the whitefly by offering a pest management strategy that is affordable, environmentally safe and easy to apply by the farmers. Findings of this study will also contribute to the existing scientific knowledge on tomato culture.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Information on Tomato

Tomato is one of the fruit vegetables belonging to the family Solanaceae. Its origin can be traced to Andes in South America. The crop was introduced to Europe in the 16th century and later to East Africa by colonial settlers in early 1900 (Wamache, 2005). Today, there are many varieties of tomato that are widely grown in greenhouses in cooler climates and outdoor by small to medium holder farmers in the sub-tropical and tropical regions like Kenya. The demand for tomato for both fresh consumption and processing is always high in most countries in the world (Mungai *et al*., 2000).

Tomato is fairly adaptable to a wide range of soil types, as long as they are high in organic matter and well-drained with a pH range of 5 - 7.5 (KARI, 2006). The crop also does well in a wide range of climatic conditions but will grow best in warm conditions. The optimum temperature range for tomato is 15 °C - 25 °C. Very low temperatures delay colour formation and ripening while temperatures above 30 °C inhibit fruit set and lycopene and flavour development. High humidity has also been reported to reduce fruit set and yields. Tomato thrives best in low to medium rainfall with supplementary irrigation during the off-season. Although these conditions favour optimal tomato growth and performance, they also offer an ideal environment for disease and insect pest attacks and development (Santini, 2001).

In the tropics, tomato production has been associated with extreme vulnerability to abiotic stresses like extremes of temperature, humidity, soil moisture and air flow among others (Ajwang *et al*., 2002) and biotic stresses represented by insect pests (thrips, aphids, whitefly) and viral diseases vectored by the insect pests (Thongrit *et al*., 1986; Premachandra *et al*., 2005). Growth and yield differences of tomato in the tropics have also been associated with microclimate changes that occur under the prevalent fluctuating weather conditions. High solar radiation affect growth through hormonal malfunction and enhance crop damage that can lead to lower tomato yield and quality in the open fields (Harmanto *et al*., 2006). Such weather challenges together with the high cost of chemicals commonly used to control the biotic stresses and the subsequent development of resistance to pesticides by insect pests have prompted many producers and researchers to explore alternative cropping and management systems that could enable them deal with the adverse climatic conditions while at the same time reduce on dependency and/or frequency of pesticide usage.

2.2 An Overview of Vegetable Production under Protected Culture

Protected crop culture technology dates back to 1437A.D when Romans used hydrous magnesium silicate to cover windows with the objective of screening out light in order to extend growth of plants. It is a technology that encompasses various systems and practices ranging from insect screen nets, plastic low tunnels to hydroponic greenhouses and growing rooms which are aimed at manipulating the crop environment. The production of crops under protection has since dramatically grown in many countries as a result of the increasing demand for high-quality fresh produce (Garnaud,1988) and declining arable land. Advancement in protected cropping technologies has seen a more stable supply of vegetables in the markets especially of the developed world, preventing seasonality in the availability of fresh produce (Andriolo *et al*., 2000).

Urban and peri-urban vegetable production is often affected by a wide range of pests and diseases that require intensive crop protection. Inadequate farmers' training in pest-management techniques often leads to repeated use of high doses of pesticides on vegetables in an effort to control pests (Dinham, 2003). The result of such practices has increased pesticide residues in the soil, water and the harvested produce as well as development of resistance to many of the insecticides in the market by most important pest species (Martin *et al*., 2002; Otoidobiga *et al*., 2002). As a result of these challenges, many farmers have been prompted to grow vegetables under protective structures which not only have the ability to offer physical or visual barrier to pests but also improve the plant growth microclimate for better crop performance.

A wide range of protected cultivation systems have so far evolved ranging from low-tech, low- cost plastic tunnels and exclusion net houses to high-tech expensive glasshouses in use in Western Europe and North America. These systems differ in size, shape and material used as covers (Hemming *et al*., 2008). In modern research, the use of greenhouse technology has been utilized extensively in the control of environmental parameters such as temperature, relative humidity, light intensity, light duration, CO_2 level, irrigation, nutrient supply and uptake, spacing, growing medium and root development (Baghel *et al*., 2003) but has proven expensive for most small-scale vegetable growers to afford. There are however, a variety of other fairly affordable forms of protected structures in use in warmer climates ranging from shade houses, lath houses, mist houses, to screen and netting houses. Such structures are ideal in preventing damage to plants as they permit sufficient movement of air, thus cooling the structure and reducing humidity that can enhance plant pathogen development (Castilla and Moreno, 2008), as well as avoiding insect infestations by serving as physical barriers (Weintraub *et al*., 2008).

An alternative for growers who cannot afford the high initial construction costs of net houses or plastic greenhouses to grow vegetables has been achieved through the use of temporary net tunnels (Talekar *et al.*, 2003). Temporary tunnel screens have been used in many developed countries mainly for early production of field crops such as potato, carrot and salad vegetables. In addition, with the growing demand for pesticide-free produce, direct covers are also being used to protect crops from insect pests such as whitefly resulting to reduced frequencies of insecticide applications, better produce quality, and higher marketable yield.

2.3 An Overview of Tomato Pests

Pathogens, weeds, and invertebrates cause significant crop losses worldwide and thus viewed as major barriers to the achievement of global food security and poverty eradication (Pretty and Bharucha, 2015). Viewed in terms of food security, crop losses due to pests can be estimated to feed over 1 billion people yearly (Birch *et al.*, 2011). More than 10,000 insect pest species (Dhaliwal *et al.*, 2007) have been documented and known to attack food crops worldwide with yield and quality losses reaching as high as 100% (Abate *et al*., 2000).

Vegetable demand continue to increase day by day and can be grown in different seasons of the year hence the need for vegetable production sustainance to meet the increasing demands from consumers. In spite of the increase in demand, yield per unit area of vegetable is quite low due to insect pest attacks with Rahman, (2006) attributing 25% yield loss to insect pests alone and even 100% in case of menace if no control measure is applied. Pests are known to cause damages at all stages of growth and development as a result of direct feeding and through transmitting disease causing organisms (Lange and Bronson, 1981). Attle *et al.* (1987) reported as high as 100% yield reduction of different bean crops due to aphid infestation while Nagrare *et al. (*2009) reported mealybug's economic damage of up to 40-50 % in infested bean fields in several parts of Gujarat.

Tomato crop being a worldwide grown vegetable is prone to serious arthropod pests and viral disease infestations with devastating effects during both the rainy and dry seasons (Mailafiya *et al.*, 2014). Lange and Bronson (1981) reported between 100 and 200 pest species that attack this crop with capacity to cause damage at all stages of growth and development (Mansoor *et al*., 2003). In the tropical and sub-tropical regions of the world, successful tomato production is majorly constrained by pest infestations due to their high activities (Lapidot *et al.*, 2001) besides unfavorable growth conditions. Some of the notable insect pest of this crop identified include leafminers (*Lyriomyza* sp.), cotton bollworms (*Helicoverpa armigera* Hubner), onion thrips (*Thrips tabaci* Lindeman), mites (*Tetranychus* sp.), whiteflies (*Bemisia tabaci* Gennadius), russet mites (*Aculops lycopersici* Massee) (Acari: Eriophyidae), aphids (*Aphis* sp.) (Tumwine *et al.,* 2002), the tomato leafminer, (*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Biondi *et al.*, 2015) among many others. Besides direct damage to the crop, some of these pests have been associated with transmission of other pathogens. Members of the *B.tabaci* group have been associated with both direct and indirect damage caused by feeding directly on tomato plants, sucking sap from the phloem resulting in leaf and fruit spotting, weakening of plants and irregular fruit ripening (Abate *et al.,* 2000). In addition, it has been associated with transmission of over 100 begomoviruses that have catastrophic impact on plant growth and survival (De Barro *et al.,* 2011). For instance tomato yellow leaf curl virus (TYLCV), a complex of geminivirus that infect tomato crop worldwide (Berlinger, 1986) is solely transmitted by the *B. tabaci* (Attathom *et al.,*1990., Sawangjit *et al.,* 2005) and stands out to be a major constraint to tomato growers with huge crop losses being experienced. Desneux *et al.* (2010) also reported that tomato leafminer could cause yield losses of between 80-100% in the absence of control strategies and attributed this loss to attacks on the leaves, flowers, stems, and fruits at any developmental stage, from seedlings to mature plants.

Pesticides have long been used to control pests and disease in agricultural fields (Zhang *et al.,* 2011) in order to enable growers to produce high fruit yields and quality as well as meet the stringent standards of the industry. Pests have mostly been managed through treating fields with large quantities of pesticides (Aktar *et al.,* 2009) that has consistently caused increase in crop loss (Dhaliwal and Koul, 2010) besides harming non-target living organisms (Cork *et al*., 2003). Degri and Mailafiya (2013) reported the use of insecticides as a major control measure for tomato fruit borer in Nigeria which is not only an environmental and health hazard but also costly for the growers. On the other hand, these pests continuously develop resistance to many commonly used synthetic sprays (Siqueira *et al*., 2001; Haddi *et al*., 2012; Roditakis *et al*., 2015). Proper methods of insect pests management are therefore needed as suggested by Gupta *et al*. (2004) that integrate proven methods of pest control against the target pests hence replacing insecticides to which the pests had developed resistance leading to reduction in the number of sprays and increase in yield (Grewal *et al.*, 2011; Ahuja, *et al.*, 2012).

2.4 Effects of Net Covers on Insect Pest Infestation and Crop Damage

The use of net covers to protect plants against insect pest invasion is a common strategy among vegetable growers in many developed countries. The screens act as physical barrier preventing migratory insects from reaching the plants, and thus reduce the incidence of direct crop damage and of insect-transmitted viral diseases (Teitel *et al*., 2008). A reduced insect pest incidence under screen nets lowers the indiscriminate application of insecticide by small-scale farmers. Documented advantages of such an approach include protection of human health by reducing insecticide sprays, reducing environmental pollution from insecticide residues and increasing the effectiveness of crop protection (Licciardi *et al*., 2007).

In many parts of the world, physical barriers have been used in horticulture as reliable and efficient mechanism to protect tomato cultivations and nurseries from several key insect pests such as whiteflies, thrips, aphids and tomato leafminers (Castellano *et al.*, 2008; Harbi *et al.*, 2012). Gogo *et al*. (2014) reported the use of floating row covers (FRCs) as effective pest management tool against various insect pests of tomato, including aphids, whiteflies, and their related pathogens. In Spanish tomato production systems, exclusion netting strategies have been used to reduce populations of the whitefly and the risk of viruses for which they vector (Stansly *et al*., 2004). Likewise, in Africa, mobile net houses made of mosquito nets were found effective as physical barriers against the diamondback moth (*Plutella xylostella* L.), cutworms (*Agrotis sp*), and cabbage loopers (*Trichoplusia ni* Hubner) providing 66 to 97% control of moths and caterpillars (Martin *et al*., 2006).

Licciardi *et al*. (2007) conducted two trials to test the ability of screened tunnels to protect brassicas against the diamondback moth, aphids (*Lipaphis erysimi* Kaltenbach) and borer (*Hellula undalis* Fabricius) in Cotonou, Benin, West Africa. From their works, they observed that the number of diamondback moth and borers on cabbage protected with tunnel screens was significantly lower than the plots conventionally treated with insecticides. However, the tunnel screens were not effective against the armyworm (*Spodoptera littoralis* Boisduval) which laid eggs on the screen. Aphid populations were also not effectively controlled under the temporary tunnel screens but tunnel screens impregnated with deltamethrin protected young plants in seedling nurseries against infestation by the aphids.

Elsewhere in Germany, working on low-flying dipteran pests, such as the cabbage maggot fly (*Delia radicum* L.), the onion maggot fly (*D. antiqua* Meigen), the seed corn maggot fly (*D. Platura L*) and the carrot rust fly (*Psila rosae* F.), Vernon (2003) showed that these pests could be impeded from entering their host crops through erecting screen fences around the field perimeters. Exclusion fences 0.9 m high with downward-sloping screen overhangs about 25cm long prevented more than 80% of female cabbage fly from entering enclosed plantings of rutabaga with associated maggot damage significantly reduced relative to unfenced controls. Likewise, in France, Sauphanor *et al*. (2012) investigated the use of exclusion netting Alt'carpo against the false codling moth (*Cydia pomonella* L) and demonstrated that exclusion netting had high potential application in preventing codling moth attacks and significantly reduced the densities of codling moth and leaf rollers (*Epiphyas postvittana*) on apple orchards.

Further work done by Berlinger *et al*. (2002) both in the laboratory and open field in Israel aimed at studying the effectiveness of insect screen nets against whitefly which vectored the Tomato Yellow Leaf Curl Virus (TYLCV) on tomato revealed that the screen materials used were effective against the whitefly. Other insects included western flower thrips (*Frankliniella occidentalis* Pergande), onion thrips *(Thrips tabaci* Lindeman), melon and cotton aphids (*Aphis gossypi* Glover), peach-potato aphid *(Myzus persicae* Sulzers), and leaf miners (*Liriomyza brassicae* Riley) in addition to leafhoppers of genus *Empoasca* and unidentified psyllids (*Trioza sp*). Similar results were obtained in China by Feng-cheng *et al*. (2010) who demonstrated a 90% reduction in the occurrence of tomato yellow leaf curl virus due to the near elimination of whiteflies under a 50-mesh net house.

Working with white eco-friendly agronets as physical barriers on cabbage seedling production in Kenya, Muleke *et al*. (2013) observed a significant reduction on populations of leafminers on cabbage seedlings and attributed the effect to the brightness of the nets which could have served as a visual barrier, besides the physical barrier benefit provided by the net. Similarly, in a tunnel experiment on cauliflower in the Philippines, Palada and Ali (2007) reported a reduction of insect populations under tunnels roofed with nets by 80% with marketable yields obtained being 1.5 to 2.0 times higher than in the open field. Likewise, growing head cabbage under net tunnels in the Solomon Islands reduced insect incidence by 38-72%, and resulted in significantly higher economic returns (Neave *et al*., 2011).

Gogo *et al*. (2012) reported a considerable reduction in the populations of leafminers (*Liriomyza sp*), cotton bollworm (*Helicoverpa sp*), onion thrips (*Thrips tabaci*), mites (*Tetranychus sp*), silverleaf whitefly (*Bemisia tabaci)* and aphids (*Aphis sp*). Elsewhere, in Bangladesh, Khorsheduzzaman *et al*. (2010) evaluated the use of mosquito net barrier on sweet gourd seedling beds alongside other approaches such as chemical, mechanical, and botanicals against red pumpkin beetle (*Aulacophora foveicollis* Lucas). Among six treatments evaluated, results indicated that seedling beds of sweet gourd covered with mosquito net barrier upto 45 days before planting were most effective and provided 97.59 and 100% protection against the red pumpkin beetle with higher benefit cost ratio of 21.99 compared to 9.74 with Furadan 5G applied in the soil and 4.35 using neem seed oil for the average of two years applied against red pumpkin beetle.

2.5 Other Benefits Associated with Use of Net covers in Crop Production

Apart from pest control, the use of net covers in crop production has been shown to come along with many other benefits. The modification of environmental factors associated with better plant growth through enhanced leaf characteristics, biomass accumulation, and relative growth rate are among the benefits obtained from use of netting covers (Martin *et al*., 2006). Besides, benefits like regulation of air temperature by use of screen nets has been observed to reduce crop stresses associated with temperature that cause significant effects on crop development and the subsequent yield (Kittas *et al.*, 2012). Alterations in microclimate occur in protected environments that can affect the production and partitioning of photo-assimilates in plants and consequently, the composition of the produce (Bakker, 1995).

Documented evidence from many parts of the world show that netting has frequently been used to protect agricultural crops from excessive solar radiation (Ilić *et al*., 2012), improve the thermal climate (Kittas *et al.*, 2009), shelter the crop from wind and hail stones, apart from exclusion of birds, insects and insect-transmitted virus diseases (Teitel *et al*., 2008; Shahak, 2008). The shading effect of the nets used on crops has been shown to result in a number of changes on both the local microclimate and crop activity. In Serbia, for instance, use of shading nets is considered a popular practice in shading crops against the very high temperatures during the summer season which often range between 35- 40 °C. This makes the use of nets an important tool in the manipulation of plant morphology and physiology, an exercise that has been undertaken for a long period of time particularly under greenhouse environments (Wilson and Rajapakse, 2001). Under such warm climatic condition, Smith *et al*. (1984) observed that the air temperature was lower where shading nets were used than that of the ambient air with the level of decrease being dependent on the shading intensity. Such a benefit can be achieved cheaply through simple mechanism of deploying shade nets over crops to reduce heat stress (Elad *et al*., 2007; Retamales *et al*., 2008). Alternatively the netting can be applied over net-house constructions, or combined with greenhouse technologies (Shahak *et al*., 2004). In Riyadh state of Saudi Arabia, Mawgoud- Abdel *et al*. (1994) demonstrated that air and leaf temperatures under shade net conditions were lower by an average of 2 °C than that of the open field during day time and higher by 3 °C under shade conditions than of the open field during the night.

On the contrary in cooler climates, Stamps (1994) and Pe´rez *et al*. (2006) observed that in enclosed net (shade) houses, temperatures during the day were typically higher than outside and lower at night. Likewise, relative humidity under netting was higher than outside. This phenomenon was explained to occur as a result of water vapor being transpired by the crop and reduced mixing with drier air outside the netted area even when temperatures under the netting were higher than outside. Similar findings were obtained by Gogo *et al*. (2012) who noted that the mean daily temperature and relative humidity were significantly higher under the netting treatment compared with the non-covered control thus advancing tomato seedling emergence by at least 2 days. The daily average temperature obtained was 26.8 °C under net and 23.3 °C in control treatments (open field). Relative humidity was recorded at 58.2% under the netting compared to 52.7% for the control translating to an increase of temperature and relative humidity of 14.8% and 10.4%, respectively which led to enhanced seedling growth.

Measuring environmental and crop growth parameters under netting in low-chill stone fruit and under conventional bird and bat netting, Lloyd *et al*. (2004) established that netting increased maximum temperatures by 4.4 °C and decreased minimum temperatures by 0.5 °C. Although exclusion netting reduced irradiance by approximately 20%, the higher temperatures recorded under netting enhanced fruit development by 7-10 days and improved fruit quality by increasing sugar concentration by 20-30% and colour intensity by 20%. Contrary findings on temperature were reported by Licciardi *et al*. (2007) in Benin who pointed out that the use of a tunnel screen did not cause significant changes in temperature and relative humidity (RH) between 1700 and 0900 h with mean of 25.6 ± 0.28 °C and 98.9% ± 0.4% RH recorded, respectively. During the rest of the daytime, however, RH was found to be 8% higher under the tunnel screen compared with the no-tunnel control with 75.3 ± 3.1% and 67.4 ± 3.4% RH, respectively. Temperatures within the screen treatment was 33.3 ± 0.78 °C and the control 35.5 ± 0.98 °C registering no significant difference.

Agronet covers have also been found to not only decrease light quantity but also alter light quality to varying extent. Research results have shown that high light intensity can lead to disorders in the development and appearance of tomato fruit (Dorais *et al*., 2001). Heinze and Borthwick (1952) noted that light during ripening has considerable effect on the carotenoid content on the skins of tomato fruits and also influences the colour of the outer wall of the epidermal cells. Sunscald injury and uneven ripening are two disorders brought on by direct effects of light on fruits. Adegoroye and Jolliffe (1987) observed that sunscald injury of tomato fruit increased with irradiance and air temperature and their combined effects which are a common phenomenon with tomato grown in open field.

Wong (1994) pointed out that any shade netting can scatter radiation, especially ultraviolet because netting is usually made using ultraviolet-resistant plastic. Modification of sunlight through the use of nets has therefore been used as a way of improving the plants' microclimate through modifying the spectrum (in the visible, and/or Ultra Violet (UV), Far Red (FR) or Infra-Red (IR) regions) of the incident radiation, and at the same time enriching the relative content of scattered light (Nissim-Levi *et al*., 2008) . Spectral manipulation of light tends to influence physiological responses within plants whereas light scattering improves light penetration into the plant canopy (Shahak *et al*., 2004). Further, diffuse light has been shown to increase radiation use efficiency, yields (both at the plant and ecosystem level), and also serve as a factor affecting plant flowering in terms of timing and amounts (Sinclair *et al*., 1992; Guenter *et al*., 2008).

Changes on the local microclimate modify CO_2 assimilation and consequently crop growth and development (Kittas *et al*., 2012). In a study carried out by Waterer *et al*. (2002) to investigate how net coverings around a crop influence concentration of the surrounding air; it was established that CO_2 levels in the tunnels varied with the time of day. At mid-day, CO_2 levels were well below ambient levels only to build up later during the day. This reflected on the photosynthetic activity of the plants within the confines of the tunnels. By contrast, at night, CO_2

levels in the tunnels were well above ambient reflecting the tunnel materials' ability to trap the CO_2 generated by respiration of the plants and soil micro-organisms at night. The extent of the diurnal fluctuation in CO_2 levels depended on the porosity of the covering material used with the fluctuation being more noticeable when the tunnels were constructed of non-perforated clear polyethylene than when constructed of the more porous woven materials.

In other areas where frost damage is prevalent, Teitel *et al*. (1995) demonstrated that shading screens stretched horizontally above the ground were effective in reducing the risk of frost damage. The screens reduced the net amount of long- wave radiation from the ground to the sky during the night and thus kept the plants under the screens at higher temperature than the ambient air.

2.6 Effects of Net Covers on Crop Yield and Quality

The general composition, yield and quality of many crops can be affected by the growth environment. Variations in environmental stresses contribute to variations in crop yields year to year throughout the world. Such stresses have been associated with most common disorders occurring in crop plants such as tip burn in lettuce which has been associated with high temperature as well as cat face in tomato caused by poor pollination resulting from low temperature (Kalloo, 1986), blossom end rot and cracked skin (Lorenzo *et al*., 2003), sunscald injury and uneven ripening which are all caused by abiotic stresses such as increased irradiance, air temperature and their combined effects (Adegoroye and Jolliffe, 1987) as well as high light intensity effects (Dorais *et al*., 2001) among many others disorders.

Vegetable quality for fresh consumption is determined by appearance (colour, shape, size, freedom from physiological disorders and decay), firmness, texture, dry matter and organoleptic (flavor) and neutraceptic (health benefit) properties (Dorais *et al*., 2001). These quality parameters have often been found to be extensively affected by both environmental factors such as light, temperature and agronomic techniques used in open field or tunnel production (Dumas *et al*., 2003). When tomato is exposed to direct solar radiation as is the case in open field production, such qualities as titratable acidity, total soluble solids, sugar to acid ratio among others are interfered with giving rise to fruits with reduced or unacceptable market value. Milenković *et al.* (2012) reported that in an exposed fruit, the temperature may rise by 10°C or more above the ambient. When the temperature of such an exposed fruit portion exceeds

40 °C especially at the green-mature stage, the affected position may become white and sunken (sunscald or sunburn) resulting to loss of market value and income to the growers.

Shading nets have been used extensively in the amelioration of such heat stresses in vegetable crops (Diaz-Perez, 2013). Net houses and its variants have been used in some European, South American and Southeast Asian countries for producing egg plants (Kaur *et al*., 2004), leafy greens (Talekar *et al*., 2003) and cabbage in West Africa (Martin *et al*., 2006). In all these studies, the use of net covers has shown success in the improvement of growth, yield and quality of most crops. Talekar *et al*. (2003) demonstrated that 15 cycles of various leafy vegetables could be produced free of any pesticide use without any resultant loss in yield or quality over a two-year period under nets. In addition to leafy vegetables, tomato, eggplant, cauliflower, broccoli, yard-long bean, and bitter gourd have also been successfully grown in net houses.

Rylski and Spigelman (1986) working on sweet pepper (*Capsicum annuum*) showed that under field conditions during the summer where day temperatures were ≥32 °C, fruit set was reduced. A reduction in radiation by approximately 26% under shade net had a significant impact and increased production in sweet pepper compared with exposure to full sunlight. In Spain, Adams *et al*. (2001) noted that the use of mobile shade net applied under intense sunlight resulted in an increase of marketable yield by 10% compared to full exposure to sunlight. On the other hand, Gent (2007) working with nets of different shading intensities noted that total yield decreased linearly with increasing shade, though he reported no significant difference among shade treatments in marketable yield.

Caliman *et al*. (2010) studied the effect of shading on TSS/TA ratios of tomato fruit in the Southern part of Serbia (Aleksinac). Different colour shade nets were used while full sunlight exposure was used as control. From this work, it was pointed out that fruits produced in the open field had greater titratable acidity (0.37% citric acid) and were more acidic compared to fruits in protected environment (0.24% citric acid). Field grown fruits were also found to have greater total soluble solids (TSS) content (5.42° Brix) than those in protected environment (5.10° Brix). Significantly higher lycopene content was observed in protected environment than in open field.

In a study by Milenkovic *et al*. (2012) aimed at evaluating the influence of different shade nets on yields and physiological disorders on open field tomato production in the Southern part of Serbia (Aleksinac), a reduction in appearance of tomato cracking by about 50% and elimination of sunscald on tomato fruits under shade nets was observed. Marketable tomato fruits increased by 35% under shade nets compared to non-shading condition. The reduced total and marketable yields of un-shaded plants in this study was attributed to high heat stress. Further, Seekar and Hochmuth (1994) reported higher marketable yield of sweet pepper (4.62 kg m^{-2}) under plastic cover compared to 3.40 kg m^{-2} in the open field. Similar observations were made by Buoczlowska (1990) who reported an early harvesting under net cover compared to open field and higher total yields under net covered plants at 98.00 t ha^{-1} compared to the open field's 68.00 t ha^{-1}.

2.7 Effects of Companion Planting on Pest Infestation

Extensive research work done has provided sufficient evidence that insect pests cause a lot of damage to almost all cultivated crops which leads to enormous reduction in the ultimate yield, quality and market value of crops consequently cutting down on farmers income. A wide range of documented literature indicates that higher plants harbor numerous compounds which provide them with resistance to pathogenic organisms. Using such advantages in a vegetational diversity in the ecosystem can enhance system stability and decrease the incidences of major insect pest outbreaks observed in monoculture systems (Altieri and Letourneau, 1982; Andow, 1991). Such a reduction on pest incidences under diversified vegetational mix may be attributed to chemical repellency, masking effect from the mix and /or emigration leading to decreased colonization of pests among several other factors (Matteson *et al*., 1984). The array of colors, aromas and ripening time causes camouflage of odor and appearance often confusing plant pests in search of a suitable host.

Companion planting has been viewed as a good source for creating vegetational diversity and is considered one of the sustainable pest management strategies in which case, crops with repellent properties or masking volatiles that disrupt insect pest–host finding behavior have been used (Ratnadnass *et al*., 2011). Companion plants control insect pests either directly, by discouraging pest establishment, and indirectly, by attracting natural enemies that can kill the pest. The non-host plant disrupts the behavior of the insect pest leading to a reduction in host-plant suitability for oviposition by the insect pest (Finch and Collier, 2000). Some plants for instance, tomato is known to contain numerous defense mechanisms that are effective against insect pests, such as glandular trichomes (Simmons *et al*., 2005), synthesis of allelochemicals

(Carter *et al*., 1989), expression of enzymes such as proteinase inhibitors (Howe *et al*., 1996) and polyphenol oxidase (Thaler, 1999) making them ideal against certain pests.

Different companion planting methods have been combined to work synergistically and improve pest control. Such companion plants are grown as either ‘trap crops’, ‘barrier crops’or ‘intercrops’ among other forms used to reduce insect infestations while providing a refuge for beneficial insects. Trap cropping on one hand refers to planting of crops with the main crop to attract, intercept, retain and/or reduce targeted insects or the pathogens they vector hence reducing damage to the main crop (Shelton and Badenes-Perez, 2006). Intercrops which refer to two or more crops grown simultaneously in the same field, on the other hand encourage natural enemies’ population build-up as well as offering greater total land productivity as expressed by land equivalent ratio (Songa *et al.*, 2007). In actual sense, intercropping increases crop diversity while at the same time modifying the insects’ habitat and further causes interference with the insects’ identification of, and responses to its host plant (Tahvanainen and Root, 1972) leading to a reduction in insect pest incidence and damage compared with monocropping (Ofuya, 1991; Pitan and Odebiyi, 2001; Pitan *et al*., 2002).

Barrier crops have also been used traditionally as companion plants to obstruct flight direction and landing location of pests hence rendering host plants less apparent. When used as companion plants, barrier crops may visually or physically obstruct host plant location rendering host plants less apparent. For instance, several tall-growing non-host plants have been used as companion plant barriers and found effective in reducing the spread and transmission of insect vectored viruses (Toba *et al*., 1977). Morales *et al*. (1993) reported that a sorghum (*Sorghum bicolor* (L.) Moench) barrier reduced whitefly densities and transmission of Tomato Yellow Leaf Curl Virus (TYLCV) on tomato. On the other hand, Pearl millet (*Pennisetum typhoides* Burm.) and Hubbard squash (*Cucurbita maxima.*) barrier reduced whitefly virus transmission on cowpea (*Vigna unguiculata* (L.) Walp) (Sharma and Varma, 1984) and on soybean (*Glycine max* (L.) Merrill) (Rataul *et al*., 1989).

Finch *et al*. (2003) observed that non- host plants disrupted the host plant finding ability of cabbage root fly (*Delia radicum* L.) with the least number of eggs (18%) laid on host plants surrounded by goosefoot (*Chenopodium album* L.) weed and most eggs (64%) laid on host plants surrounded by the weed fumaria (*Fumaria officinalis* L). For the onion fly (*Delia antique* (Meig), the most disruption with only 8% of eggs laid was found on green-leaved variant of the bedding plant zonal geranium (*Pelargonium× hortorum* L. H. Bailey) and least disruption (57%) was observed on the aromatic plant sweet mint (*Mentha piperita × citrata* (Ehrh) Brig). Reddish foliage plants were found to be less disruptive than cultivars with green foliage. Also observed was the differences on the behavior of the flies where those that landed on a host plant searched the leaf surface in a relaxed manner whereas those that landed on a non –host plant remained more or less motionless.

Trap crops used in companion cropping lure pests away from the main crop and thus protecting it from attack (Michaud *et al*., 2007; Shelton *et al*., 2008). The principle of trap cropping relies on combining plants in such a way that they occupy different ecological niches. Such crops will either produce organic compounds that attract insects for pollination and repel destructive insect pests. Different cultivars have been found to produce varying degrees of unique volatiles allowing some species and cultivars to repel insect pests more strongly than others thus making them ideal for selection as trap crops. Many studies indicate that trap crops have been used successfully to manipulate the behavior of herbivores and reduce pest pressure (Hartwig, 2002; Gbèhounou and Adango, 2003). Castor (*Ricinus communis*) has been considered as a suitable host plant (Balasubramanian *et al*., 1984) leading to speculation that it might be used as a trap crop to attract and destroy army worm (*Spodoptera litura*).

Repellence properties of companion crops were studied by Legaspi *et al*. (2011) who worked on three varieties (giant red, tender green and ragged leaf) of mustard (*Brassica juncea* (L) Czern) as possible repellent companion crops for collards (*Brassica oleraceae* var. *acephala* de Condolle) against the silver leaf whitefly (*Bemisia argentifolii*). In their work, they observed that remarkably higher numbers of whitefly landed on leaves of collards than of any of the mustards even when mustards were grouped together as companion crops. Further analysis on egg count showed oviposition preference for collards by the whitefly as compared to any of the mustard varieties.

Plants with aromatic qualities have been known to contain volatile oils that may interfere with host plant location, feeding, distribution and mating, resulting in decreased pest abundance (Lu *et al*., 2007). Herbs such as basil (*Ocimum basilicum* L.) planted with tomato have been recorded to repel thrips (Anon, 2004a) and tomato hornworms (Anon, 2004b). Plants in the genus *Allium* (onion) have been observed to exhibit repellent properties against a variety of insects and other arthropods including moths (Landolt *et al*., 1999), cockroaches (Scheffler and

Dombrowski, 1993), mites (Dabrowski and Seredynska, 2007) and aphids (Amarawardana *et al*., 2007). Aromatic plants produce essential oils that contain highly volatile compounds with low persistence (Papachristos and Stamopoulos, 2002; Park *et al*., 2003) thus making them ecologically acceptable. Dubey *et al.* (2010) observed that some aromatic plants contain certain components which tend to show chemosterilant activity that cause complete inhibition of ovarian development of different insects. Such products have been employed in integrated pest management programmes to limit the chances of physiological development by insects. However, the response to a repellent plant may vary depending on the behavior of the insect and the plant involved. As a result, a repellent plant that can be effective for one pest might not provide effective control for another (Poveda *et al*., 2008).

Work done on cotton (*Gossypium barbadense* L.) intercropped with putative repellent basil (*Ocimum basilicum*) to evaluate basils effect on pest infestation, yield and economical parameters revealed reduction in the total pest infestation with a 50 % reduction in pink bollworm (*Pectinophora gossypiella* (Saunders)) compared to the non-intercropped plots (Schader *et al*., 2005). Further, Roxas (2009) found that intercropping pechay (*Brassica pekinensis*) with basil reduced flea beetle (*Phyllotreta striolata*) population numbers. In a similar experiment, molasses grass (*Melinis minutiflora* (Beauv)) was found to produce volatiles that deterred oviposition against spotted stem borer (*Chilo partellus* (Swinhoe)) in maize intercrop (Kimani *et al*., 2000). On the contrary, the use of companion crops rue (*Ruta graveolens* L.), zonal geranium (*Pelargonium* × *hortorum* (Bailey)) and chives (*Allium scheonparum* L) to protect rose plant (*Rosa* × *hybrid* “Ultimate Pink”) against Japanese beetle (*Papillia japonica* (Newman)) showed no reasonable decrease in number of Japanese beetles on roses compared to the control (Held *et al*., 2003).

In Southeast Asia (Thailand), Kianmatee and Ranamukhaarachchi (2007) indicated that Chinese cabbage (*Brassica rapa* subsp *pekinensis*) associated with sacred basil had the lowest number of both flea beetle (*Phyllotreta sinuate* Steph) and cabbage webworm (*Hellula undalis* Fabricius) while citronella grass had the lowest number of common cutworm (*Spodoptera litura* Fabricius). The lowest pest damage and highest quality of yield were in plots associated with sacred basil at 29.6 tha^{-1} compared to 21.8 tha^{-1} in plots associated with coriander (*Corriandrum sativum* L).

2.7 Effects of Companion Planting on Crop Yield and Quality

Interplanting of crops by smallholder and peasant farmers is a common practice undertaken in the sub-tropics and tropical regions with an aim of increasing the net income obtained per unit area (Kizilsimsek and Erol, 2000). Besides, other benefits linked to the practice of growing two or more crops on the same piece of land include enhanced ecosystem productivity (Wiley, 1979), an environment-friendly pest management strategy (Mitchell *et al*., 2002), enhanced nutrients availability to plants (Houggaard-Nielsen *et al*., 2001), weeds management (Midmore, 1993), provision of better produce quality (Anil *et al*., 1998) as well as cushioning farmers against crop failure (Ofori and Stern, 1987). Research has shown that many plants grow better when grown near others and in turn exhibit efficient utilization of available resources to generate high and stable yields with lower inputs requirement (Feike *et al*., 2010). Taking the 'Three sisters' ancient practice of companion cropping applied by many native American tribes throughout North America comprising of growing corn, squash and beans together on the same field as an example, the practice proved that these crops could thrive well together and provide high yield and high quality with minimal environmental impact. From the mix, it was observed that corn offered a structure for the beans to attach and climb, the beans in turn helped to replenish the soil with nutrients and finally the large leaves of squash provided living mulch that conserved water and provided weed control giving rise to high yield (Jane, 2006).

Traditionally, companion cropping with perennial legumes was deemed an effective method of agricultural crop production specifically in forage production and it was associated with stable and high yield, reduced weed competition, and increased protein content within a mixed diet and higher land-use efficiency (Anil *et al*., 1998). However, not all intercrops offer increased yield. Houggaard-Nielsen *et al*. (2001) reported that in a cereal-legume intercrop system, there was often a marked increase in cereal yield and a decrease in legume intercrop yield noting that cereals generally have much greater rooting densities making them more competitive with respect to uptake of nutrients from the rhizosphere. Studies done to evaluate the effect of companion planting on yields and quality of various crops have come up with varying result with respect to components that constitute yield of a crop. Guvenc and Yildirim (2006) observed that when cabbage was intercropped with radish, some growth features such as leaf number, head diameter, head height and yield of cabbage were adversely affected.

Ogol and Makatiani (2007) conducted studies at different sites in Kenya to explore how the use of companion vegetable crops as either trap or repellent crops faired in the management of diamondback moth (DBM) on cabbage and kale and their subsequent effect on the marketable yield. In terms of marketable yield, tomato offered best repellent for DBM in both cabbage and kale intercrops resulting in higher and better quality marketable yield.

In Ethiopia, Agegnehu *et al*. (2006) compared the performance of mixed intercrop of teff (*Eragrostis tef*) with faba bean (*Vicia faba*) in comparison to sole cropping. They were able to report significant effect in all intercrop treatments for seed and biomass yield of each crop species. Increasing the seed rate of faba bean in teff/faba bean mixture increased faba bean seed yield but decreased teff grain yield. Overall, they observed that mixed cropping of faba bean with teff increased Land Use Efficiency and gave higher total yield compared to growing either species in sole culture.

Nyasani *et al*. (2011) conducted an experiment at the Kenya Agricultural Research Institute (KARI) Embu, Kenya to determine thrips species composition, population density and damage on French-bean planted as a sole crop or as an intercrop with either sunflower, Irish potato, or baby corn, in various combinations within 2 growing seasons. Results of the study showed that the percentage of pods that could be rejected in the market due to thrips damage was highest on monocrop French-bean plots (68% and 63%) and lowest on plots with French-bean intercropped with baby corn (35% and 37%) in the first and second seasons, respectively. In conclusion they observed that intercropping French bean with other crops compromised on French-bean yield but reduced damage to the French-bean pods, thereby enhancing marketable yield.

CHAPTER THREE

3.0 METERIALS AND METHODS

3.1 Experimental Site Description

Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Njoro. The field lies at a latitude of 0º 23′ South, longitudes 35º 35′ East in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of approximately 2,238 meters above sea level with a mean annual rainfall of 1000mm. The soils are predominantly well drained sandy-vintric mollic andosols (Jaetzold and Schmidt, 2006). Weekly mean temperature and relative humidity of the site during the study period are shown in Fig. 1.

3.2 Planting Material

The planting material used in the study was tomato seedlings 'Rio Grande' planted either in companion with basil or grown as a monocrop. Rio Grande is a determinate tomato cultivar with a high yielding potential thus preferred by many farmers. Seeds used to raise the tomato seedlings were obtained from Simlaws Seed Company in Nakuru (Kenya) and established in a nursery for 6 weeks before transplanting. Basil (*Ocimum basilicum* L.) variety "Bonanza" seeds were obtained from Amiran Kenya Limited, Nairobi. Basil is a perennial herb planted as an annual in tropical climates. The choice of basil as a companion crop was made due to its tolerance to warm tropical climate and the characteristic strong smell of the essential oils that it contains.

3.3 Experimental Design and Treatments Application

The experimental design used in the field study was Randomized Complete Block Design (RCBD) with five replications. There were six treatments consisting of: i) tomato under agronet cover with 1 row basil surrounding outside of the agronet cover, ii) tomato under agronet cover with a row of basil in between adjacent rows of tomato iii) tomato under agronet cover with no companion basil, iv) tomato without agronet cover but with 1 row of basil surrounding the crop, v) tomato without agronet cover but with a row of basil in between adjacent rows of tomato crop and vi) tomato with no agronet cover or companion basil (control).

Equal number of basil plants were used per treatment spaced 30cm apart. The average pore diameter of the net covering material used was 0.4mm to allow for gaseous movement.

Each experimental plot measured 3m by 5m. Individual blocks measured 32.5m x 3m separated from each other by 1 m buffer while plots within the blocks were separated by 0.5m path (Fig. 2). Four posts, 1.2 m long were used to support the net in net covered plots where one post was placed at each corner and sisal twine and binding wire used to join the posts and also to support the crop.

Completely Randomized Design (CRD) was used for the tomato post-harvest quality determination experiment in the laboratory. The laboratory experiment had six treatments replications three times giving a total of eighteen (18) experimental units (Fig. 3). The treatments consisted of i) tomato under agronet cover with 1 row basil surrounding outside of the agronet cover, ii) tomato under agronet cover with a row of basil in between adjacent rows of tomato iii) tomato under agronet cover with no companion basil, iv) tomato without agronet cover but with 1 row of basil surrounding the crop, v) tomato without agronet cover but with a row of basil in between adjacent rows of tomato crop and vi) tomato with no agronet cover or companion basil (control). Each experimental unit comprised of twenty four (24) tomato fruits randomly selected from the harvest of the individual respective treatments in the field experiment.

3.4 Crop Establishment and Maintenance

Land used for the field experiment was manually prepared using hoes and garden rakes to obtain a medium tilth. Transplanting holes were then manually dug using hoes and Diammonium phosphate (DAP) fertilizer applied at the rate of 240 Kg ha^{-1} (approx. 10g per hole) (HCDA, 2006) and thoroughly mixed with the soil prior to transplanting. Tomato seedlings were transplanted in four rows in each experimental unit at spacing of 80 cm between rows and 50 cm within the row giving a total of forty plants per plot. Basil was drilled as per the treatments at the same time with the sowing of tomato seeds in the nursery so as to have them (basil) well established by the time of transplanting tomato seedlings. Thinning of the basil seedlings was done when the plants were about 5 cm tall to a spacing of 30 cm between plants. Thereafter, all other agronomic and maintenance practices including gapping, watering, weeding, top-dressing among others was uniformly done on all treatments following the technical recommendations for the respective crops. Yellow sticky traps (Horivers) obtained from Koppert Biological Systems (K) Ltd were mounted at the center of each experimental unit one week after transplanting for monitoring of the whitefly.

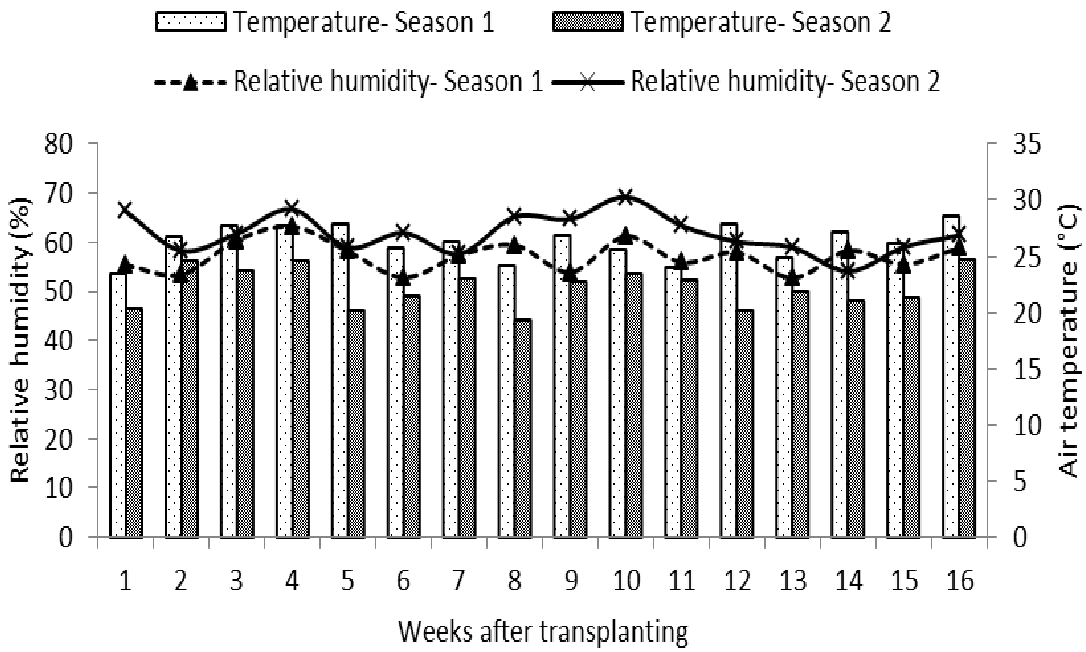


Fig 1. Temperature and relative humidity conditions during open field tomato production in season 1 (Dec 2013-Apr 2014), and Season 2 (May 2014-Sept 2014)**.**

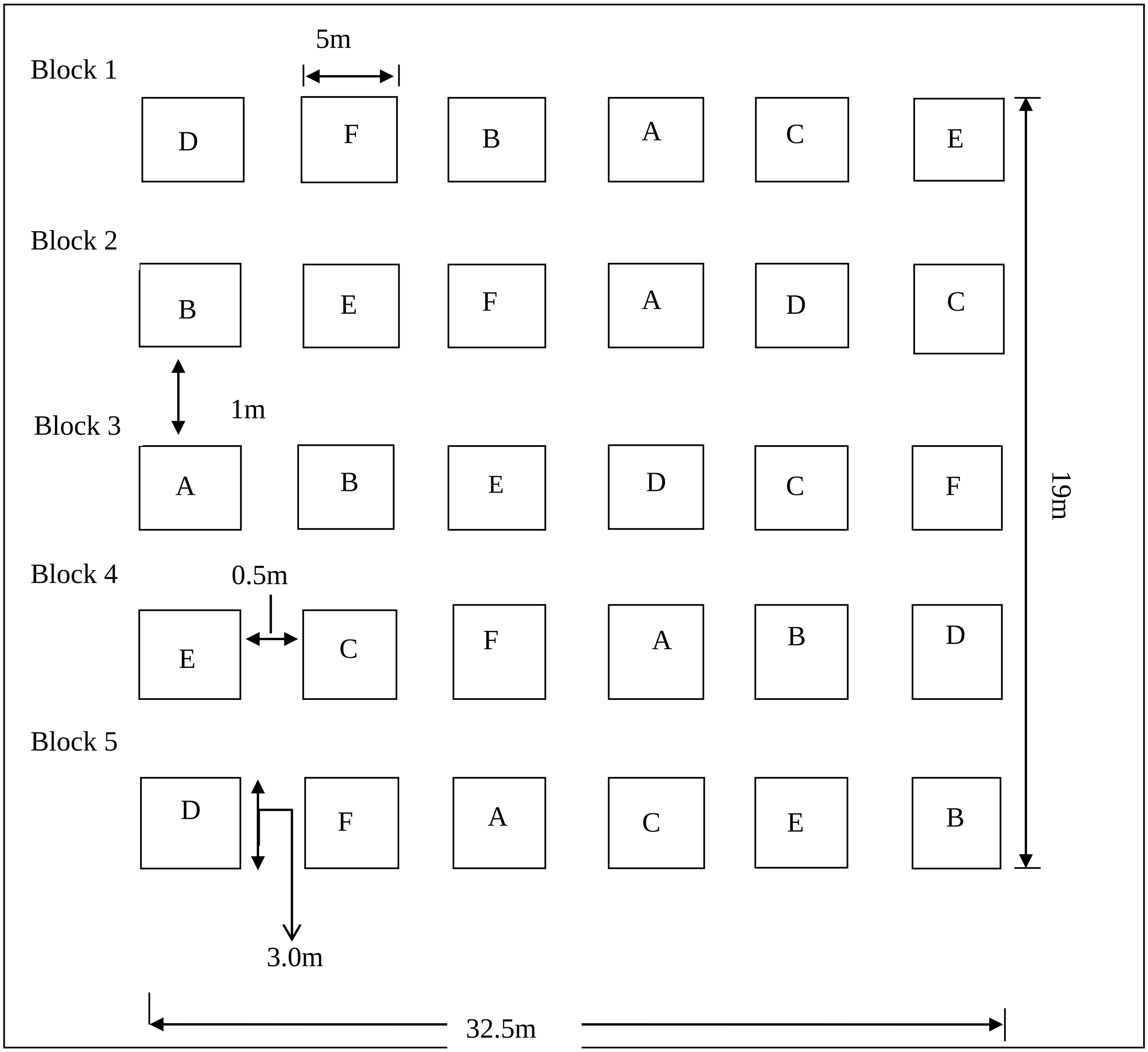


Fig 2. The experimental field layout for open field tomato production

KEY: **A** – Tomato produced under net with basil surrounding the outside of the net cover (T+N+BB), **B** – Tomato produced under net with basil in between adjacent rows of the crop (T+N+BI), **C** - Tomato produced under net with no companion basil (T+N), **D** - Tomato produced without a net cover with basil surrounding the crop (T+BB), **E** - Tomato produced without a net cover with basil in between adjacent rows of the crop (T+BI), **F** - Tomato produced without net cover or basil (TC) (control).

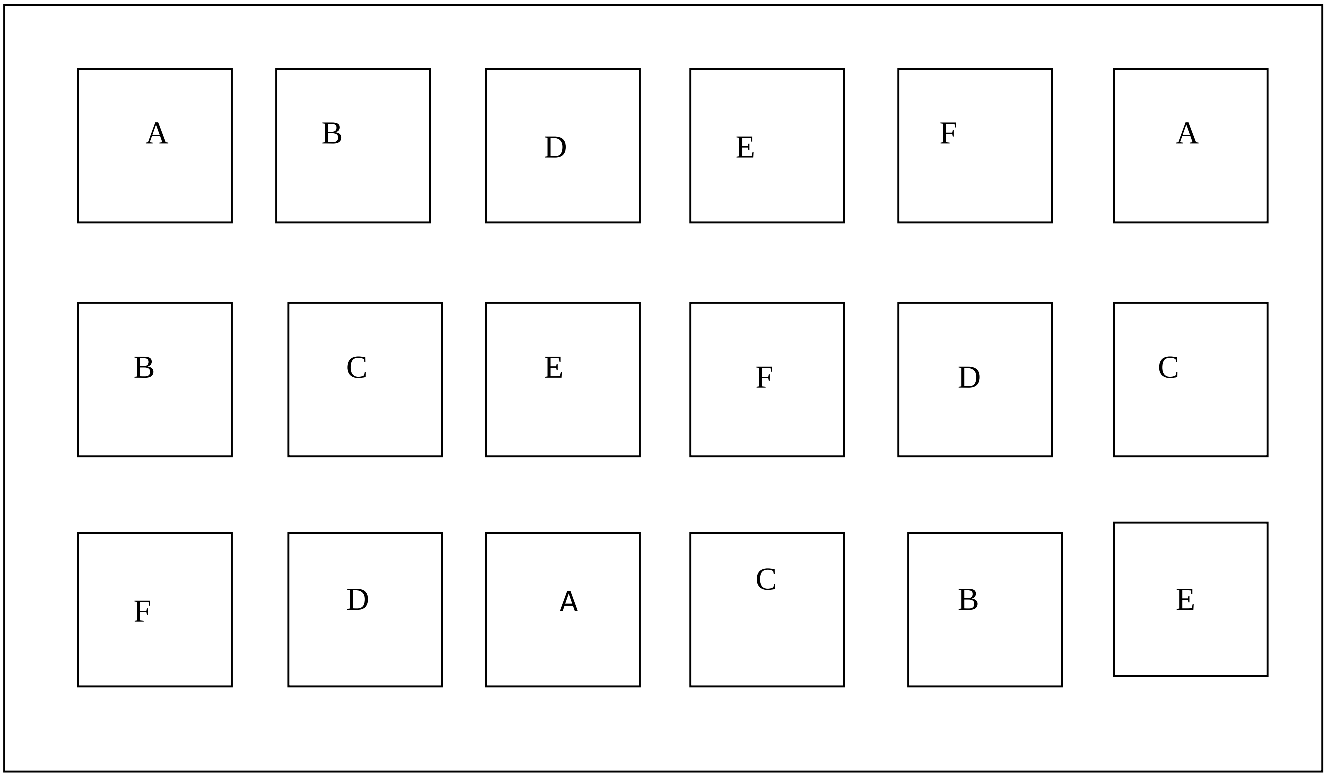


Fig 3. The experimental layout for tomato postharvest quality determination.

KEY:

A - Tomato produced under net with basil surrounding the outside of the net cover (T+N+BB), **B** - Tomato produced under net with basil in between adjacent rows of the crop (T+N+BI), **C** - Tomato produced under net with no companion basil (T+N), **D** - Tomato produced without a net cover with basil surrounding the crop (T+BB), **E** - Tomato produced without a net cover with basil in between adjacent rows the crop (T+BI), **F** - Tomato produced without net cover or basil (TC) (control).

3.5 Data Collection

Data collection was done from the inner twelve (12) tomato plants of each experimental unit leaving the outer plants as guard rows. The variables measured were:

3.5.1 Stomatal Conductance

Leaf stomatal conductance was measured on a recently fully expanded leaf at the top of the canopy using a Steady State Leaf Porometer (SC-1, Decagon Devices, Inc. Hopkins Court Pullman, USA.) and the observed readings recorded in $mmol \cdot m^{-2} \cdot s^{-1}$. This was done on a fortnightly basis starting 2 weeks after transplanting for a period of 8 weeks.

3.5.2 Growth Parameters

i) Plant Height

Tomato plant height was measured using a meter rule (GTS-R-078; Shangai Precision and Scientific Instrument Co., Shangai, China), from the ground surface to the top most leaf of the main stem starting 2 weeks after transplanting and readings recorded in centimeters (cm). Subsequent measurements were done fortnightly to the end of the trial period. The reading from the 12 plants measured in each experimental unit was averaged to obtain the mean plant height for the treatment at the time of measurement expressed in cm.

ii) Number of Branches

Total number of branches of tomato plants were also counted and recorded on a fortnightly basis starting 2 weeks after transplanting to the end of the trial. Readings obtained from the 12 plants in every experimental unit were averaged to get the mean number of branches per plant per treatment at the time of measurement.

3.5.3 Whitefly Infestation

Yellow sticky traps (Horivers) obtained from Koppert Biological Systems (K) Ltd were mounted at the center of each plot 1 week after transplanting. After every 2 weeks, the number of adult whitefly stuck on the sticky traps was counted and recorded as number per treatment. Sampling of immobile (instar) stage was also done as described by Gu *et al*. (2008) whereby two leaves randomly selected but not cut away from plant at the 6^{th} to 8^{th} node from the growing point of the sample plants in every experimental unit was used to count immobile larger nymphs of whitefly (4^{th} nymph stage). This was done early in the morning from the underside of leaves using a $\times$ 10 magnification hand lens (H-2 2001, Precision Instruments LTD, Shanghai, China) on a fortnightly basis beginning 2 weeks after transplanting to the end of the trial. The number obtained was recorded as a measure of whitefly population in the field.

3.5.4 Number of Fruits with Viral Symptoms

Since tomato spotted leaf curl virus is the major disease transmitted by whitefly, the number of fruits from each treatment showing viral symptoms were counted and recorded on a weekly basis at harvest time. This was later pooled together at the end of each trial and recorded as total number of tomato fruits with viral symptoms per treatment which was later converted to total number per treatment per hectare.

3.5.5 Yield Components and Yield Variables

i) Number of Flower Trusses and Flowers per Truss

The number of flower trusses were counted and recorded from the appearance of first flower truss per experimental unit to the end of each trial and recorded as number of flower trusses per tomato plant per treatment. During each data collection day, individual flowers on each truss were also counted and recorded as number of flowers per truss.

ii) Fruit Numbers

Twice every week, tomato fruits were harvested at breaker stage from the sample plants in every experimental unit and physically counted, averaged and recorded as total number of fruit per plant. Eventual total number of fruits per treatment was obtained by summing up the respective number of fruits obtained at various harvest dates per experimental unit and recorded as total number of fruits per plant per treatment. This was later converted to total fruit number per treatment per hectare.

iii) Fruit Weight

At each harvest, fruits from the different experimental units were separately weighed using a weighing balance (ATZ; Shangai Precision and Scientific Instrument Co., Shangai, China) in grams which was later converted to kilograms. Thereafter, non-marketable fruits categorized as fruits damaged by insects, birds, diseased, cracked, sun scalded, rotten and small in size below 30mm in diameter were sorted out and separated from marketable ones. Thereafter marketable fruits were weighed and recorded. Total weights for marketable fruits obtained for different harvest dates for a similar treatment were later summed up after the last harvest to obtain total marketable yield in kilograms per experimental unit and later converted to tons per hectare. Non-marketable fruits were counted and recorded as number of non-marketable fruits per experimental unit. Eventually this was converted to number of non-marketable fruits in tonnes per hectare.

3.5.6 Post-Harvest Quality Determination

After harvesting, tomato fruits at breaker stage from similar treatments drawn from the different replicates were pooled together, sorted to ensure that the fruits were free from sun scorch, insect pest or disease damage which could affect the normal ripening process. A total of 72 fruits were randomly selected and graded to a minimum and maximum diameter of between 30-45mm from the composite sample of each treatment to ensure uniformity of tomato fruits to be used for post-harvest quality determination. The experiment was then set up in a Complete Randomized Design (CRD) with 3 replications each having 24 fruits and the following variables measured.

i) Fruit Firmness

Fruit firmness was determined using a destructive sampling procedure involving 3 tomato fruits per treatment per replicate starting from the first day of storage and later repeated periodically at a 3 day interval for a period of two weeks. A hand held penetrometer with 8mm plunger size (model 62/DR, UK) was used to determine firmness of tomato fruit and the results recorded in Kg Force (KgF).

ii)Total Soluble Solids

The same fruits used to determine fruit firmness were used for Total Soluble Solids (TSS) determination. A hand held refractometer (0-30 ºBrix) (RHW Refractometer, Optoelectronic Technology Company Ltd. UK) was used according to the procedure described by Tigchelaar (1986). This was also done at 3-day interval for a period of two weeks. The results were recorded as °Brix.

iii) Titratable Acidity

Titratable Acidity (TA) of fruits was determined from the same fruits used to measure fruit firmness and TSS. TA was determined through titration using phenolphthalein coloured indicator method as described by Turhan and Seniz (2009). This was also repeated on a 3-day interval and results recorded as % citric acid.

iv) Sugar Acid Ratio

Sugar acid ratio was determined using the formula;

Sugar:acid ratio = °Brix value/ Percentage acid (Gormley and Maher, 1990)

3.6 Data Analysis

The data collected were subjected to Analysis of Variance (ANOVA) at $P \leq 0.05$ and means for significant treatments at the F test separated using Tukey's honestly significant difference (Tukey's HSD) test at $P \leq 0.05$. SAS statistical package version 10.1 (SAS Institute, 2010) was used in data analysis. The basic model fitted for the experiment was:

$$\mathbf{Y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + \alpha\tau_{ik} + \varepsilon_{ij}}$$

i = 1, 2; j = 1, 2, 3, 4, 5; k = 1, 2, 3, 4, 5, 6

Where; Y_{ijk} – Tomato response, μ – Overall mean, α_i --effect of the i^{th} season, β_j – effect of the $_j{}^{th}$ blocking, τ_k – effect of the k^{th} treatment, $\alpha\tau_{ik}$- interaction effect of the i^{th} season and k^{th} treatment, ε_{ij}— random error component which is assumed to be normally and independently distributed about zero mean with a common variance σ^2.

The basic CRD model fitted for laboratory experiment was:

$$\boldsymbol{Y_{ij} = \mu + \beta_i + \alpha_j + \alpha\beta_{ij} + \varepsilon_{ij}}$$

i =1, 2, 3, 4, 5, 6; ***j*** = 1, 2, 3, 4……14.

Where; Y_{ij} – Tomato response, μ – overall mean, β_i – effect of the i^{th} treatment, α_j– effect of the j^{th} day after storage, $\alpha\beta_{ij}$ – interaction effect of the i^{th} treatment and j^{th} day after storage, ε_{ij} – random error component which is assumed to be normally and independently distributed about zero means with a common variance σ^2.

In addition contrasts were constructed for both experiments to capture the effects of agronet covered treatments versus open field treatments, companion planting with basil verses planting tomato with no basil as a companion crop, and companion planting design with a row of basil in between adjacent rows of tomato versus a basil row surrounding tomato plants in an open field tomato production system. The results obtained have been presented and discussed in the subsequent chapters of this document.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the results of both the field and laboratory experiments. The order followed in the presentation covers the result on effect of agronet cover and companion planting with basil on i) leaf stomatal conductance and growth of tomato plants, ii) whitefly population, iii) yield components and fruit yield and iv) post-harvest quality of tomato fruits measured in terms of fruit firmness, TSS, TA and sugar acid ratio.

4.1 Effects of Agronet Cover and Companion Planting with Basil on Leaf Stomatal Conductance and Growth of Tomato Plants

4.1.1 Leaf Stomatal Conductance

Use of agronet covers and companion planting with basil significantly influenced tomato leaf stomatal conductance (Table 1). Over the two seasons, leaf stomatal conductance tended to be higher in tomato grown under agronet cover with companion basil planted either in between adjacent rows of tomato or surrounding the tomato from outside of the net cover as well as in the treatment where tomato was grown as a pure stand. It was low in the other open treatment with the control treatment recording the lowest reading in all sampling dates. Comparing the two growing seasons, higher leaf stomatal conductance was recorded in season 1 compared to season 2 in all sampling dates.

Comparing the main effect of growing tomato with or without agronet cover on leaf stomatal conductance, leaf stomatal conductance was enhanced when tomato plants were grown under agronet cover compared to when the plants were grown in the open. In all sampling dates of the two seasons, mean leaf stomatal conductance was higher under agronet covered treatments compared to no net covers (Fig.4a). The main effect of companion planting with basil was also significant (Fig. 4b). Growing tomato in companion with basil also enhanced tomato leaf stomatal conductance in all sampling dates of the two seasons compared to treatments where basil was not used as a companion crop. In regard to the two basil planting arrangement, planting a row of basil in between adjacent rows of tomato recorded higher leaf stomatal conductance compared with surrounding the tomato plants with a row of basil boarder in sampling dates (Fig.4c).

Table1. Effects of agronet cover and companion planting on leaf stomatal conductance (µmol/m-2/s) during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting			
		14	28	42	56
T+N+BB	1	126.8a*	120.9ab**	102.6abc	124.0ab
T+N+BI	1	131.8a	132.2a	112.0ab	136.3a
T+N	1	112.6ab	127.0a	126.6a	134.6a
T+BB	1	85.7c	104 4abc	85.6bc	95.5bc
T+BI	1	99.7abc	111.4ab	96.5bc	110.5abc
TC	1	89.0bc	103.5abc	94.7bc	102.2bc
T+N+BB	2	91.2bc	90.0bc	88.4bc	88.2cd
T+N+BI	2	94.0abc	87.4bc	85.5bc	90.6c
T+N	2	86.1bc	82.5c	83.1c	87.6cd
T+BB	2	86.8bc	86.7bc	80.3c	91.2c
T+BI	2	87.3bc	86.9bc	81.1c	81.2d
TC	2	84.3c	86.2bc	82.5c	82.2d

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$)

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

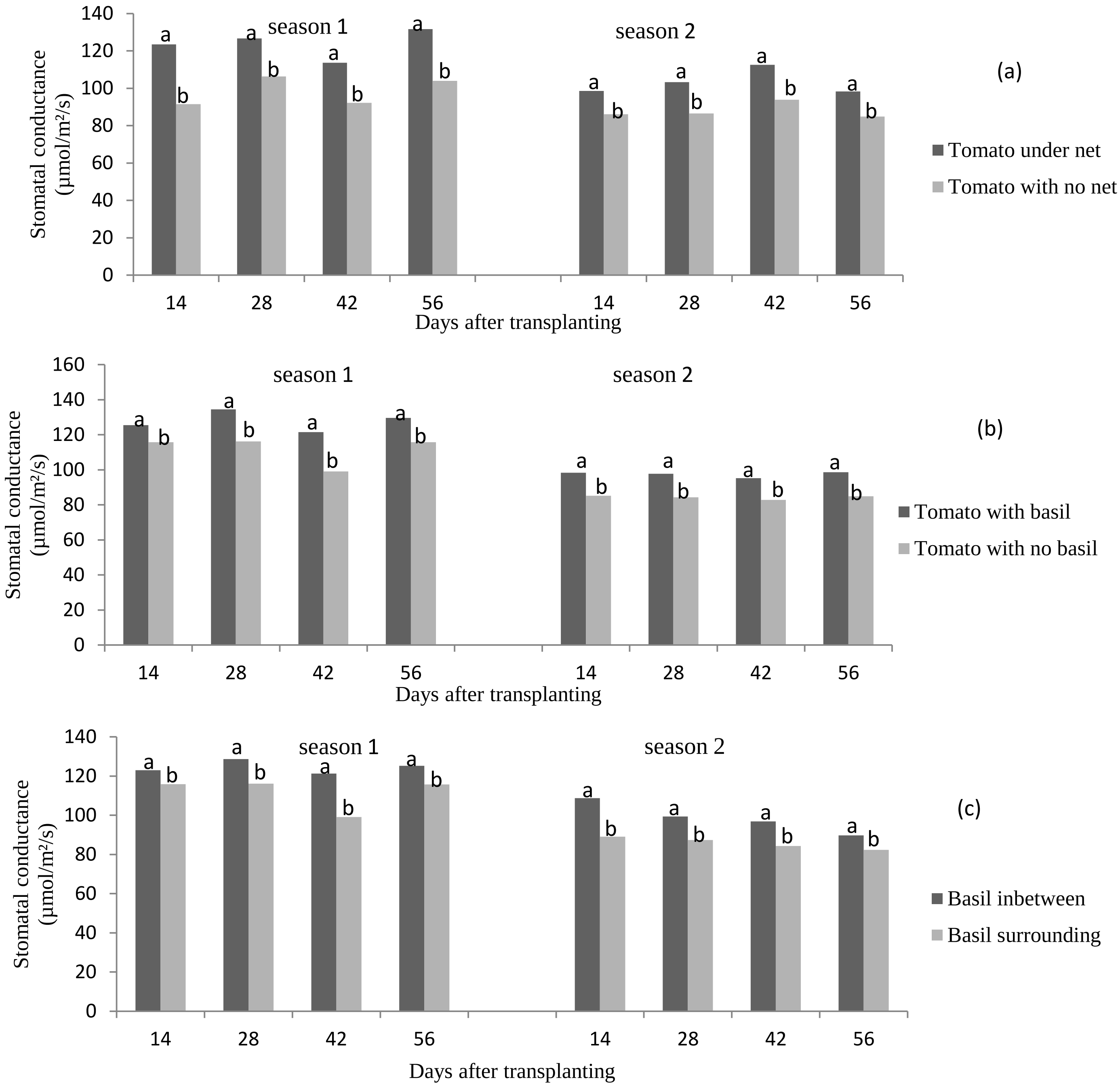


Fig 4. The effects of (a) agronet cover (b) companion planting and (c) basil planting design on leaf stomatal conductance during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at ($P \leq 0.05$).

4.1.2 Plant growth

a) Plant Height

Combined use of agronet cover and companion cropping significantly influenced tomato plant height compared with the control except during the first data collection date at 14 DAT (Table 2). Over the two seasons, tomato plants tended to be tallest when grown under agronet cover and in companion planting with a row of basil in between adjacent rows of tomato in most sampling dates. The shortest plants were on the other hand recorded under the control treatment with no net cover or basil companion in most sampling dates. Among the other treatments, plants were taller under agronet cover with a row of basil surrounding tomato plants from the outside of the agronet cover and under agronet cover alone as a pure stand compared with plants grown in the open without agronet cover but in companion with basil. Generally plants of season 2 grew taller than those of season 1.

Comparing the main effect of growing tomato with or without agronet covers, the use of agronet covers enhanced tomato plant height compared to when the plants were grown without net covers (Fig. 5a). In all sampling dates of both seasons, taller plants were realized under agronet covered treatments compared to no net cover treatments except during the first sampling date at 14 DAT in both seasons. Similarly, growing tomato in companion with basil generally resulted in taller plants compared to when tomato was not grown in companion with basil in all data sampling dates except at 14 DAT of both seasons where no statistical significant difference was observed between the two cropping regimes (Fig. 5b). Comparing the two basil planting arrangement, taller plants were also realized in treatments where a row of basil was planted in between adjacent rows of tomato compared to planting a row of basil surrounding tomato from outside at all data sampling dates except at 14 DAT where no statistical significant difference was observed in tomato plant height in both seasons (Fig. 5c).

b) Number of Branches

Except at 14 DAT, combined use of agronet cover and companion planting with basil significantly influenced the number of branches produced by tomato plants in all the data sampling dates (Table 3). Over the seasons, plants grown under agronet cover with a row of basil in between adjacent rows of tomato produced the highest number of branches while the least number of branches was recorded under the control treatment in all sampling dates.

Table 2. Effects of agronet cover and companion planting on plant height (cm) during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting				
		14	28	42	56	70
T+N+BB	1	11.2*	23.5cd**	49.3bcd	65.1c	85.4c
T+N+BI	1	11.5	30.6bc	53.7bc	79.2ab	100.7a
T+N	1	11.0	23.4cd	51.7bcd	65.3c	89.2c
T+BB	1	11.0	20.0d	41.0bc	54.7def	69.5de
T+BI	1	11.9	22.4cd	41.8def	60.5cde	81.5cd
TC	1	10.5	19.7d	34.3g	49.3f	62.6e
T+N+BB	2	20.6	35.2b	57.9ab	76.0ab	88.4bc
T+N+BI	2	21.6	47.5a	66.9a	86.3a	92.7ab
T+N	2	20.1	35.0b	53.2bc	70.3bc	78.8cd
T+BB	2	20.7	28.1bc	47.6cdef	64.0cd	78.7cd
T+BI	2	21.8	28.9bc	45.1cdef	61.7cd	72.2de
TC	2	20.4	28.6bc	40.0efg	50.6ef	63.8e

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

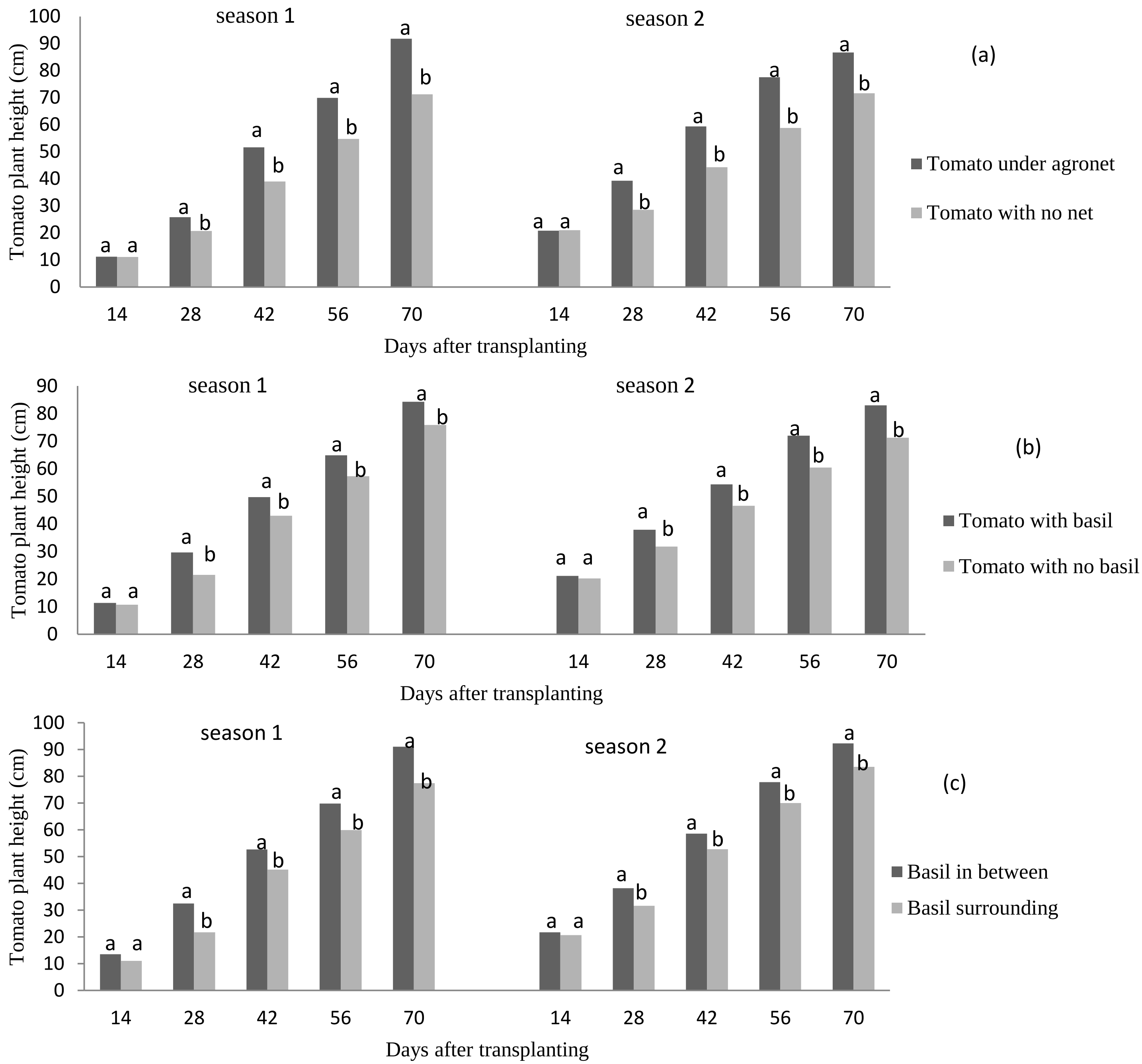


Fig 5. The effects of (a) agronet cover (b) companion planting and (c) basil planting design on tomato plant height during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test (P≤0.05).

tomato plants grown with a row of basil surrounding the crop from outside and those grown under agronet cover without companion basil also produced more branches than the control plants in most sampling dates. Lower number of branches per plant was also obtained where tomato was grown in the open without a net cover but with a row of basil planted in between adjacent rows of tomato or surrounding tomato plants. The control plants had the lowest although the differences were not significant in most sampling dates.

Comparing the main effect of growing tomato under agronet covers against no nets, more branching was achieved for agronet covered tomato compared to tomato grown in the open at all sampling dates except at 14 DAT in season 1 and at 14 and 28 DAT in season 2 (Fig. 6a). Tomato grown in companion with basil also had more branches compared to tomato grown as a pure stand in all sampling dates except at 14 DAT in season 1 and 14 and 28 DAT in season 2 where no statistical significant difference in number of branches among the two treatments was observed (Fig.6b). Comparing effects of basil planting arrangement on the number of branches, planting a row of basil in between adjacent rows of tomato plants resulted to a significant mean increase in number of branches compared to planting a row of basil surrounding the tomato crop from outside in all data sampling dates in both seasons except at 14 DAT in season 1 at 14 and 28 DAT in season 2 (Fig. 6c).

4.2 Effect of Agronet Cover and Companion Planting with Basil on Whitefly Population

Whitefly population on tomato plants under each experimental unit was determined and presented in the following form; a) average number of whitefly per tomato plant and b) average number of whitefly per yellow sticky trap.

4.2.1 Whitefly Population on Tomato Plants

Combined use of agronet cover and companion planting significantly reduced whitefly population on tomato plants (Fig.7). In both seasons, whitefly population on tomato plants grown under agronet cover in companion with either a row of basil in between adjacent rows of tomato or surrounding the tomato crop from outside of the net cover as well as in tomato grown under agronet cover alone as a pure stand registered a higher reduction in whitefly population compared to the control treatments. Generally, whitefly population on tomato plants was also lower on tomato plants grown in the open without agronet cover but in companion with basil compared to the population registered for the control treatment in most sampling dates.

Table 3. Effects of agronet cover and companion planting on number of branches (no/plant) during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting				
		14	28	42	56	70
T+N+BB	1	2.1*	4.1ab**	5.9cd	9.0ab	10.1abc
T+N+BI	1	2.0	4.5a	7.3ab	10.0a	11.9a
T+N	1	2.0	3.8ab	5.7cd	8.2bc	10.5abc
T+BB	1	1.8	3.5abc	4.8de	6.5de	8.2d
T+BI	1	1.8	3.4bc	5.2cde	7.5cd	9.8bcd
TC	1	1.8	2.6c	4.2e	6.3e	7.4f
T+N+BB	2	2.9	4.0ab	6.5bc	9.7a	11.1ab
T+N+BI	2	2.7	4.4ab	7.8a	10.2a	11.5ab
T+N	2	3.0	3.9ab	6.2bcd	9.0ab	10.6abc
T+BB	2	2.9	3.7ab	5.1de	8.3bc	9.9bcd
T+BI	2	2.8	3.9ab	5.3de	8.4bc	9.9bcd
TC	2	2.7	3.8ab	4.8de	7.7c	9.2cd

* Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$)

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

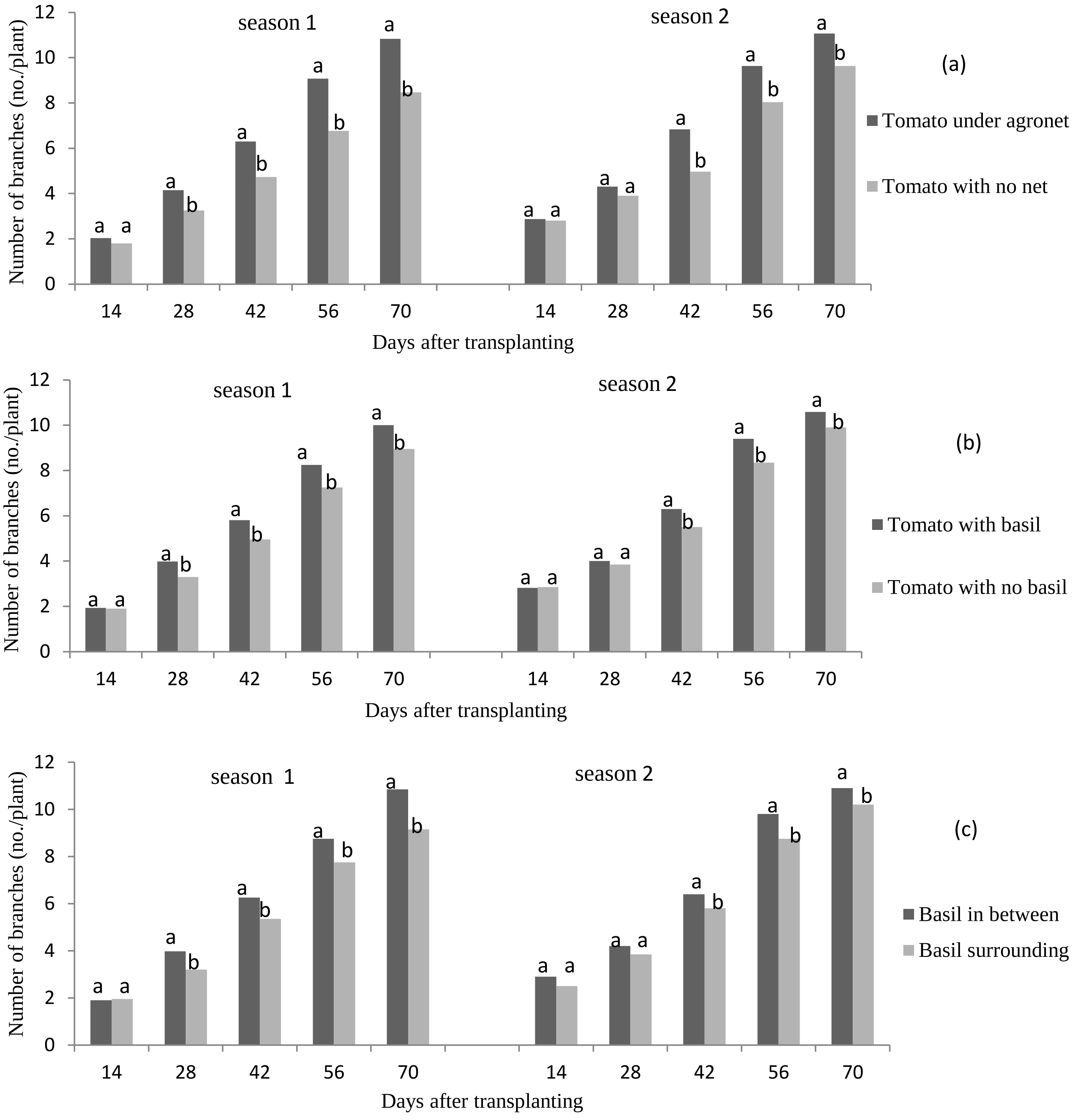
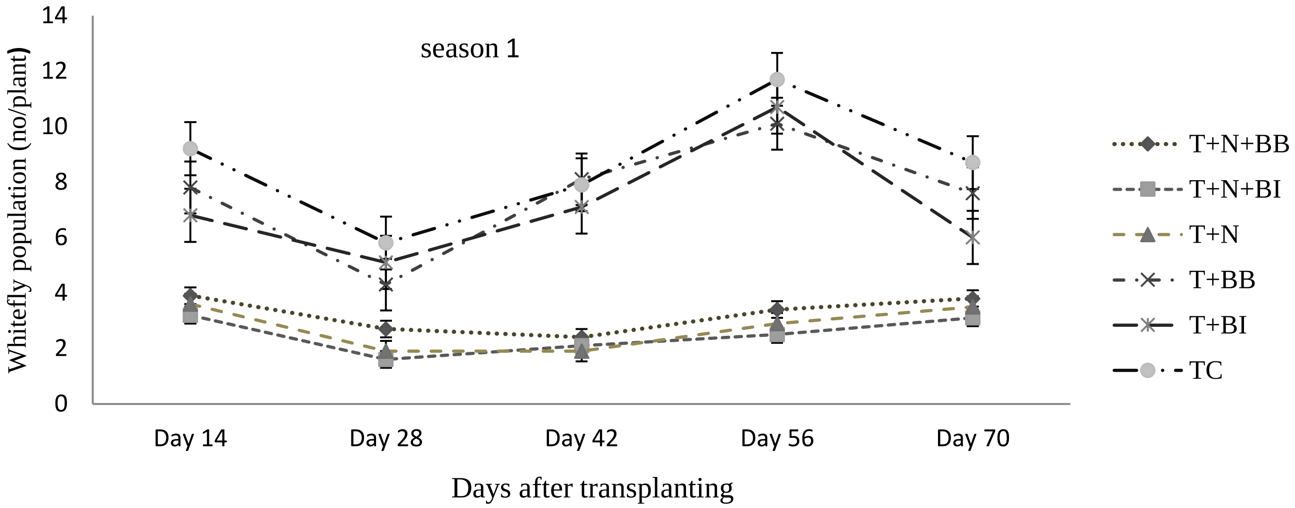


Fig 6. The effects of (a) agronet cover (b) companion Planting and (c) basil planting design on number of branches per plant during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test (P≤0.05).



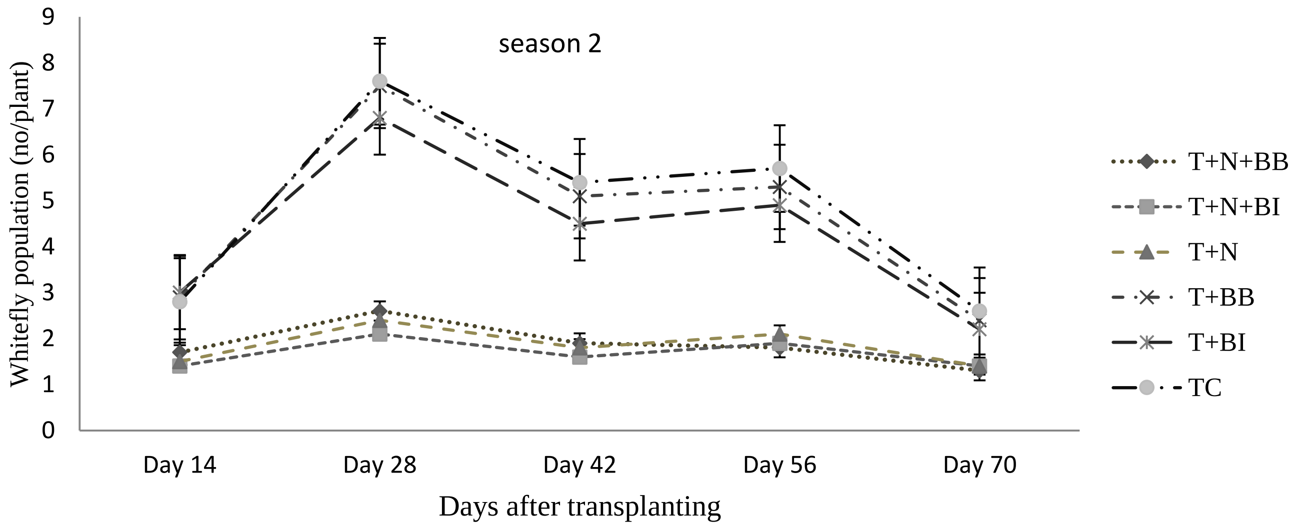


Fig 7. The effects of agronet cover and companion planting on whitefly population on tomato plants (no./plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

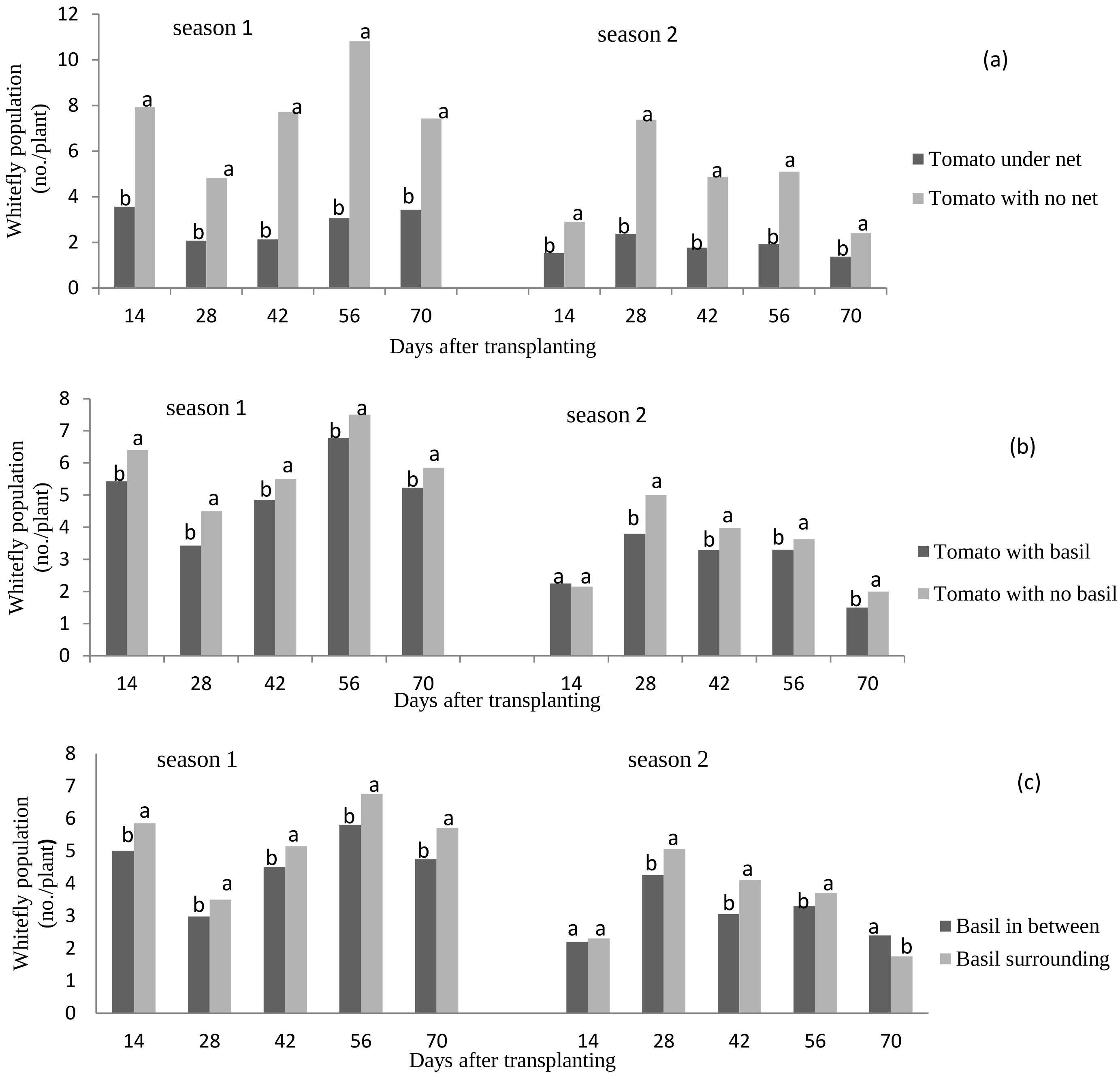


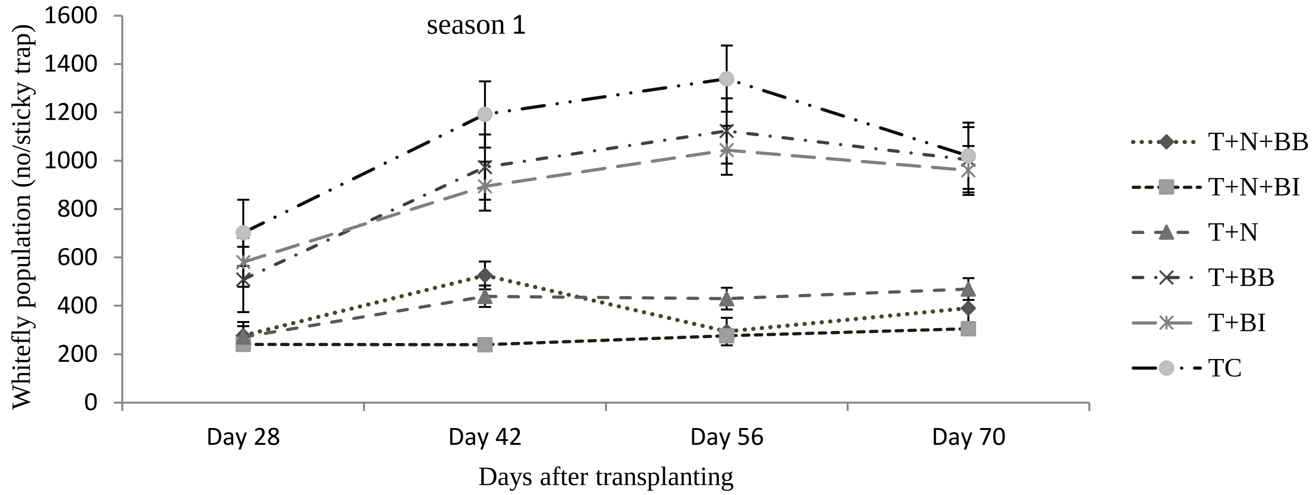
Fig 8. The effects of (a) agronet cover (b) companion planting and (c) basil planting design on whitefly population on tomato plants during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test (P≤0.05).

Comparing the effect of growing tomato with or without agronet covers, using agronet covers reduced whitefly population on tomato plants. Throughout the data collection period, whitefly population on agronet covered treatments was significantly lower than in uncovered treatments in both seasons (Fig 8a). Companion planting with basil also reduced whitefly population compared to treatments where basil was not used throughout the data collection period in both seasons except at 14 DAT in season 2 where the difference between the two cropping regimes was not statistically significant (Fig 8b). Similarly, planting a row of basil in between adjacent rows of tomato plants resulted in a significantly higher reduction in whitefly population compared to planting a row of basil surrounding the tomato crop from outside in all sampling dates of both seasons except at 14 DAT in season 2 (Fig 8c).

4.2.2 Whitefly Population on Sticky Traps (Horivers)

Whitefly population on sticky traps (Horivers) was also significantly influenced by the use of agronet covers and companion planting (Fig. 9). In both seasons, tomato plants grown under agronet cover with either a row of basil planted in between adjacent rows of tomato or surrounding the tomato crop from the outside of the net cover had lower whitefly population on sticky traps compared to most other treatments in most sampling dates. High reduction in whitefly population on sticky traps was also observed where the tomato crop was grown alone as a pure stand under net cover compared to the control treatment in most evaluation dates of both seasons. A reduction in whitefly population on sticky traps was also recorded for open treatments with no agronet cover but with a row of basil in between adjacent rows of tomato or surrounding the tomato crop although the difference in number of whitefly between these treatments and the control treatment was not significant in most sampling dates.

Comparing the effects of growing tomato with or without agronet cover, the use of agronet cover resulted to greater reduction in whitefly population on sticky traps compared to when the plants were grown without a net cover in all the sampling dates of season 1 and 2 (Fig 10a). Similarly, growing tomato in companion with basil also resulted to significantly reduced number of whitefly on sticky traps than when tomato was grown without a basil companion crop in all data evaluation dates except at 70 DAT in season 1 when the difference between the mean whitefly populations for the two cropping regimes was not significant (Fig 10b).



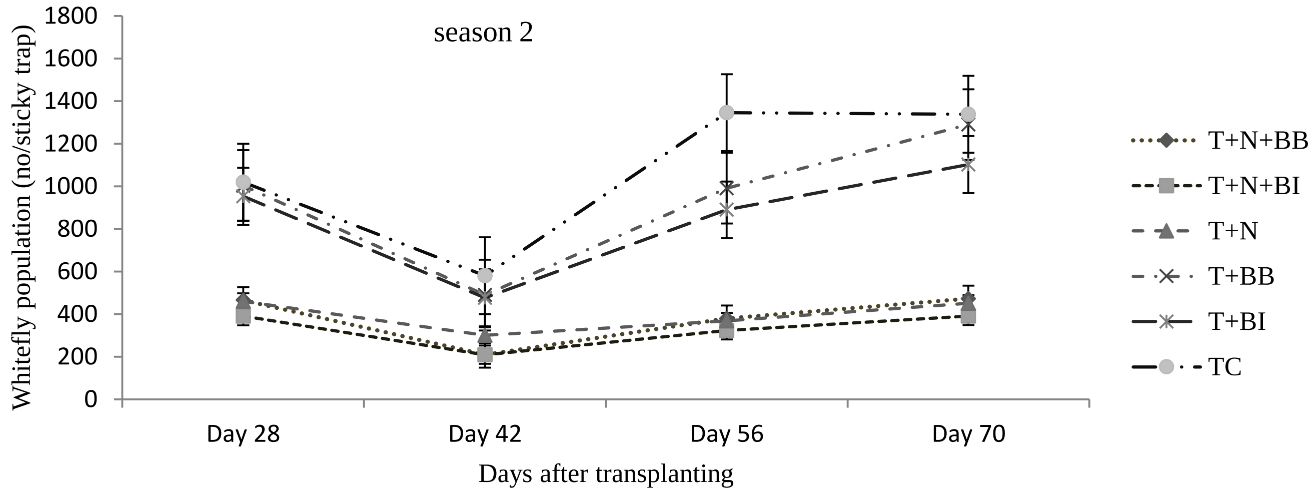


Fig 9. The effects of agronet cover and companion planting on whitefly population on sticky traps (Horivers) (no/sticky trap) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

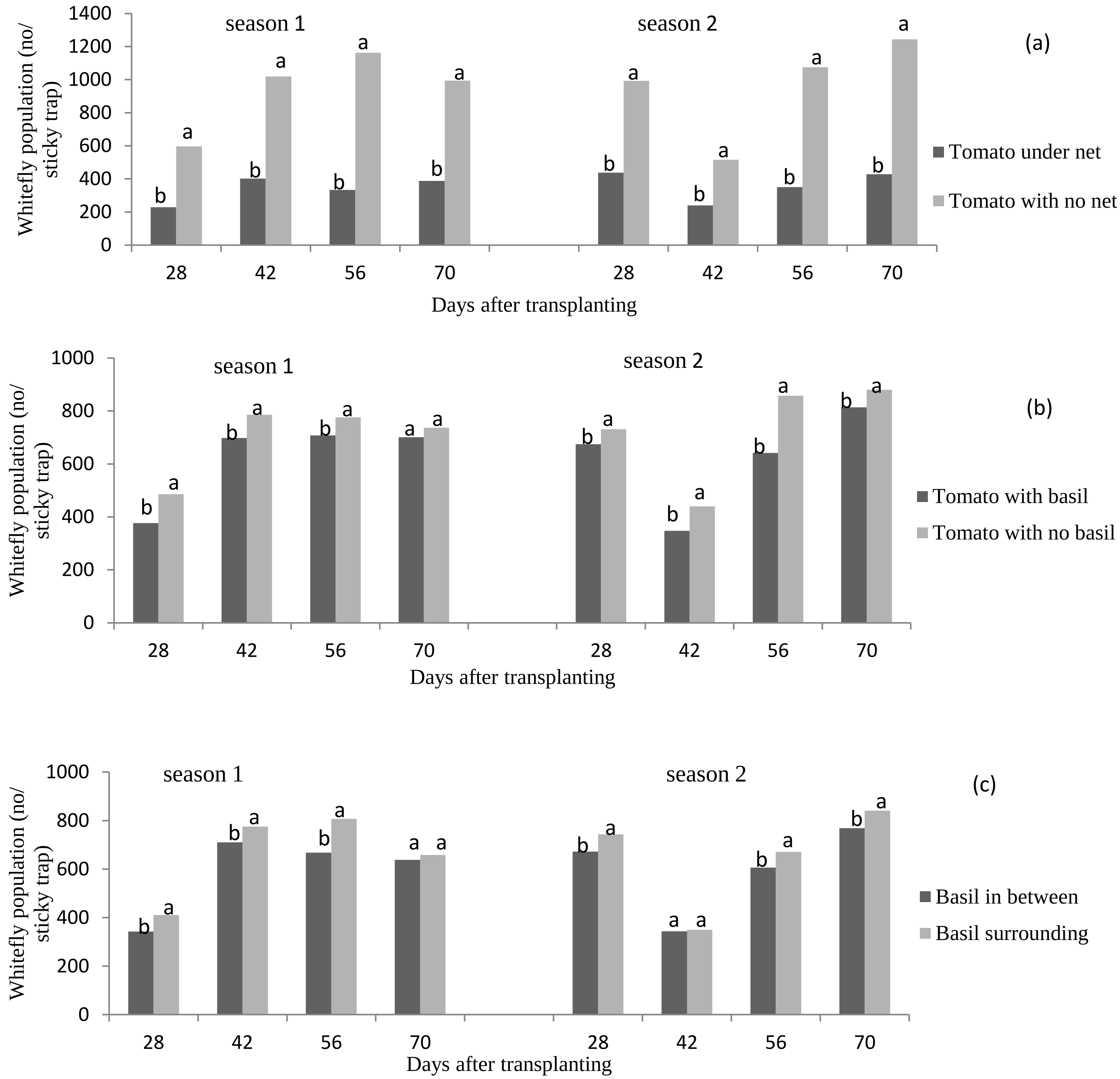


Fig 10. The effects of (a) agronet cover, (b) companion planting and (c) basil planting design on whitefly population on sticky traps during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at ($P \leq 0.05$).

Comparing the two basil companion planting designs, planting a row of basil in between adjacent rows of the tomato plants also resulted to a reduction in whitefly population on sticky traps in all sampling dates of both seasons except at 70 in season 1 and 42 DAT in season 2 when the difference between the mean whitefly populations for the two companion planting designs was not significant (Fig 10c).

4.3 Effect of Agronet Cover and Companion Planting with Basil on the Number of Fruits with Viral Symptoms

Use of agronet covers and companion planting with basil significantly reduced the total number of tomato fruits with viral symptoms (Table 4). The lowest number of tomato fruits with viral symptoms was recorded under agronet cover and companion planting with a row of basil planted in between adjacent rows tomato plants or surrounding tomato plants from the outside of the net cover while the highest number was obtained under the control treatment with no net cover or companion basil in all data evaluation dates of both seasons. A lower number of fruits with viral symptoms were also obtained where tomato was grown under agronet cover with no companion basil compared to the control treatment in all sampling dates. Lower number of tomato fruits showing viral symptoms was also realized in tomato grown in the open without agronet cover but in companion with a row of basil planted in between adjacent rows of tomato or surrounding the tomato crop from outside although the mean differences of these treatments were not statistically significant from that of the control treatment in most data evaluation dates of both seasons.

Comparing the main effects of growing tomato with or without agronet covers, the use of agronet cover resulted to a significant reduction in the number of tomato fruits with viral symptoms compared to when the plants were grown without net covers in all the sampling dates of both seasons (Fig 11a). Similarly, the main effect of companion planting with basil was also significant with a reduction in number of tomato fruits with viral symptoms being recorded where companion basil was used compared to when basil was not used as a companion crop in all sampling dates of the two seasons (Fig 11b). Comparing the two basil planting arrangements, planting a row of basil in between adjacent rows of the tomato plants also resulted in a reduction in number of tomato fruits with viral symptoms compared to surrounding the tomato plants with a row of basil in all data sampling dates except on 90 and 105 DAT in season 1 where the difference in mean of the two treatments was not significant (Fig. 11c).

Table 4.Effects of agronet cover and companion planting on tomato fruits with viral symptoms during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days After Transplanting			
		90	98	105	112
T+N+BB	1	1.93c*	2.16c**	2.13c	2.08bc
T+N+BI	1	1.71c	2.08c	2.06bc	1.7c
T+N	1	2.31bc	2.36bc	2.51bc	2.67bc
T+BB	1	3.41a	3.31ab	3.99a	3.35ab
T+BI	1	3.51a	2.78abc	4.03a	4.32a
TC	1	3.84a	3.76a	4.11a	3.53ab
T+N+BB	2	2.15bc	2.38bc	2.74bc	2.37bc
T+N+BI	2	1.77c	2.09c	2.29c	2.05c
T+N	2	2.04c	2.71abc	2.66bc	2.24bc
T+BB	2	3.05ab	3.27ab	4.15a	3.33ab
T+BI	2	3.03ab	2.86bc	3.19ab	3.00abc
TC	2	3.67a	3.62a	4.14a	4.20a

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

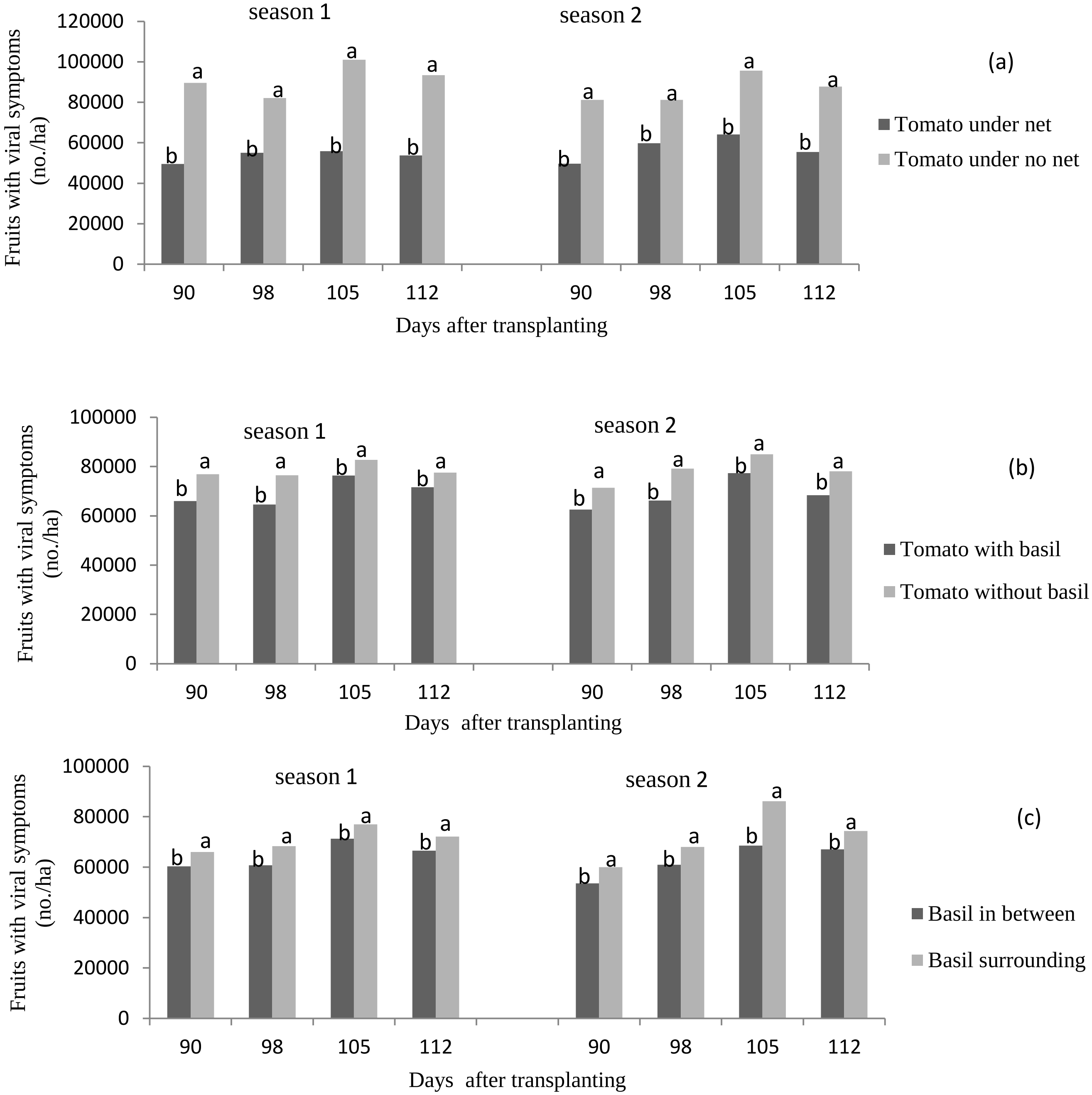


Fig 11. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato fruits with viral symptoms during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).Means having the same letter within an evaluation date are not significantly different according to LSD test at (P≤0.05).

4.4 Effect of Agronet Cover and Companion Planting with Basil on Yield Components and Yield of Tomato

Aspects of yield components of tomato studied were a) number of flower trusses per tomato plant and b) flower numbers per plant while yield variables were a) marketable fruit numbers per plant b) marketable fruit weight per plant c) non-marketable fruit numbers per plant d) non-marketable fruit weight per plant e) total fruit number, weight and non-marketable fruit per hectare.

4.4.1 Yield Components

a) Flower Trusses per plant

Similar to the effects of agronet cover and companion planting with basil on growth of tomato plant, the use of agronet covers and companion planting significantly influenced the number of flower trusses produced by tomato plants (Table 5). Throughout the data collection period, the highest number of flower trusses was recorded in tomato plants grown under agronet cover in companion with either a row of basil planted in between adjacent rows of tomato plants or surrounding the tomato plants from outside as well as in treatments where tomato was grown alone under agronet cover. The lowest count of flower trusses per plant was recorded in the control treatment in most sampling dates. On the other hand, growing tomato in the open with no agronet cover but in companion with a row of basil either in between adjacent rows of tomato plants or surrounding the tomato crop also registered an increase in number of flower trusses. The control treatment recorded the least numbers although the difference was not statistically significant in most sampling dates of both seasons. Generally, season 1 produced higher number of flower trusses per plant compared to season 2.

Comparing the effects of growing tomato with or without agronet covers, the use of agronet cover resulted in a significant increase in tomato flower trusses compared with open treatments on all sampling dates (Fig 12a). More flower trusses were also recorded for tomato grown in companion with basil compared to tomato grown as a pure stand in all sampling dates except at 35 DAT of both seasons where no statistical significant difference was observed between planting tomato with basil or without basil as a companion crop (Fig. 12b). Statistical significant differences were also observed amongst the two basil planting arrangements whereby tomato planted with a row of basil in between adjacent rows of the tomato produced more flower

Table 5. Effects of agronet cover and companion planting on flower trusses (no/plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting				
		35	49	63	77	84
T+N+BB	1	7.6a*	16.1ab**	21.4ab	25.8ab	33.6a
T+N+BI	1	8.7a	17.4a	24.1a	27.1a	34.4a
T+N	1	7.0a	19.4a	23.6ab	26.8a	30.6ab
T+BB	1	5.7b	11.1abc	15.4bc	19.8abc	22.0de
T+BI	1	5.9bc	12.5abc	16.8abc	18.4bc	21.8de
TC	1	5.3bc	10.1bc	13.8c	16.9bc	20.4e
T+N+BB	2	7.9a	15.2ab	19.7abc	25.7ab	29.1ab
T+N+BI	2	8.5a	13.3abc	19.4abc	25.8ab	31.6ab
T+N	2	7.3a	13.7abc	19.5abc	23.7abc	28.2abc
T+BB	2	4.0c	9.2bc	14.3c	17.4bc	23.8cde
T+BI	2	4.3c	9.5bc	15.9bc	18.8bc	23.0cde
TC	2	4.1c	8.7c	14.0c	16.3c	19.1e

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

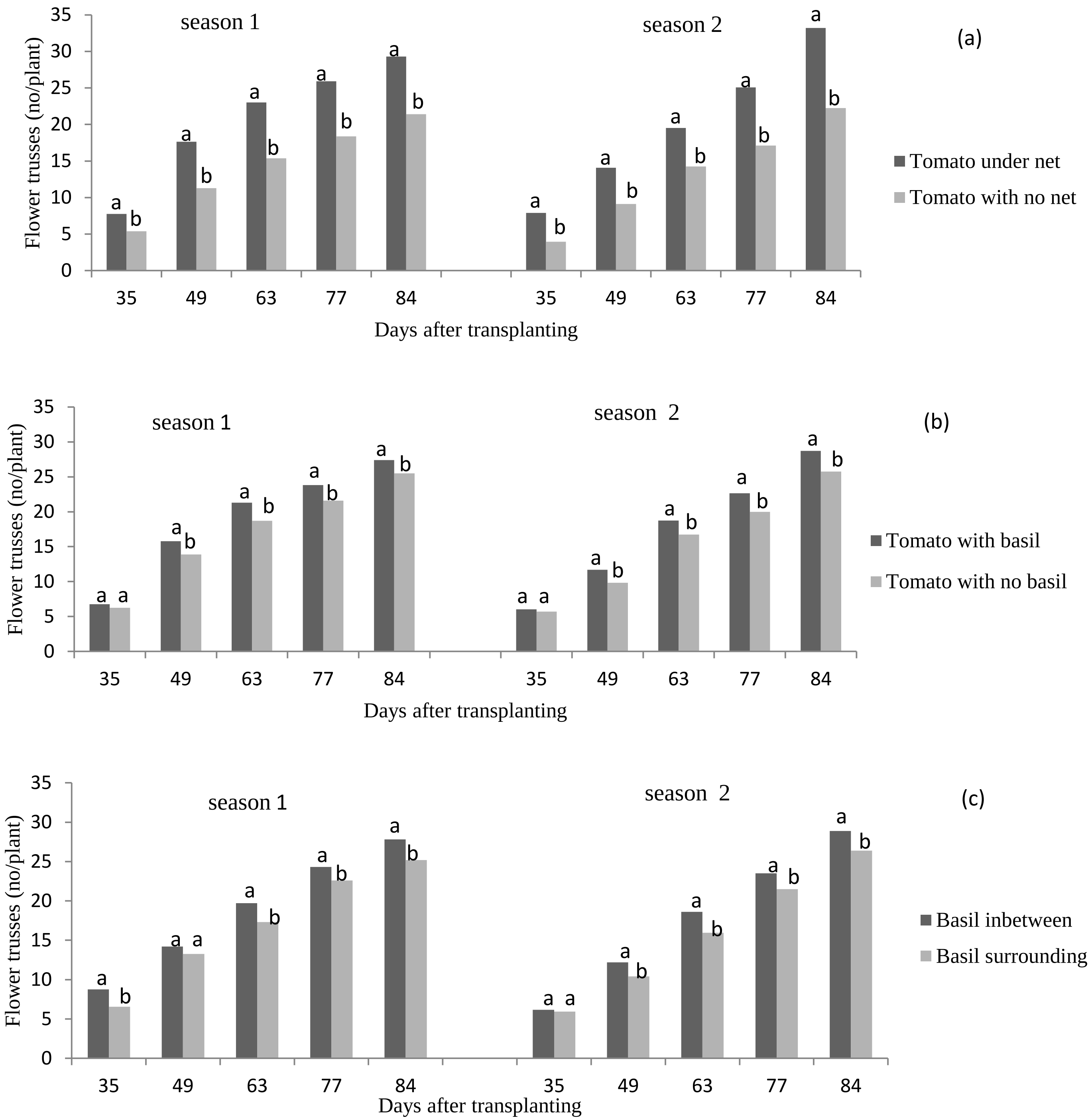


Fig 12. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on flower trusses per plant during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means followed by the same letter within an evaluation date are not significantly different according to LSD test at ($P \leq 0.05$).

trusses compared to where basil was planted surrounding tomato plants from outside in most sampling dates except at 49 DAT in season 1 and 35 DAT in season 2 (Fig 12c).

b) Flower Numbers per plant

Flower numbers per tomato plant followed a trend similar to that of flower trusses (Table 6). Growing tomato under agronet cover and in companion planting with a row of basil planted either in between adjacent rows of tomato plants or surrounding the tomato crop from outside of the net cover significantly improved flower numbers produced per plant. In all sampling dates, the highest number of flowers per plant was recorded from tomato grown under agronet cover with a row of basil in between adjacent rows of tomato while the lowest numbers were recorded under the control treatment. The numbers of flowers produced by tomato plants grown under agronet cover alone with no companion basil were also comparable to those recorded for tomato grown under agronet cover and in companion with basil in most sampling dates. Growing tomato without an agronet cover but in companion with basil on the other hand, marginally improved flower numbers produced by tomato plants but the effect was not significant in most sampling dates of both seasons. Overall season1 yielded more flower numbers per plant compared to season 2.

Considering the main effects of growing tomato with or without agronet cover, use of agronet cover increased flower numbers per plant with more flowers being recorded from the first sampling date through all the subsequent data evaluation dates in both seasons compared to the control treatment (Fig 13a). Comparing the use of basil as a companion crop against no companion basil more flowers were recorded in tomato plants grown together with basil as a companion crop compared to those grown alone as a pure stand in most sampling dates except at 35 DAT in season 1 and 49 DAT in season 2 (Fig 13b). Significant statistical differences were also observed between the two basil planting arrangements with high number of flowers per plant being recorded where basil was planted in between adjacent rows of tomato compared to planting a row of basil surrounding tomato plants from outside in most sampling dates except at 35 WAT in season 1 where the difference between the means of the two basil planting designs was not significant (Fig. 13c)

Table 6. Effects of agronet cover and companion planting on flower numbers (no/plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting				
		35	49	63	77	84
T+N+BB	1	119.3ab*	133.6abc**	150.7ab	172.2a	182.0ab
T+N+BI	1	135.a	156.6a	173.8a	191.4a	204.6a
T+N	1	118.7ab	136.1ab	153.8ab	168.2ab	178.5ab
T+BB	1	77.0bcd	94.4bcde	119.0bcd	131.5bc	140.2bc
T+BI	1	93.4bc	105.9bcde	122.6bcd	134.7bc	144.9bc
TC	1	76.3cd	91.8cde	108.6cde	119.5c	130.0cd
T+N+BB	2	101.2abcd	126.9abc	144.1abc	164.4abc	179.7ab
T+N+BI	2	108.7abc	126.8abc	140.8abc	169.7a	186.9a
T+N	2	103.0abcd	119.6abcd	140.5abc	166.3a	184.4a
T+BB	2	60.3d	78.2de	100.6de	120.9d	130.2c
T+BI	2	65.6cd	77.1de	81.3e	107.2d	135.4c
TC	2	62.3d	73.8e	87.5de	108.6d	122.9d

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$)

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

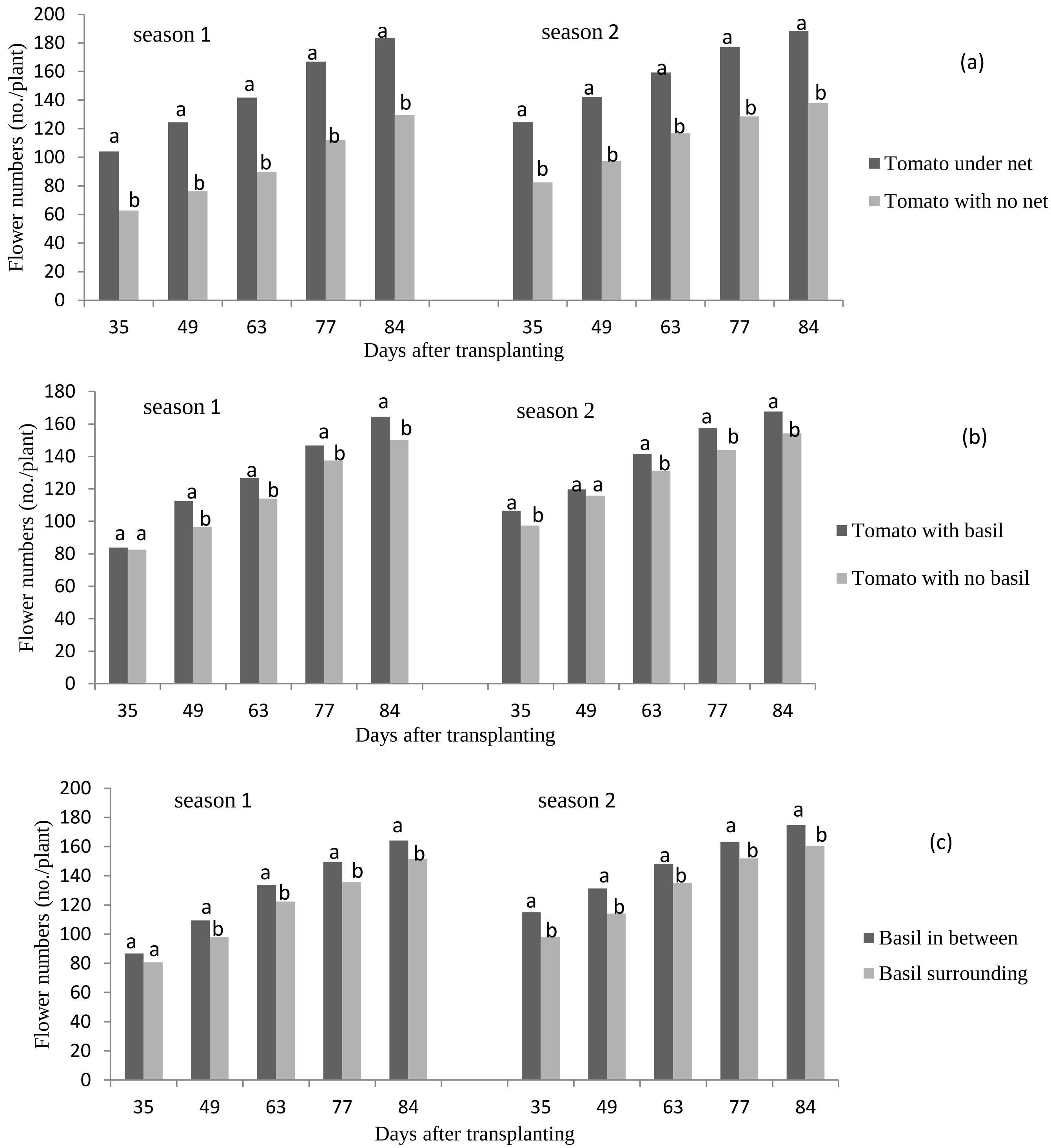


Fig 13. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on flower numbers during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at (P≤0.05)

4.4.2 Tomato Yield

a) Number of Fruits per Plant

Growing tomato under agronet cover in companion with basil significantly enhanced the number of tomato fruits harvested in both seasons (Table 7). In season one, tomato fruit numbers were highest under agronet cover and companion planting with a row of basil in between adjacent rows of tomato although the difference was not statistically significant from the other agronet covered treatments. The control treatment recorded the lowest number of tomato fruits in almost all the sampling dates of both seasons. Higher tomato fruit numbers were also obtained where tomato was grown in the open without a net cover but with a row of basil in between adjacent rows of tomato or surrounding the tomato crop compared to the control treatment although the differences were not significant in most sampling. Overall, season 1 yielded more tomato fruits compared with season 2.

Comparing the main effects of growing tomato under agronet cover against the use of no net cover, more fruits were achieved from agronet covered tomato plants compared to tomato grown in the open without a net cover in all the different data sampling dates of both seasons (Fig. 14a). Comparing the two basil cropping regimes, planting tomato with basil as a companion crop produced more tomato fruits compared to treatments where tomato was planted without companion basil in most sampling dates of both seasons (Fig 14b). Significant differences were also recorded for the two basil planting designs with more tomato fruits being harvested in treatments where basil was planted in between adjacent rows of tomato in most data collection dates compared to where a row of basil surrounded the tomato crop from outside (Fig. 14c).

b) Fruit Weight per Plant

Similar to fruit numbers, fruit weight obtained during individual harvests was significantly influenced by the use of agronet cover and companion planting with basil in most sampling dates (Table 8). In most sampling dates, the highest marketable fruit weight was obtained in tomato grown under agronet cover in companion with a row of basil in between adjacent rows of tomato. Also, higher fruit weight at each harvest was obtained from tomato grown under agronet cover alone as a pure stand or where a row of basil surrounded the crop compared to the control and other open treatments. The control treatment recorded the lowest tomato fruit weight in all data collections dates of both seasons. Growing tomato in the open without net cover but with a row of basil planted in between adjacent rows of tomato or

Table 7. Effects of agronet cover and companion planting on fruit numbers (no./ plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting			
		98	105	112	120
T+N+BB	1	11.4a*	14.4ab**	15.4a	18.2ab
T+N+BI	1	14.1a	16.0a	18.8a	22.2a
T+N	1	14.0a	14.8ab	16.8ab	19.7ab
T+BB	1	6.3bc	10.4cd	12.5bcde	14.7bc
T+BI	1	8.6ab	13.4abc	14.6abcd	16.5ab
TC	1	5.0c	7.8d	10.5cde	9.5cd
T+N+BB	2	7.0bc	8.7d	11.9cde	8.4de
T+N+BI	2	8.0abc	11.1bcd	12.1bcd	11.5cd
T+N	2	7.7bc	10.2bcd	10.1cde	9.9cde
T+BB	2	6.6bc	7.8d	8.4e	6.2e
T+BI	2	7.5bc	9.6cd	9.1de	7.2de
TC	2	5.1c	7.1d	7.9e	5.6e

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

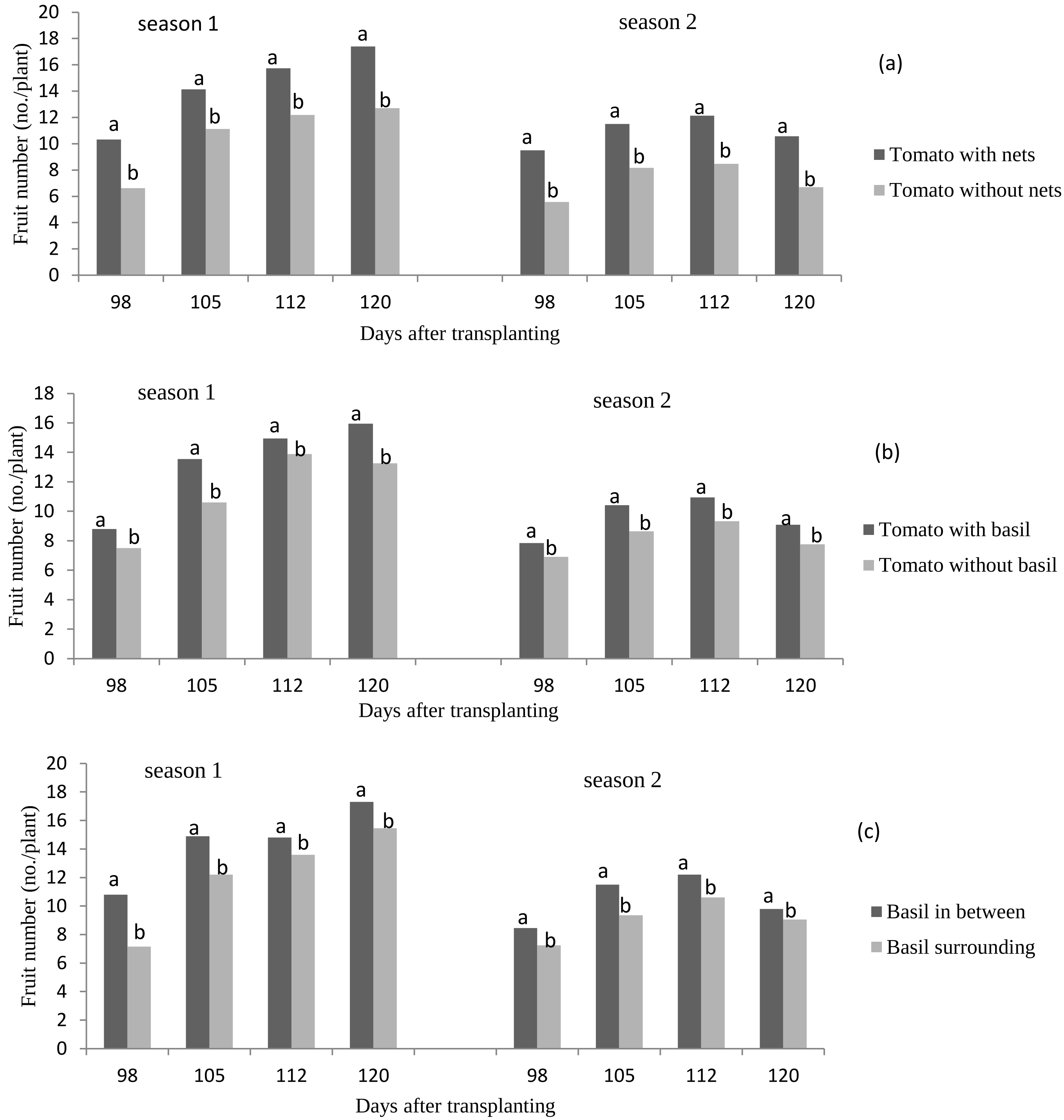


Fig 14.The effects of (a) agronet cover (b), companion planting and (c) basil planting design on fruit number per plant during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at ($P \leq 0.05$).

Table 8. Effects of agronet cover and companion planting on fruit weight (kg /plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting			
		98	105	112	120
T+N+BB	1	0.456ab*	0.543ab**	0.559b	0.682a
T+N+BI	1	0.520a	0.587a	0.657a	0.735a
T+N	1	0.416b	0.486b	0.574b	0.635ab
T+BB	1	0.393bc	0.435bc	0.468bc	0.480bc
T+BI	1	0.408bc	0.485bc	0.495bc	0.515bc
TC	1	0.291d	0.295d	0.443cd	0.391cde
T+N+BB	2	0.413bc	0.398cd	0.430cd	0.434cd
T+N+BI	2	0.488a	0.459bc	0.466bc	0.482bc
T+N	2	0.397bc	0.405bcd	0.432cd	0.422cd
T+BB	2	0.334cd	0.302d	0.348de	0.320e
T+BI	2	0.388bc	0.362cd	0.382cde	0.347de
TC	2	0.232e	0.294d	0.309e	0.291e

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

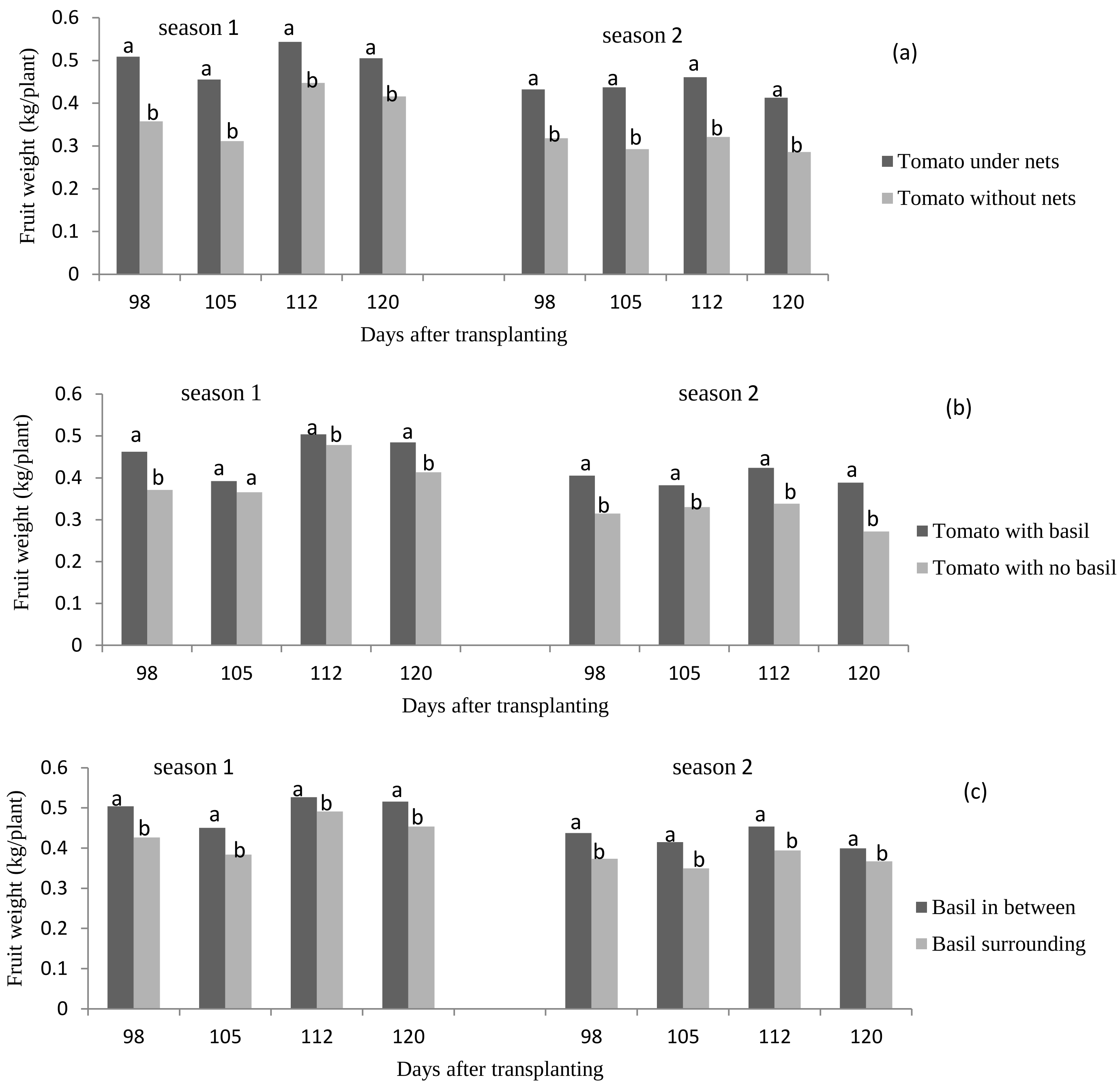


Fig 15. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato fruit weight during production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at (P≤0.05).

surrounding the tomato plants also yielded more tomato fruit weight at each individual harvest compared to the control treatment although the differences were not statistically significant in most sampling dates. Heavier fruits per plant were obtained in season 1 compared to those of season 2.

The main effect of growing tomato under agronet cover on fruit weight was statistically significant during all harvesting dates (Fig 15a).Tomato plants grown under agronet covers yielded higher fruit weight on average than those grown in the open field throughout all the individual harvest of both seasons. Significantly higher fruit weight was also obtained from tomato plants grown in companion with basil compared to when tomato was grown as a pure stand in all sampling dates except at 105 DAT in season 1 (Fig 15b). Similarly, the main effect of basil planting arrangement was also significant in all sampling dates of both seasons with planting a row of basil in between adjacent rows of tomato plants yielding higher tomato fruit weight compared with when a row of basil surrounded tomato plants (Fig 15c).

c) Non-Marketable Fruit number per Plant

Non-marketable fruits yield was significantly reduced by the use of agronet covers and companion planting with basil in all sampling dates (Table 9). Growing tomato under agronet cover and in companion with basil generally reduced the number of unmarketable fruit with the highest reduction obtained when tomato plants were grown under agronet with a row of basil in between adjacent rows of tomato or surrounding the tomato plants. Growing tomato as a pure stand but under agronet covers also substantially reduced on the number of unmarketable fruits compared to the control. Growing tomato in the open without agronet cover but in companion with basil also recorded a reduction in the number of unmarketable fruits compared to the control treatment although the reduction was not statistically significant in most sampling dates. Overall, non-marketable fruit numbers per plant for the two seasons was similar.

Overall, non-marketable fruit numbers were significantly reduced following the use of agronet covers compared to no net covers as observed for all data collection dates of both seasons (Fig 16a). Planting tomato in companion with basil resulted to a reduction in total number of non- marketable fruits compared to pure stand production of tomato in most sampling dates except at 120 DAT of both seasons where no statistical significant difference was realized (Fig 16b). Comparing the two basil planting arrangements, planting tomato with a single row of basil in between adjacent tomato rows recorded lower non-marketable fruit numbers compared to

Table 9. Effect of agronet cover and companion planting on non-marketable fruit numbers (no/plant) during tomato production in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting			
		98	105	112	120
T+N+BB	1	2.5bc*	2.7bc**	2.2de	2.7bc
T+N+BI	1	2.3c	2.4bc	1.9e	2.4bc
T+N	1	2.5bc	2.3bc	2.8cd	2.8bc
T+BB	1	4.6ab	4.7a	4.3abc	4.9ab
T+BI	1	4.2ab	2.4bc	4.7abc	5.4a
TC	1	6a	5.0a	6.3a	6.0a
T+N+BB	2	2.6bc	2.3bc	2.5cde	2.7bc
T+N+BI	2	2.2c	1.8c	2.1de	2.1c
T+N	2	2.6bc	2.7bc	3.1bcd	2.5bc
T+BB	2	4.2ab	3.8ab	4.7abc	4.1abc
T+BI	2	3.9ab	3.5abc	3.7bc	3.5abc
TC	2	4.9a	4.4a	5.1ab	4.5ab

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

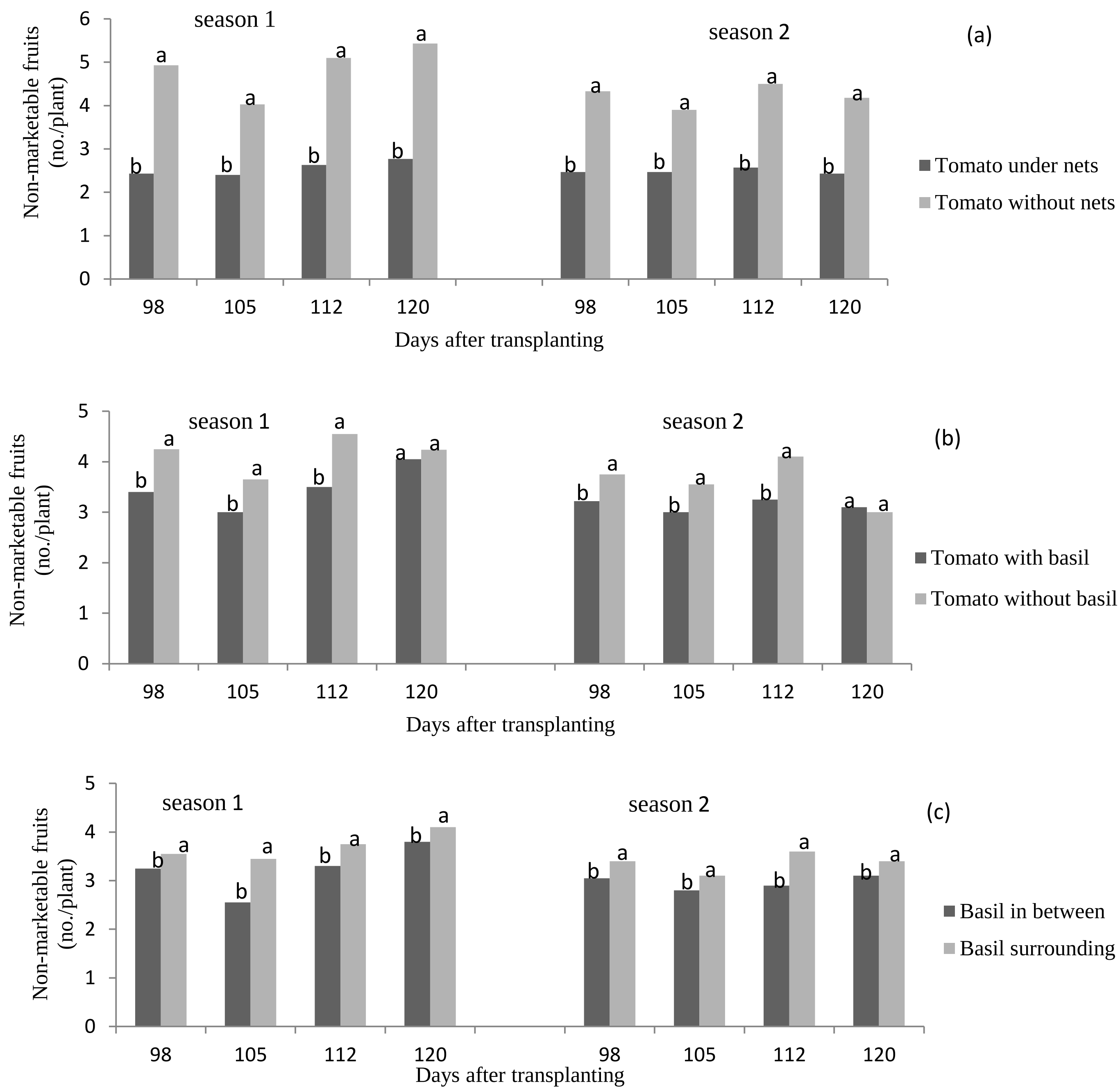


Fig 16. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on non-marketable fruit number during tomato production season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within an evaluation date are not significantly different according to LSD test at ($P \leq 0.05$)

planting a row of basil surrounding the tomato plants in most sampling dates of both seasons (Fig 16c).

d) Non- Marketable Fruit Weight

Non marketable fruit weight followed a similar trend to that of non-marketable fruit numbers in almost all the sampling dates (Table 10). Use of agronet cover and companion planting with basil resulted in a reduction of harvestable non marketable fruit weight with the lowest weight being recorded under agronet cover and companion planting with a row of basil planted in between adjacent rows of tomato in all sampling dates. Other agronet covered treatments also recorded low weight compared to the open treatments and the control. The highest non-marketable fruit weight was recorded under the control treatment in all sampling dates. Growing tomato in the open without net cover but with a row of basil planted in between adjacent rows of tomato or surrounding the tomato plants also recorded high non-marketable fruit weight though lower than the control treatment in most sampling dates indicating no statistical significant difference.

Comparing the main effects of growing tomato under agronet cover against the use of no net cover, the least non-marketable fruit weight was recorded under agronet covered treatments compared to treatments where agronet covers were not used in all the different sampling dates of both seasons (Fig. 17a). Considering the two cropping regimes, planting tomato with basil as a companion crop also recorded a reduction in non-marketable fruit weight in almost all sampling dates except at 120 DAT in season 2 where no statistical significant difference was recorded compared with the treatment where tomato was planted as a pure stand without companion basil (Fig 17b). Comparing the two basil planting designs, non-marketable fruit weight was lowest where basil was planted in between adjacent rows of tomato in most data evaluation dates compared to where a row of basil surrounded the tomato crop except at 105 DAT in season 1 and 112 WAT in season 2 (Fig 17c).

e) Total Yields

Growing tomato under agronet cover and in companion with basil significantly enhanced total number of tomato fruits, total fruit weight and significantly reduced total number of non-marketable fruits per hectare in both seasons (Table 11).The highest total number of tomato fruits and total fruit weight was recorded under agronet cover and companion planting with a

Table 10. Effects of agronet cover and companion planting on non-marketable fruit weight (kg/plant) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Days after transplanting			
		98	105	112	120
T+N+BB	1	0.2883d*	0.2456cd**	0.3254bc	0.2878cd
T+N+BI	1	0.2354e	0.2146d	0.2707cd	0.2785cd
T+N	1	0.2930d	0.2890bc	0.3148bc	0.2948cd
T+BB	1	0.3563bc	0.3431b	0.4586a	0.4276a
T+BI	1	0.3516bc	0.3360b	0.3649b	0.3520b
TC	1	0.4875a	0.3869a	0.4587a	0.4353a
T+N+BB	2	0.2584de	0.2758bcd	0.2457d	0.2674de
T+N+BI	2	0.2323e	0.2448cd	0.2442d	0.2219e
T+N	2	0.2567de	0.2543cd	0.2813cd	0.2480de
T+BB	2	0.3875b	0.3312b	0.3616b	0.3168bcd
T+BI	2	0.3345cd	0.3016bc	0.3576b	0.3200bc
TC	2	0.3974b	0.4154a	0.4326a	0.3212bc

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$)

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

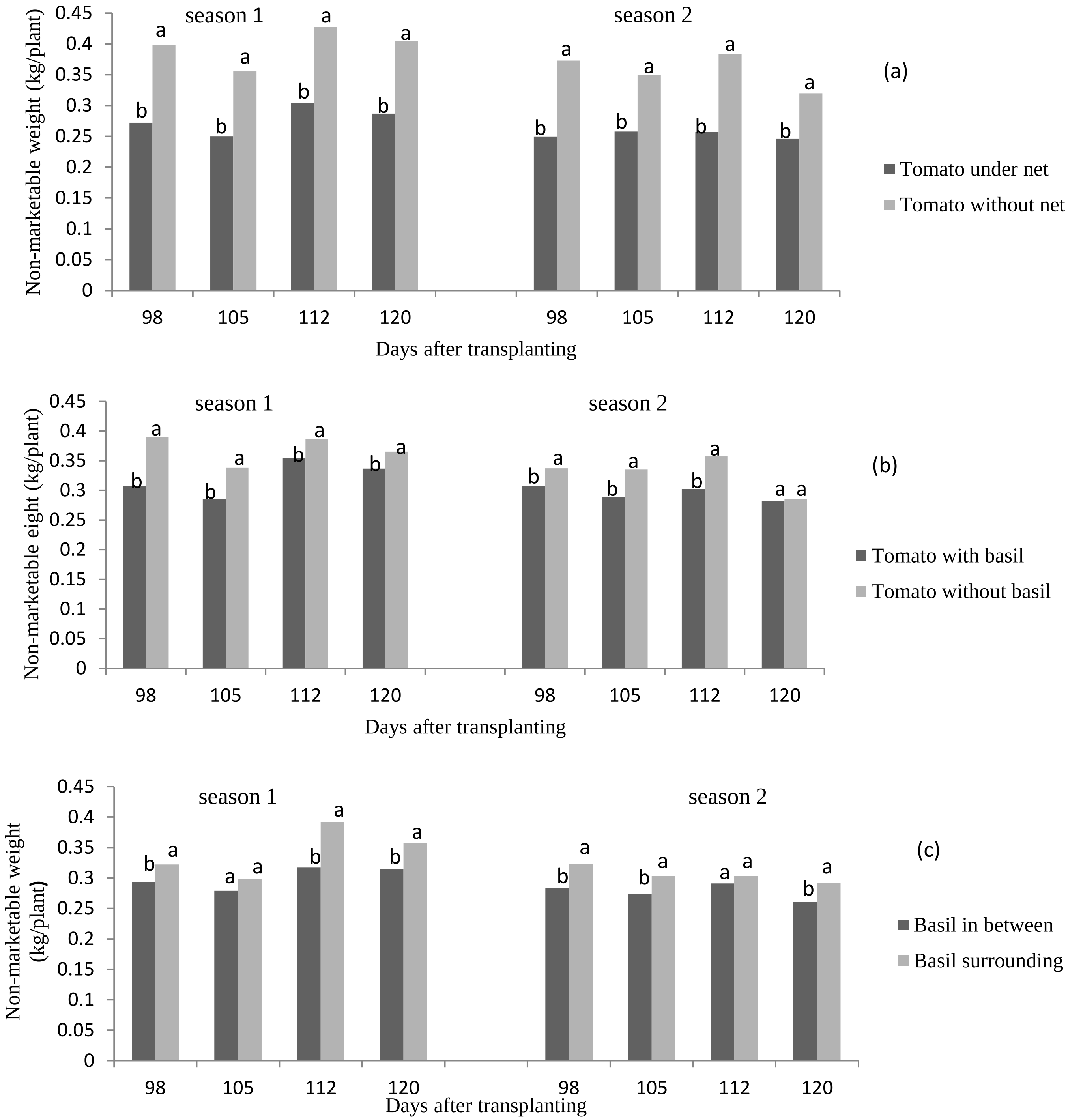


Fig 17. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on non-marketable fruit weight during tomato production season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within an evaluation date are not significantly different according to LSD test at (P≤0.05)

Table 11. Effects of agronet cover and companion planting on total marketable fruit number (no./ha), total fruit weight (t/ha) and total non-marketable fruit (no./ha) during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Treatment	Season	Total marketable fruit number (no./ha)	Total marketable fruit weight (t/ha)	Total non-marketable fruits (no./ha)
T+N+BB	1	350,000ab*	12.41ab**	48,875ef
T+N+BI	1	385,000a	13.75a	43,625f
T+N	1	345,000ab	11.58ab	64,375cd
T+BB	1	274,500bc	9.51bc	95,625abc
T+BI	1	299,500abc	10.47bc	81,125bc
TC	1	223,750cde	8.75bcd	101,875ab
T+N+BB	2	276,250bc	10.47b	56,875de
T+N+BI	2	300,000abc	12.59ab	51,250e
T+N	2	243,125bc	9.79bc	68,125bcd
T+BB	2	180,750e	8.21cd	79,460bc
T+BI	2	200,750de	8.73bcd	101,250ab
TC	2	160,165e	5.9d	118,125a

*Means not followed by a letter within a column are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

**Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

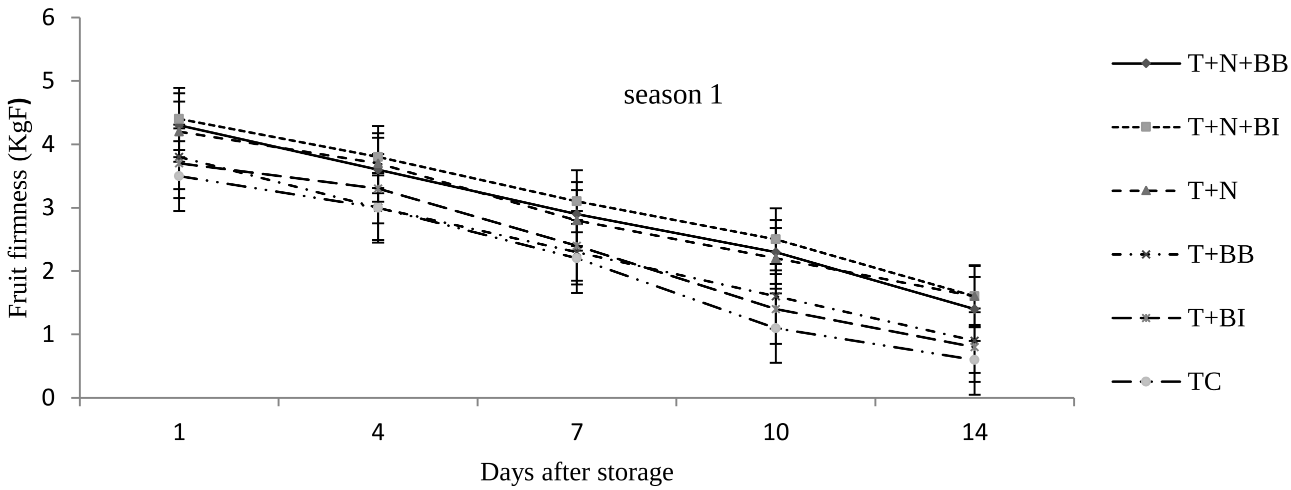
row of basil in between adjacent rows of tomato though the difference was not statistically significant from the other agronet covered treatments. Total non-marketable fruit numbers were highest under the control treatment with the least number of non-marketable fruits being recorded under the treatments where tomato was grown under agronet cover in companion with basil particularly under the treatment where tomato was grown under agronet cover with a row of basil planted in between adjacent rows of tomato.

4.5 Effects of Agronet Cover and Companion Planting with Basil on Postharvest Quality of Tomato Fruit

Postharvest fruit quality attributes studied include i) fruit firmness, ii) Total Soluble Solids (TSS), iii) Titratable Acidity (TA), and iv) Sugar Acid ratio (TSS/TA).

a) Fruit Firmness

The use of agronet cover and companion planting significantly influenced tomato fruit firmness during storage (Fig 18). As expected, fruit firmness decreased with ripening of tomato fruit throughout the study period. During the first growing season, firmer fruits were obtained on tomato plants grown under agronet cover in companion planting with a row of basil either in between adjacent rows of tomato or surrounding the tomato crop from outside of the net cover. Percent loss in firmness increased with advancement in storage period from 14% at 4 DAS to 64% at 14 DAS in tomato grown under agronet cover with a companion row of basil in between adjacent rows of tomato compared to the control treatment and from 16 % at 4 DAS to 65 % at 14 DAS in tomato produced under agronet cover with a row of companion basil surrounding the tomato crop from the outside of the agronet cover compared to the control. The control treatment had the highest percent firmness loss of 20% at 4 DAS and 83% at 14 DAS. Firmer fruits were also obtained from tomato plants grown as a pure stand under agronet cover with a gradual percent firmness loss rising from 12% at 4 DAS to 62% at 14 DAS compared to 83% loss of firmness in the control treatment during the same sampling period. Similarly, loss in fruit firmness was also slower in tomato grown in the open without agronet cover but in companion with basil compared to control tomato although the difference was not statistically significant in all the sampling dates.



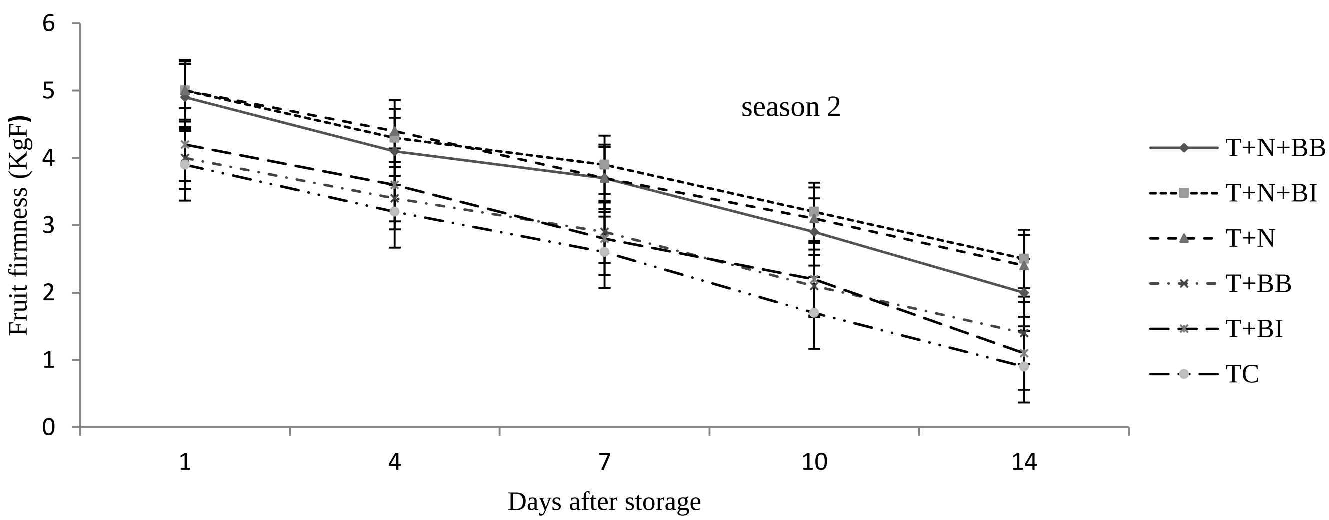


Fig 18. The effects of agronet cover and companion planting on tomato fruit firmness (KgF) during storage in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Means having the same letter within a sampling date are not significantly different according to LSD test at ($P \leq 0.05$).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

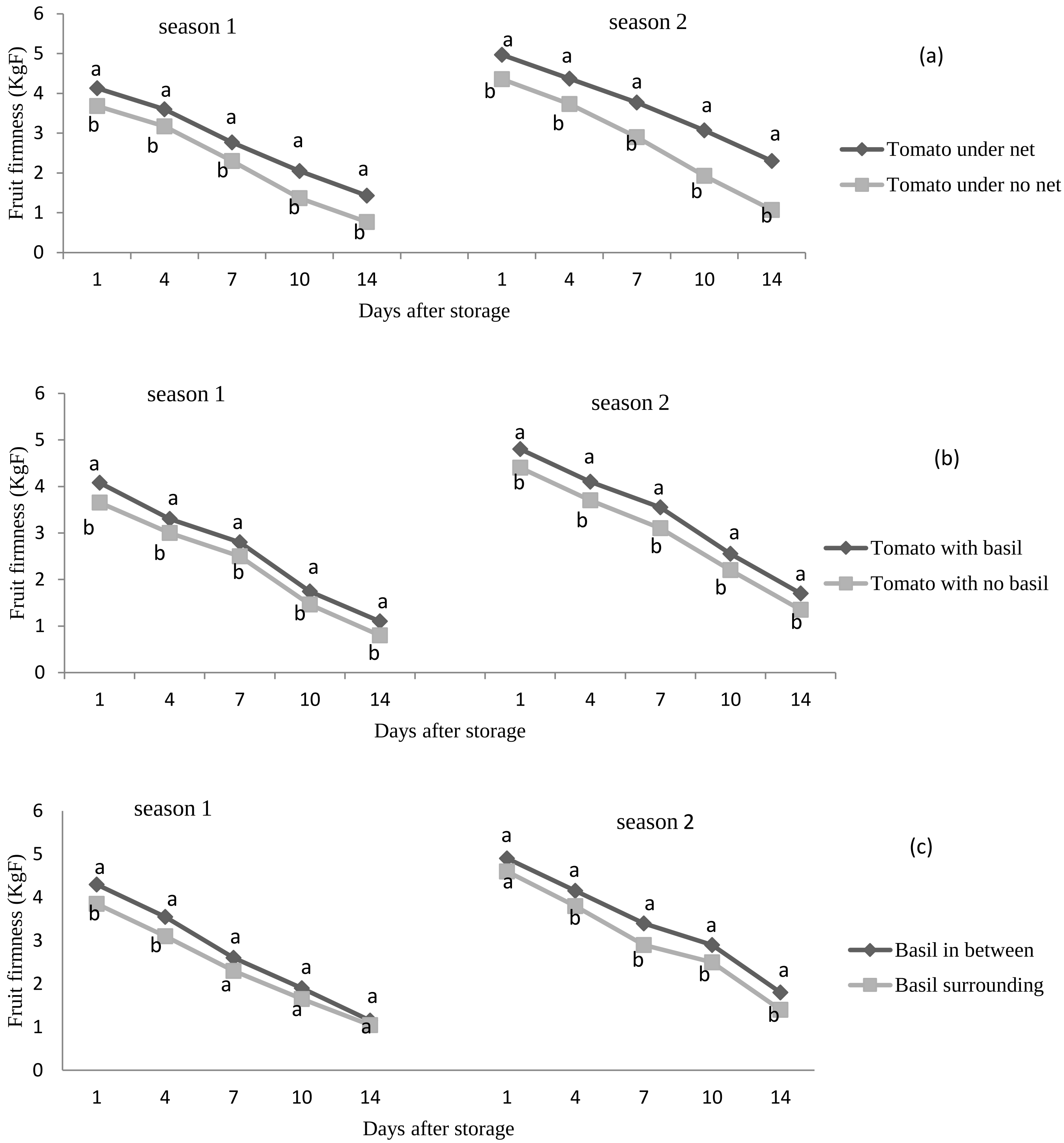


Fig 19. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato fruit firmness in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Data points with the same letter are not significantly different according to Tukey's Honestly Significant at ($P \leq 0.05$).

A similar trend was observed during the second season, with tomato grown under agronet covers and in companion with basil treatments recording even lower rate of firmness loss compared to the control. Firmness loss in tomato fruits grown under agronet cover and companion planting with a row of basil in between adjacent rows of tomato was 8 % at 4 DAS rising to 50 % at 14 DAS while treatments where tomato was grown under agronet cover with a row of basil surrounding the tomato crop from the outside of the net cover recorded a firmness loss of 13 % at 4 DAS rising to 59 % at 14 DAS. The control treatment recorded firmness loss of 19 % at 4 DAS rising to 81 % at 14 DAS. Growing tomato under agronet cover as a pure stand on the other hand recorded a firmness loss of 12 % at 4 DAS rising to 52 % at 14 DAS. A reduction in firmness loss was also recorded in fruits obtained from open treatments but in companion with basil compared to the control although the difference was not statistically significant in all sampling dates.

Comparing the use of agronet covers with no nets, tomato plants grown under agronet cover produced firmer fruits compared to those grown without net covers in all the sampling dates of both seasons (Fig.19a). Much firmer tomato fruits were also recorded from tomato grown in companion with basil compared to tomato grown as a pure stand in most sampling dates except at 10 DAS in season 1 and at 1 DAS in season 2 where the difference in firmness from the two cropping regimes was not statistically significant (Fig.19b). Comparing the two basil planting arrangements, planting a row of basil in between adjacent rows of tomato plants produced much firmer fruits as recorded in most sampling dates except at 7, 10 and 14 DAS in season 1 and at 1 DAS in season 2 where the main effect of planting pattern on fruit firmness was not statistically significant (Fig.19c).

b) Total Soluble Solids (TSS)

Tomato fruit total soluble solids (TSS) during storage were significantly influenced by the use of agronet cover in companion planting with basil during the production phase of the crop in both seasons (Fig 20). In season 1, tomato plants grown under agronet cover in companion with basil and those grown as a pure stand under agronet cover produced fruits with the highest increase in sugar levels of 53 to 67% respectively at 10 DAS while the lowest sugars were recorded in the control treatment with 37 % at 10 DAS. Higher TSS was also recorded in fruits grown under agronet cover in companion planting with a row of basil surrounding tomato from outside of net cover with 48 % increase in TSS at 10 DAS.

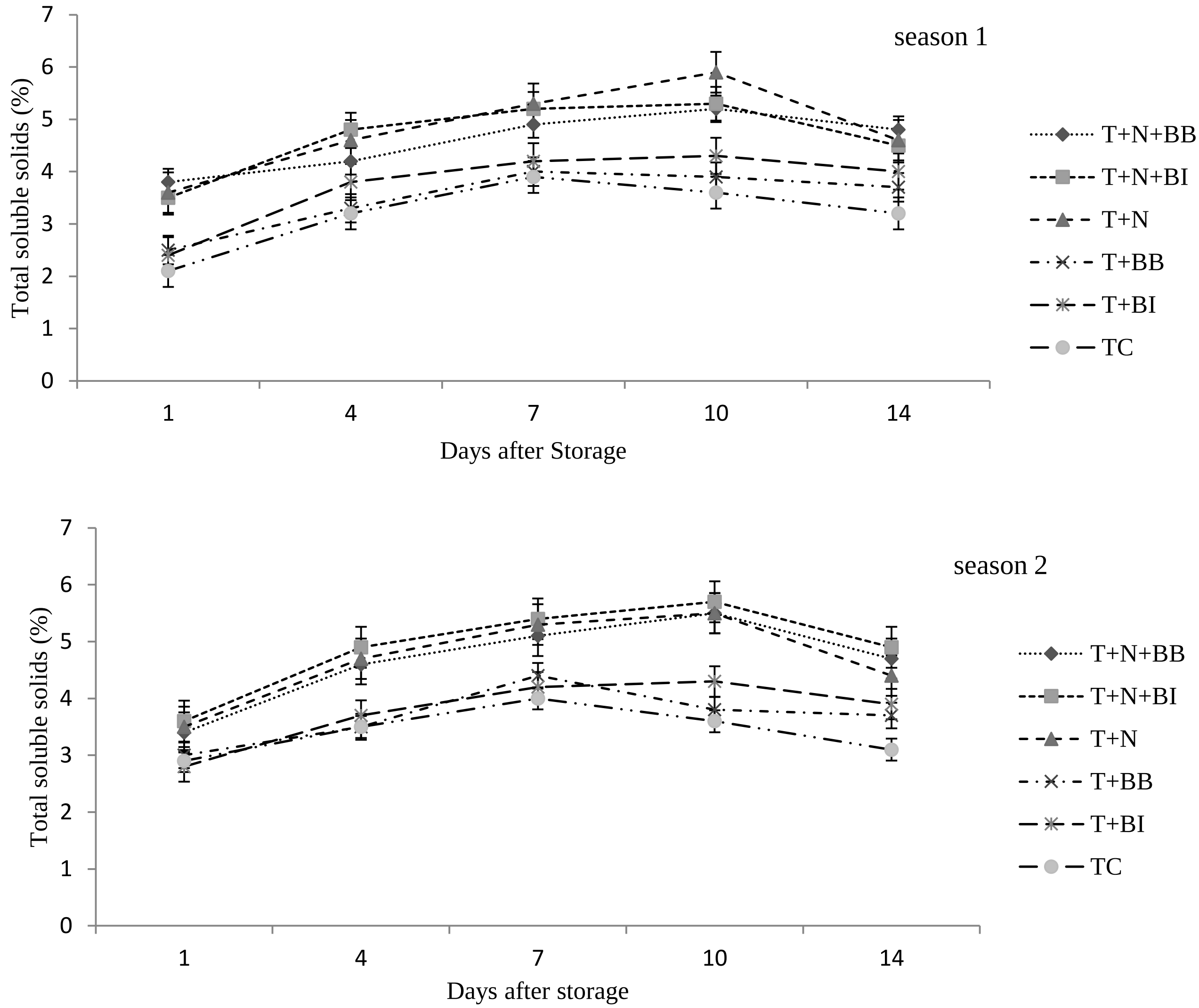


Fig 20. The effects of agronet cover and companion planting on tomato fruit total soluble solids (%) during storage in season 1 (Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014).

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

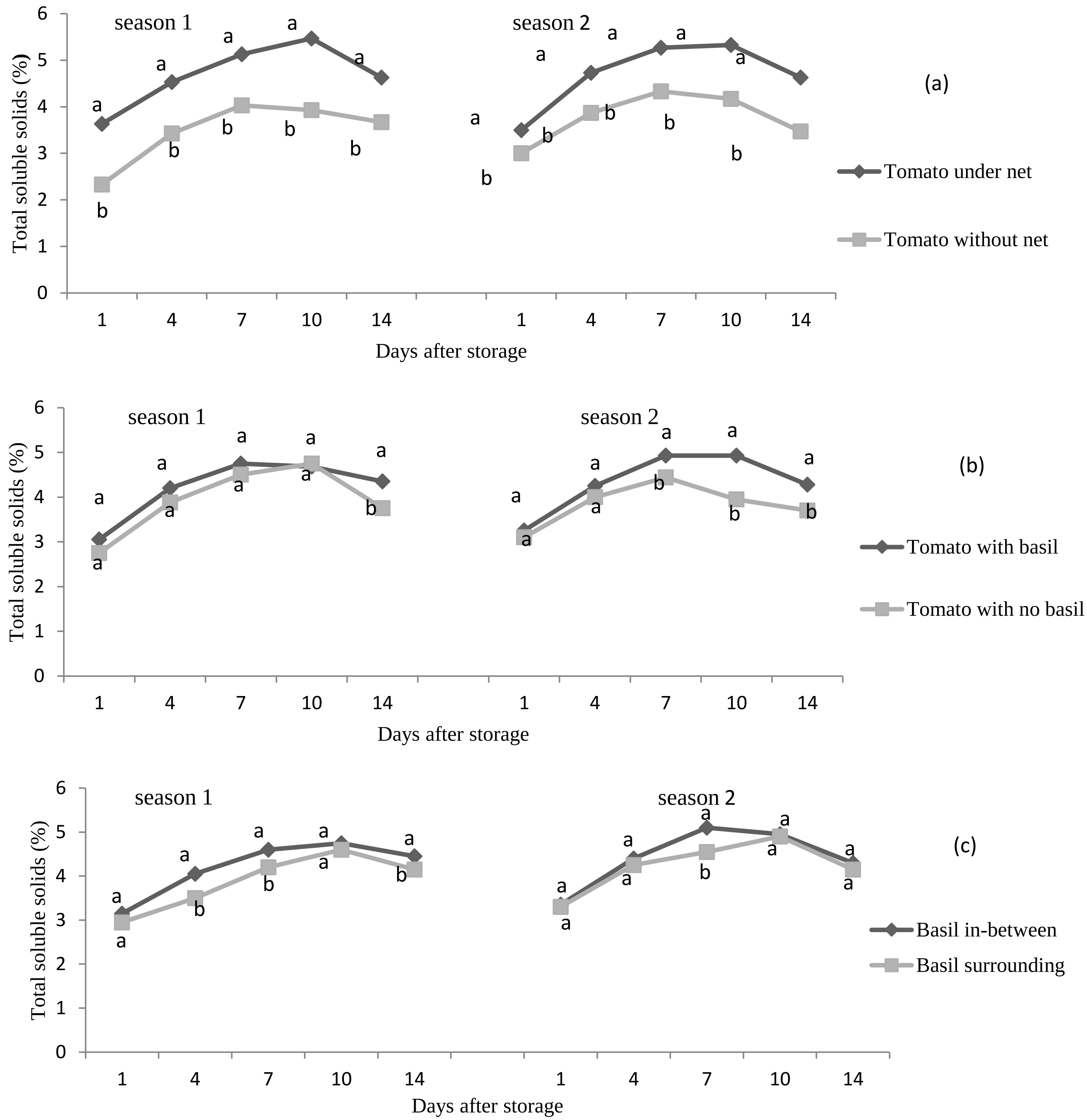


Fig 21. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato fruit total soluble solids during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Data points with the same letter are not significantly different according to Tukey's Honestly Significant at ($P \leq 0.05$).

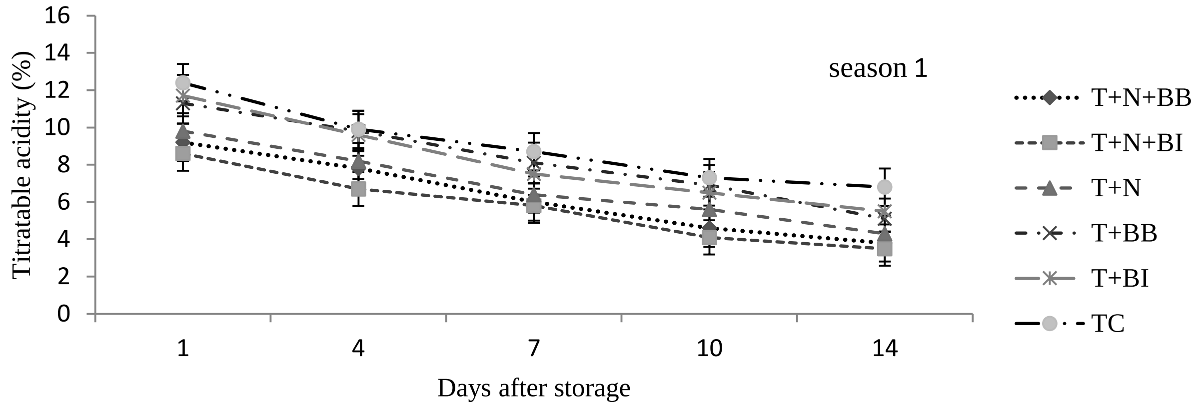
Growing tomato in the open without agronet cover but in companion with basil also recorded high fruit sugars compared with the control treatment although the differences were not statistically significant in most sampling dates. A similar trend was also observed during the second growing phase with higher sugar levels being recorded in fruits harvested from agronet covers and companion planting with a row of basil planted in between adjacent rows of tomato with 57 % sugar level at 10 DAS. Tomato grown under agronet cover alone recorded 51% at 10 DAS. Also, surrounding tomato with basil from outside of the net cover recorded a 49% increase in soluble solids as at 10 DAS. Generally fruit TSS in all treatments increased with increase in time of storage up to10 DAS beyond which sugar levels began to decline.

Comparing the main effect of growing tomato with or without agronet covers, the use of agronet covers yielded to tomato fruits with higher sugars compared to when the plants were grown without net covers as recorded in all data collection dates (Fig 21a). Similarly, fruits harvested from plants grown in companion with basil recorded higher TSS compared to those harvested from plants grown without basil except at 10 DAS in season 1 and at 1 DAS in season 2 where no statistical significant difference was recorded (Fig 21b). No statistical significant difference was observed in the two basil planting arrangements except at 4 and 7 DAS in season 1 and at 7 DAS in season 2 where planting a single row of basil in between adjacent rows of tomato plants yielded tomato fruits with higher total soluble solids compared with when basil was surrounding tomato plants (Fig 21c).

c) Titratable Acidity (TA)

Titratable acidity (TA) determined as the amount of citric acid in tomato fruit was significantly influenced by the use of agronet cover and companion planting in both seasons (Fig 22). The greatest decrease in TA was recorded in fruits obtained from tomato plants grown under agronet cover and companion planting with basil either in between adjacent rows of tomato or surrounding the tomato crop from outside of the net cover by a 56 to 59% decrease in acidity as at 14 DAS while tomato fruits harvested from plants grown under agronet cover alone as pure stand recorded a 56% decrease in TA at 14 DAS. The control treatment had the highest TA with a percent loss in acidity of about 44 % at 14 DAS.

Fruits grown in the open with no agronet cover but in companion with basil also recorded high TA but not statistically different from the control during the first growing season but lower than that of the control treatment in the second growing season. Generally



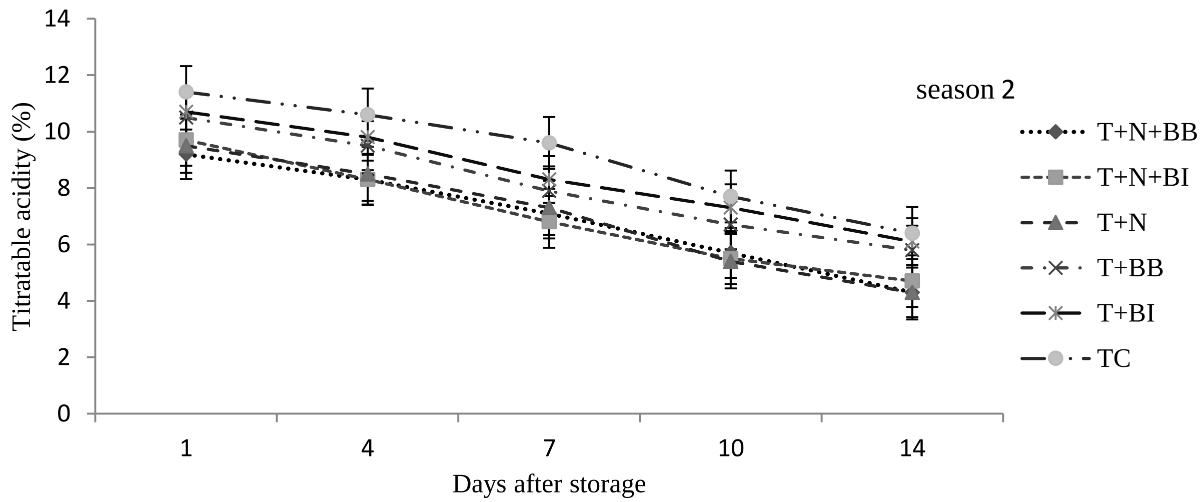


Fig 22. The effects of agronet cover and companion planting on titratable acidity (TA) of tomato fruit (%) during storage in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014)**.**

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

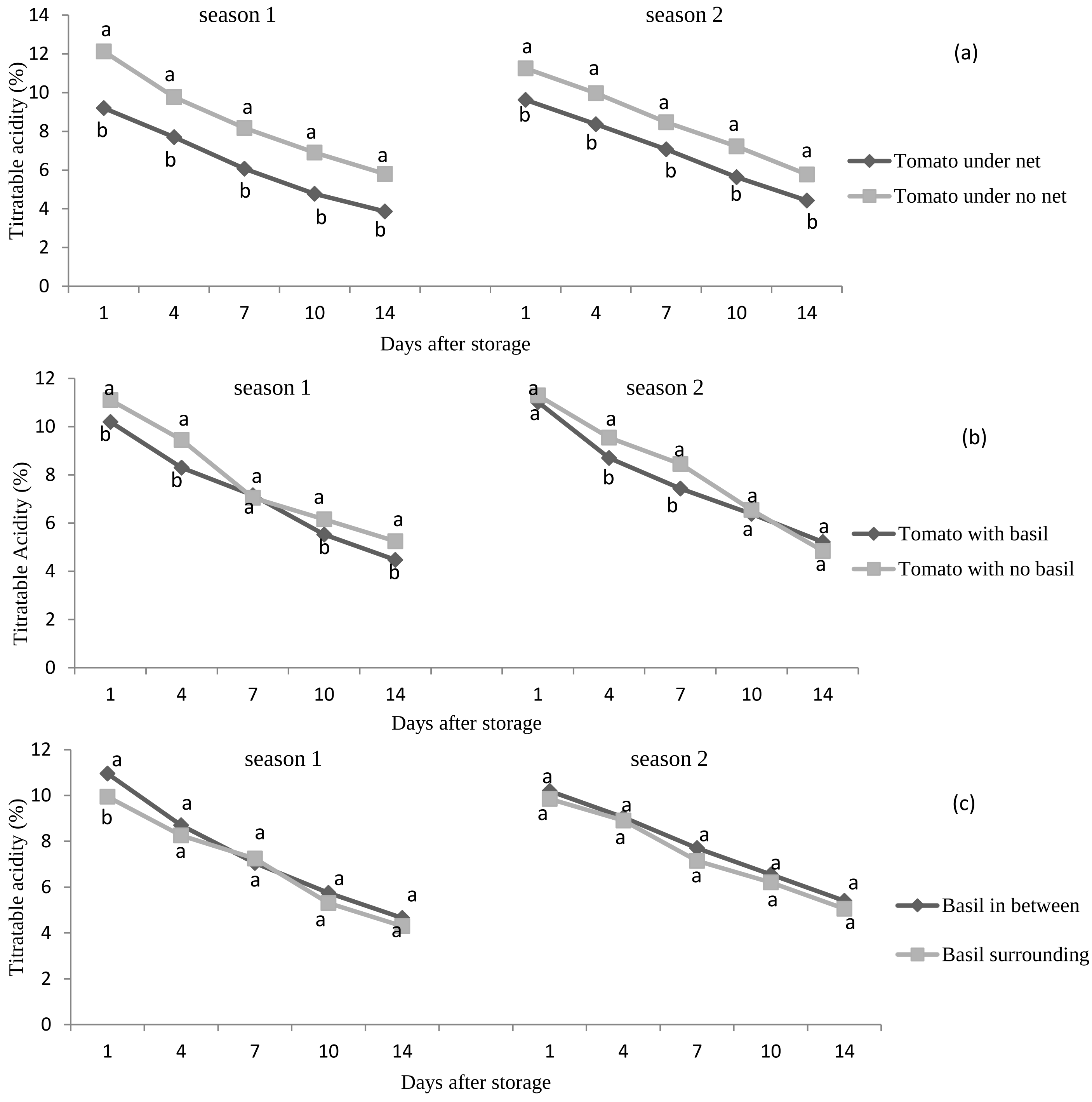


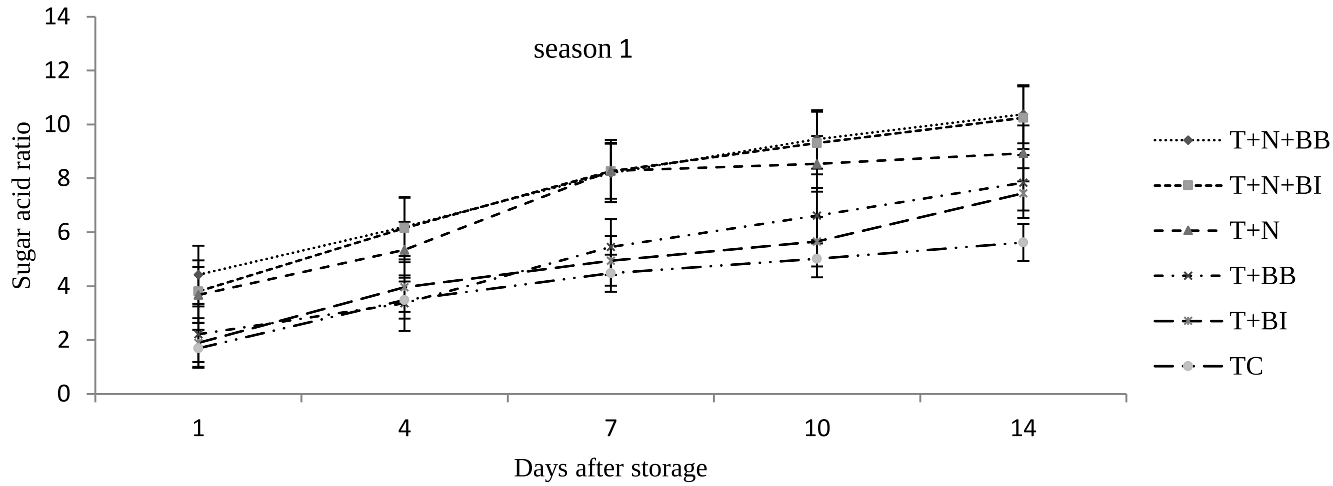
Fig 23. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato fruit titratable acidity during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Data points with the same letter are not significantly different according to Tukey's Honestly Significant at ($P \leq 0.05$).

the amount of TA decreased with increase in storage time regardless of the condition under which the tomato fruits were produced.

Comparing the use of agronet cover against no net cover, TA was significantly reduced under agronet cover treatments compared to the open treatments in all the sampling dates of both seasons (Fig. 23a). Companion planting with basil also produced tomato fruits with lower TA compared to fruits obtained from treatments where basil was not used in most sampling dates except at 7 DAS in season 1. In season 2, no statistical significant difference in fruit TA was observed amongst the treatments in all sampling dates except at 4 and 7 DAS where tomato plants grown without companion basil crop yielded fruits with higher TA compared to those grown in companion with basil (Fig. 23b). Considering the different basil planting arrangements, there was no statistical significant difference in TA between treatments planted with a row of basil in between adjacent rows of tomato and those with basil surrounding the tomato crop from outside in all sampling dates except at 1 DAS in season 1 (Fig 23c).

d) Sugar Acid Ratio (TSS/TA)

Sugar acid ratio (TSS/TA) was significantly influenced by the use of agronet cover and companion planting with basil as was the case throughout the data collection period (Fig 24). In both seasons, TSS/TA percent change (%) increased with advancement in storage days with fruits produced under agronet cover in companion with basil either in between adjacent rows of tomato or surrounding tomato plants recording the highest TSS/TA of 59 % and 62 % indicating no statistical significant difference amongst these treatments. High TSS/TA was also recorded from the treatment where tomato was grown under agronet cover as a pure stand with 57% compared to the control treatment. Throughout the data collection period, the control treatment registered the lowest change TSS/TA. On the other hand, tomato fruits harvested from plants grown in the open without net covers but in companion with basil had slightly higher TSS/TA with the difference between these treatments and the control treatment showing no significant difference at most data sampling dates of both seasons.



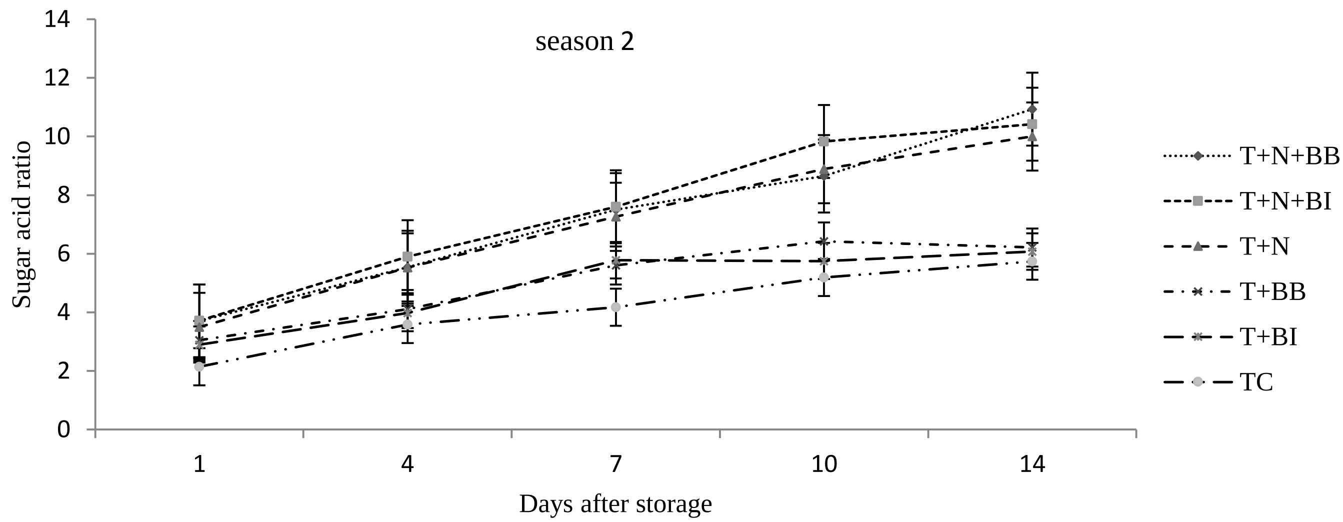


Fig 24. The effects of agronet cover, companion planting on tomato fruit sugar acid ratio during storage in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014)**.**

Key

T+N+BB is tomato produced under agronet with basil boarder surrounding outside of the net cover; T+N+BI is tomato produced under agronet with a basil row in between adjacent rows of tomato; T+N is tomato produced under agronet without basil; T+BB is tomato produced without agronet cover with a basil row surrounding outside of the agronet cover; T+BI is tomato produced without agronet cover with a basil row in between adjacent rows of tomato and TC is tomato produced without agronet cover or basil (control).

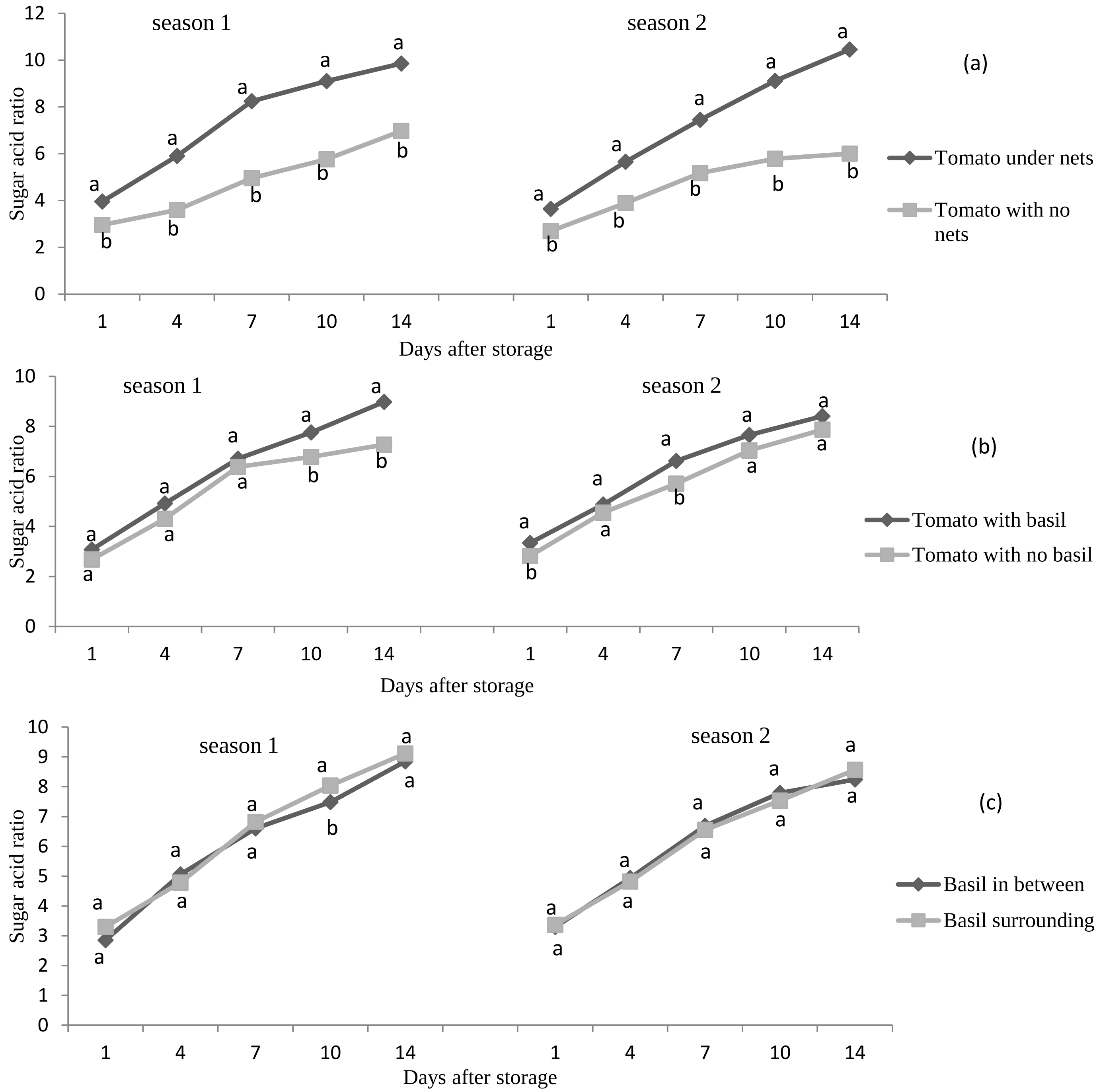


Fig 25. The effects of (a) agronet cover (b), companion planting and (c) basil planting design on tomato sugar acid ratio during tomato production in season 1(Dec 2013-Apr 2014) and season 2 (May 2014-Sept 2014). Data points with the same letter are not significantly different according to Tukey's Honestly Significant at ($P \leq 0.05$).

Comparing the main effects of growing tomato with or without agronet covers, the use of agronet covers significantly influenced tomato fruit TSS/TA compared to when the plants were grown without net covers in all sampling dates. Mean increase in tomato fruit TSS/TA was highest under agronet covered treatments compared to no nets throughout the respective data collection dates in both seasons (Fig.25a). Considering the two cropping regimes that comprised of growing tomato in companion with basil or without basil, no statistical significant difference was observed amongst the treatments in most sampling dates except at 10 and 14 DAS in season 1 and at 7 DAS of season 2 where the use of basil as a companion crop resulted to an increase in sugar acid ratio. (Fig.25b). Comparing the two basil planting arrangements that comprised of planting basil in between adjacent rows of tomato or basil surrounding the tomato crop from outside, there was no statistical significant difference observed in tomato fruit sugar acid ratio in all data sampling dates of both seasons (Fig.25c).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of Agronet Cover and Companion Planting with Basil on Growth and Leaf Stomatal Conductance of Tomato Plants

Shading nets or agricultural covers have been used in tropical and sub-tropical countries for the production of vegetables (Ilic *et al.*, 2012; Kittas *et al.*, 2012). These covers have been reported to modify internal temperature, soil moisture and diurnal temperature range within the vicinity of the crop when used for crop production (Adams *et al.*, 2001). These tend to favor physiological processes of plants leading to better growth, development, and subsequently higher yields (Weerakkody, 1998). Studies on the physiology of stomata in higher plants suggest that stomata influence the rate of gas exchange (carbon dioxide CO_2 uptake) and transpiration (water loss) through the leaf. Plants commonly respond to increased atmospheric CO_2 by adjusting their uptake and water loss. These adjustments are brought about by changes in stomatal aperture with more open stomata allowing greater conductance and consequently potentially higher photosynthesis and transpiration rates (Radin *et al*., 1988; Lawson *et al.*, 2002). Results from the current study have demonstrated that use of agronet cover and companion planting improves tomato leaf stomatal conductance compared to when the crop is grown as a pure stand in the field. Leaf stomatal conductance was highest under the treatment where agronet cover and companion planting with a row of basil in between adjacent rows of tomato were used in combination by 36% compared with the control. This happening could be attributed to the 'perceived'improved growth condition in particular soil moisture content which is vital for changes in turgor within guard cells and accessory cells which are maintained open for a longer duration thereby favoring leaf stomatal conductance (Asai *et al*., 2000).

Use of basil alone as a companion crop without agronet covers recorded 11% increase leaf stomatal conductance compared to the control. The high leaf stomatal conductance recorded in the current study could be attributed to improved growth conditions ranging from increased soil moisture, relative humidity, and temperature conditions under the net cover compared to the open treatments. Findings of the current study support results from previous studies on the effect of nets covers on tomato (Gogo *et al*., 2012; Saidi *et al*., 2013) and cabbage seedling and plant growth (Muleke *et al*., 2013) who respectively reported enhanced tomato and cabbage stomatal conductance under net covers compared to open field treatments. Similarly, lower rates of stomatal conductance observed in open treatments of the current study may be attributed to unfavorable growth conditions prevailing in the open conditions such as water stress, high temperature among others which generally causes the stoma to close down.

Companion plants have also been found to possess diverse effect on each other which can be described as being either additive, synergistic, or antagonistic (Shou *et al.,* 1991). Several researchers have reported increased soil organic matter content and soil moisture content conservation in intercrops through lowering instantaneous solar radiation reaching the ground thus maintaining higher soil moisture content with an overall increase in soil microbial and arthropod diversity and activity (Midega and Khan, 2003; Midega *et al.,* 2009). Improvement of such factors in return give rise to improved plant growth and productivity, altered root growth and nutrient availability through mineralization (Van der Heijden *et al*., 2008; Richardson *et al*., 2009; Fan *et al*., 2011). The resultant improved soil moisture status and root development enhances uptake of nutrients such as potassium and nitrogen which in turn influence stomatal movements through changes in turgor within guard cells and accessory cells thereby favoring leaf stomatal conductance (Wu and Assman, 1993; Asai *et al*., 2000).

Basil being a heavy foliaged crop could have provided green organic matter through shedding off leaves that enhanced organic matter content in the soil thus boosting microbial activity, root growth, nutrient availability and moisture conservation. This could be used to explain the enhanced leaf stomatal conductance under companion planting treatments. On the other hand, Ohashi *et al.* 2006 reported that low soil moisture content resulted to decreased photosynthetic rate, stomatal conductance and transpiration rate (Vu *et al*., 2001) as was observed in the control treatment of the current study where leaf stomatal conductance was lowest. From the above finding, it is hypothesized that enhancement of tomato plant growth microclimate by agronet covers together with enhanced soil organic matter content from the companion basil could have worked synergistically towards improving leaf stomatal conductance under agronet cover and companion planting treatments as was recorded in the current study.

In the current study, tomato plants grown under agronet cover and in companion with basil not only registered higher stomatal conductance but also better plant growth. On average, tomato plants grown under agronet cover and in companion with basil were 19.9-22.3cm taller than those of the control treatment. Branching was also enhanced under these treatments ending up with plants with an average of 1.7-2.7 more branches under the agronet cover and companion planting treatment compared to the control. Better plant growth has been likened to higher stomatal conductance and leaf chlorophyll content both of which play vital roles in enhancing photosynthetic activities of plants (Adams *et al*., 2001) leading to availability of more photosynthates which are then translocated to the growing points leading to better plant growth.

Agricultural nets and companion crops have shown certain level of effectiveness in modifying plant microclimate. One mechanism of microclimate modification by agricultural nets is through increasing air, plant and soil temperatures (Nair and Ngouajio, 2010; Stamps, 1994, Gogo *et al*., 2012; Saidi *et al*., 2013). Tomato being a warm season crop (Waterer *et al.,* 2003) greatly benefits from any temperature increase within the required temperature range of the crop thus favoring several physiological and biochemical processes like photosynthetic enzyme activity, stomatal conductance, carbon dioxide diffusion, and photo assimilate translocation leading to better plant growth as was observed in the current study.

Apart from temperature modifications, nets and companion crops enhance shading, moisture retention, organic matter content, increased light scattering as well as reducing wind speed and wind run (Stamps, 1994) all of which have been shown to have direct impact on plant growth and development. Also, basil has been termed a poor resource competitor (Bamford, 2004) with regard to water, nutrient, space and light when grown together with tomato. Given that basil companion crop provided a solid ground-cover leaving very little space for weeds to establish (Banik *et al*., 2006) may have contributed to better performance of tomato crop grown in companion with basil. Nissim-Levi *et al*. (2008) reported increased branching, plant compactness and flower numbers per plant under shaded plants. Research work by Moller and Assouline (2007) reported that shading reduced water requirement and improved on moisture utilization in bell peppers leading to improved crop microenvironment, plant growth, leaf gas exchange, and mineral nutrient content which could also offer an explanation to the improved plant height, number of branches as well as overall crop performance under nets and companion cropping treatments observed in the current study.

5.2 Effects of Agronet Cover and Companion Planting with Basil on Tomato Whitefly Infestation

Netting has been shown to act as a physical barrier to sucking pests, thereby delaying outbreaks on vegetables (Majumdar, 2010; Martin *et al*., 2006; Bextine and Wayandande, 2001). Intercropping has also been found to not only provide alternate habitat(s) but also provide alternate food or intermediate hosts for predators thus increasing natural enemies in the intercropped system (Landis *et al.*, 2005; Song *et al.*, 2010). From the current study, agronet covers and companion planting used separately or in combination helped reduce whitefly population both on tomato plants and sticky traps (Horivers). Used separately, agronet covers achieved a better whitefly reduction on tomato plants with a percent reduction of 53-60 % compared with 12.2-15.5% obtained under companion cropping with basil alone.

Nets have not only been reported to offer physical barriers that exclude migratory insect pests from accessing the target crops but also a visual barrier to insect pests due to the bright colour thus interfering with their feeding and mating habits (Antignus and Yakir, 2004). The current study's results could possibly offer support to the success of net covers as physical and visual barrier against migratory insect pests as reported by Licciardi *et al*, (2007), who while working with temporary tunnel screens in Benin showed that the netting technology was an economically viable method amongst small-scale growers in protecting cabbage against diamondback moth. Neave *et al*. (2011) reported a 38 to 72% reduction in insect incidence on cabbage grown under net tunnels in the Solomon Islands resulting to significantly higher economic returns.

Higher plants on the other hand have been documented to harbor numerous compounds that manifest as secondary plant compounds and are considered to be a part of a chemically-based defence system against phytophagous insects (Renwick, 1999). These compounds may act through exhibiting chemical repellency, attractancy, oviposition deterrence, insecticidal effects, masking effect from the mix and /or luring pests away from the main crop leading to decreased colonization by harmful pests (Matteson *et al*., 1984; Shelton *et al*., 2008). Juxtaposition of such plants and arrays of color, different ripening times and unique aromas produced in varying degrees by certain plant species or varieties have often been known to cause camouflage of odor and appearance thus confusing plant pests in search of a suitable host. Such diverse effects of companion crops on insect pest could have worked either in a synergistic or additive manner to give rise to the low population of whitefly on tomato plants and sticky trap in the current study for treatments where basil was used as companion plant compared to no basil.

Further, basil has been known to possess strong aromatic components also known as essential oils that give distinctive odour, flavour or scent that may interfere with host plant location, feeding, distribution and mating resulting in decreased pest abundance (Lu *et al*., 2007).

These oils generally have 20–60 compounds with two to three active compounds with synergistic or additive effects (Bakkali *et al*., 2008). Typically, these oils are liquid at room temperature and get easily transformed from a liquid to a gaseous state at room or slightly higher temperature without undergoing decomposition (Koul *et al*., 2008). Methyl chavicol, a predominant essential oil in basil has been found to attract various beneficial and destructive insect pests including whitefly thus disrupting their feeding on target crops such as tomato (Koul *et al*., 2008). This volatile compound is sensitive to temperature and vapourizes easily at temperature above 28ºC (Martins *et al.,* 2012). Agronet covers have on the other hand been reported to increase air temperature by 15 to 20% compared with the open treatments (Gogo *et al*., 2012; 2013) a factor that could have favored the transformation of methyl chavicol and other volatiles from liquid to gaseous state in the current study. Owing to the increase in temperature, insulating effect and reducing air circulation property of agronet covers (Saidi *et al*., 2013) the concentration of the essential volatile compounds could likely have been higher inside the agronet covers than outside. Such an occurrence could therefore have led to more whitefly and other beneficial insects being trapped inside the agronet cover onto the basil plants where tomato was grown under agronet cover with a row of basil in between adjacent rows of tomato thus reducing whitefly population on tomato plants and sticky traps as was recorded in the current study. The presence of many types of beneficial insects such bees, stink bugs, ladybird and wasps observed on the basil plants could have provided biological control measure leading to a reduction in whitefly population on tomato plants and sticky traps.

5.3 Effect of Agronet Cover and Companion Planting with basil on Number of Tomato Fruits with Viral Symptoms

The ability of the whitefly to carry and spread disease is the widest impact they have had on global food production mainly due to their significant economic damage to agronomic and horticultural crops in the world (Brown *et al.,* 1995). Whitefly, a phloem-feeding insect pest has been known to vector numerous geminiviruses that inflict a variety of plant disorders as well as physical damage leading to huge loss in quality of produce (Byrne *et al*., 1990; Hiebert *et al*., 1996). Among such viral diseases vectored by the whitefly is Tomato Yellow Leaf Curl Virus (TYLCV) that has been noted as a major limiting factor for tomato cultivation all over the world with higher incidences being recorded in tropical and subtropical areas mainly because of its high activities (Lapidot *et al.,* 2001). Early infection by TYLCV has been reported to effectively destroy a crop because fruit set terminates when virus symptoms appear in the plant two to three weeks after inoculation (Berlinger *et al*., 2002) with resultant losses of upto 100% in yield (Zhou *et al*., 2008). TYLCV is transmitted persistently by the *Bemisia tabaci* species complex. An adult whitefly can retain the virus for several weeks, spreading the virus as far as they range to feed (Cohen et al., 1988). TYLCV has also been shown to be acquired by immature whiteflies developing on infected plants. The adults however are responsible for the spread of the virus to healthy susceptible host plants with their control with foliar sprays being difficult as they live on the underside of leaves (Muniz *et al.,* 2002, Zhang *et al.,* 2004). This finding could be used to explain the high number of tomato fruits with viral symptoms in the control treatment of this study compared to the number recorded for agronet covered treatments.

Effective management of TYLCV has primarily been achieved through the use of resistant cultivars, pesticides, cultural practices, and exclusion through the use of screens, and regular or UV absorbing plastics in the case of protected production (Polston and Lepidot, 2007). Such screens have been found to dramatically decrease the number of invading whitefly into covered crops or greenhouses (Berlinger and Mordechi, 1996). This finding further supports the observations made in the current study whereby lowest numbers of adult whitefly as well as nymphs on tomato plants were recorded under agronet covered treatments compared to the control and the subsequent reduction in number of tomato fruits with viral symptoms from the same treatments.

Various research works carried out to evaluate the effectiveness of screen nets in farming amongst small-scale growers have demonstrated that exclusion nets reduce infestation of insect pests and thus the intensity of the viruses that they vector (Weintraub, 2008). The current study's finding is in agreement with the work of Stansly *et al*. (2004) who described exclusion nets and other insect-proof net strategies as an effective means of controlling whitefly and other vectors of phytoplasmas. Berlinger *et al.* (2002) also reported effective management of tomato yellow leaf curl virus through the use of physical exclusion against the silverleaf whitefly using agricultural nets. The use of agronet covers in the current study may have offered protection to tomato plants from infestations by pests through physical exclusion hence reducing their chance of proliferation and subsequent transmission of diseases on tomato plants.

Practising companion planting as a farming technique has also demonstrated that the diversification of the agroecosystem may reduce insect pest infestation through influencing the rate of migration of insect pests hence causing delay in host crop colonization resulting to lower insect pest species population levels (Al-Musa, 1982; Ahmed *et al*., 1996). Results from the current study indicated that using companion basil alone reduced the number of fruits with viral symptoms by 11.2 to 12.5% compared to the control. This could be attributed to the reduction in number of whitefly recorded on treatments where tomato plants were grown in companion with basil which attracted the whitefly hence reducing their attack on tomato plant. These findings are supported by the work of Morales *et al*. (1993) who reported a reduction in whitefly population density and transmission of Tomato Yellow Leaf Curl Virus (TYLCV) on tomato planted with sorghum (*Sorghum bicolor*) as a barrier while a Pearl millet (*Pennisetum typhoides*) barrier was observed to reduce whitefly virus transmission on cowpea (*Vigna unguiculata*) (Sharma and Varma, 1984) and on soybean (*Glycine max*) (Rataul *et al*., 1989).

In a bid to manage insect pests and viral disease transmission, researchers have combined two or more approaches with better results being realised. For instance, Deletre *et al*. (2015) observed that using a combination of visual barriers and repellent compounds emitted artificially or naturally was effective in reducing the orientation and attraction of the whitefly to host plants and thus lowering the rate of whitefly crossing the net hence reducing the risk of virus transmission. Such an observation could have applied in the current study whereby combined benefits of agronet cover and companion planting with basil may have worked synergistically towards the reduction in number of tomato fruits with viral symptoms in the treatment where tomato was grown under agronet cover in companion with basil planted either in-between adjacent rows of tomato or surrounding the tomato crop from outside that recorded the lowest number of tomato fruits with viral symptoms.

5.4 Effects of Agronet Cover and Companion Planting with Basil on Yield Components and Yield of Tomato Plant

The present study has shown that use of agronet cover and companion planting with basil led to an increase in the number of flower trusses and the subsequent total tomato fruit yield and also led to a reduction in non-marketable fruit yield compared with the control. Agronet cover combined with basil had a better effect with 64.2 to 79.4% increase in flower trusses compared with agronet cover alone with a recording of 51.4 to 54.2% or basil used alone at 25.0 to 28.3% compared with the control. In general, growing tomato under agronet cover yielded better than open field treatments. Similarly, tomato yielded better under companion planting with basil than as a pure stand. Among the two companion planting pattern, basil planted in between adjacent tomato plants improved yields more than having basil surrounding the tomato plants.

Given that tomato requires adequate soil moisture for its growth and development (Moreno *et al.*, 2002), intercropping basil with tomato under agronet cover may have enhanced shading effect on the soil leading to a reduction in the rate of evapotranspiration resulting in better moisture status of the soil which in turn favored better growth and development of the tomato observed in the current study. Adams *et al.* (2001) reported higher soil moisture content under net covered treatments translating to higher number of flowers per plant compared to open field treatments. Various studies carried out to determine the effect of water on plants at different stages of growth and development have established that water stress among other factors at the seedling and flowering stages are more critical in determining crop yield (Shou *et al.*, 1991), thus the use of basil and agronet cover may have cushioned the tomato crop against excessive water loss from the soil leading to more flower trusses, flowers and fruit yield being realized.

Also, the shading effect offered by agronet covers and companion planting, net covers have been documented to modify air temperature and the diurnal temperature range hence providing ideal growth condition leading to improved yield. Gogo *et al.* (2012) reported an average increase in daily temperature of ≈ 3.5 ºC and a decrease in diurnal temperature range by ≈ 3.4 ºC indicating more stable temperature regimes under net covers compared to open field production. Such microclimate improvement under net covers improves plant growth through changes in leaf characteristics, biomass accumulation, and relative growth rate leading to better yield and crop quality (Soltani *et al*., 1995). These findings agree with the current study results. Rylski and Spigelman (1986) working on sweet pepper (*Capsicum annuum*) showed that under field conditions during the summer where day temperatures were ≥32 °C, fruit set was reduced. Also from the same work, they reported a reduction in radiation by approximately 26% under shade net which resulted to significant increase in sweet pepper production compared with exposure to full sunlight where marketable yield was reduced due to excessive heat stress.

From the current study, higher yield in terms of fruit number and weight was obtained with the use of agronet cover and companion planting with a 35 to 51 % increase in fruit number under agronet cover alone. Combined use of agronet cover and companion planting with a row of basil in between adjacent rows of tomato recorded a 72 to 86.1 % increase in tomato fruit number and 80 to 83.5 % increase in tomato fruit weight compared to the control. The high yield obtained in the current study could be attributed to microclimate modification offered by the net covers that enhance growth and physiological responses such as increased photosynthetic ability of tomato plants leading to more food being manufactured and translocated to active sinks hence promoting growth and development. This in return may have resulted to the higher yields in terms of marketable fruit number and weight observed in the current study. Similar results were reported by Weerakkody *et al.* (1999) who reported higher marketable yield and quality fruits from protected culture treatments compared with the uncovered treatments.

Comparing the use of basil as a companion plant against no basil in the current study, companion planting with basil improved tomato yield by 17 to 19 % compared with treatments where basil was not used. Similar results were reported by Miyazawa *et al.* (2010) who recorded better yields of green manure intercrops compared to the yield sum of the component species grown alone and attributed the good performance to better use of available growth resources such as nutrients, water, and light. Bamford (2004) classified basil among the poor resource competitors in regard to water, nutrient, space and light when grown together with tomato. Such an observation may be used to offer an explanation to better tomato growth and development leading to more fruit number and weight recorded under companion planting treatments in this study.

Just like other crops grown under nets, basil under net covers displayed better vegetative growth and flowered earlier and more profusely than that grown in the open. Better growth and more flowers on basil translates to more concentration of volatile compounds leading to more attraction of insect pest including whitefly and other beneficial insect (Koul *et al*., 2008) onto the basil plant. This would in return deter the insects from feeding on tomato plants hence the minimal damage on fruits recorded under combined use of agronet cover and companion basil treatments in the current study. Such an occurrence coupled with a better growing environment under agronet cover may have led to more fruit numbers, higher fruit weight as well as reduced non-marketable fruit yield observed in the tomato-basil companion cropping treatment under agronet cover in the study.

Higher infestation on crops from pest and diseases may lead to high percent of non-marketable products (Gaye and Maurer, 1991) as was the case under the open treatments including the control treatment in the current study. Growing tomato under agronet cover and companion basil gave rise to fewer non-marketable fruits with a reduction percentage of 48.1 to

57.3% compared to the control. Insect pest damages, disease infestation, sunscald as well as physiological disorders have been known to adversely affect marketability of produce by lowering their acceptability by consumers (Gaye *et al.,* 1992). Covering tomato with agronet covers in the current study may have physically excluded pest (Majumdar, 2010; Martin *et al*., 2006) as well as improved the growth microclimate hence reducing the number of tomato fruits with physiological disorders as well as physical damage on tomato fruits leading to fewer non-marketable fruits. El-Aidy and Sidaros (1996) reported higher marketable yield and less non-marketable fruits under protected tomato compared with the non-protected ones.

5.5 Effects of Agronet Cover and Companion Planting with Basil on Postharvest Quality of Tomato Fruit

When tomato is exposed to direct solar radiation as is the case in open field production, such qualities as fruit firmness, titratable acidity, total soluble solids, sugar to acid ratio among others are interfered with, giving rise to fruits with reduced or unacceptable market value. Milenković *et al.* (2012) reported that under exposed conditions, tomato fruit temperature may rise by 10 °C or more above the ambient thus affecting its quality. Results from this current study have demonstrated that use of agronet cover and companion planting during production increases tomato fruit firmness, TSS, and sugar acid ratio, but reduces TA compared to open field production. The best quality fruits were harvested from agronet cover and companion planting with a row of basil in-between adjacent rows of tomato which recorded more firm fruits by 35.2 to 39.4 %, total soluble solids being highest at 37.6 to 44.6%, sugar to acid ratio at 80 to 90.4 % while titratable acidity was lowest at 25.3 to 34.2 % compared with the control. This may be associated with improved plant growth micro-environment under agronet cover. These observations are in tandem with those by Saidi *et al*. (2013) who reported better tomato fruit quality from tomato plants grown under agronet and floating row covers.

Temperature, water and mineral nutrition have been identified as part of pre-harvest factors that significantly affect produce quality (Weerakkody *et al.,* 1999). Microclimate modification reported in earlier studies on agricultural nets (Gogo *et al*., 2012; Saidi *et al.*, 2013) and companion cropping (Riotte, 1975) improves tomato physiological ability through influencing such biochemical processes as photosynthesis, cell wall development, cell membrane integrity and ripening process of fruits (Weerakkody, 1999; Adams *et al*., 2001) leading to better produce quality. This process in return enhances synthesis and accumulation of photosynthates such that maximal partitioning of sugars (and other components that contribute to the important quality attributes of tomato) are accumulated in the fruit, instead of the shoots prior to harvest giving rise to fruit that are firm, high in TSS and TSS/TA (Schauer *et al.,* 2005) and prolonged shelflife compared to exposed treatments. Such findings can be considered in the explanation of the current study's results for tomato fruits harvested from agronet cover and companion planting with basil. Considering the keeping quality of tomato fruits in the current study, tomato fruits from agronet cover and companion planting treatments recorded the lowest percent firmness loss of 59% at 14 DAS compared to 81% on control treatment indicating that tomato fruits obtained from agronet cover and companion planting treatments maintained firmness for a longer period compared to the control and hence could be kept for a longer period. Shading of tomato fruits has been found to ameliorate such heat stresses at the time of fruit development (Diaz-Perez, 2013).On the other hand, the high percent rate of deterioration or loss of quality in tomato fruits from the control and other uncovered treatments could be likened to high temperatures on fruit surface caused by pronounced exposure to sunlight prior to harvest hence hastening ripening and other associated events compared to covered treatments. Although no data was collected in the current study on influence of net in the colour of tomato, similar trials have shown that high light intensity can lead to disorders in the development and appearance of tomato fruit colour (Dorais *et al.*, 2001). Thus shading tomato plants with net covers may have protected the fruits from physiological disorders and physical damage resulting to better quality fruits.

Research work done for different fruits has shown that at the beginning of the ripening process the TSS/TA is low because of low sugar content and high fruit acid content which makes the fruit taste sour but as the ripening process continues, starch gets converted to sugars gradually leading to an increase in total soluble solids, reduction in titratable acidity and subsequently increase in TSS/TA value that forms an important indicator of flavour (Shyam and Matsuoka, 2004).This gradual change in conversion of starch was evident in the current study with tomato fruits obtained from agronet cover and companion planting treatments that showed a consistent gradual and high percent changes in quality attributes compared to open treatments and the control.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The following conclusion can be drawn from the present study;

i. Growing tomato under agronet cover reduces whitefly population, improves growth, yield and postharvest quality of tomato compared with open field production
ii. Using basil reduces whitefly population, improves growth, yield and postharvest quality of tomato compared with growing tomato in pure stand.
iii. Planting basil as companion crop in between tomato plants results in greater reduction of whitefly population, improved growth, yield and postharvest quality of fruits compared with having basil surrounding the tomato crop.
iv. Combined use of agronet cover and companion planting results in a greater reduction in whitefly population improved growth, yield and postharvest quality on tomato than when the two technologies are used in isolation.

6.2 RECOMMENDATIONS

Based on the above conclusion, I would recommend use of agronet covers and companion planting with basil either alone or in combination by small to medium scale growers to lower the amount of insect pest infestation on tomato as well as improve growth, yield and postharvest quality for open field tomato production systems.This could serve as an option in reducing the indiscriminate application of the costly and harmful synthetic insecticides used in the management of whitefly in the open fields. Moreover, the strategy presents itself as a viable, affordable and easy to implement practice by most small to medium scale farmers who cannot afford the costly greenhouses. It is however, worth to note that more studies need to be conducted using different aromatic plants as companion crops since a multitude of plant species contain volatile compounds in variable composition which are not chemically identical hence the need to evaluate their effect on insect pests especially the whitefly as these could be a useful complementary or alternative strategy to the heavy use of classical insecticides. Similarly further studies need to be conducted to evaluate the effects of agronet cover and companion cropping on beneficial insects used as bio control organisms.

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APPENDICES

Appendix 1. Publication

Mutisya, S., Saidi, M., Opiyo, A., Ngouajio, M. and Martin, T. (2016). Synergistic Effects of Agronet Covers and Companion Cropping on Reducing Whitefly Infestation and Improving Yield of Open Field-Grown Tomatoes. ***Agronomy*****, 6 (3); 42.**

Appendix 2. Effects of agronet cover and companion planting on stomatal conductance (µmol/m^{-2}/s) at 42 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	20918.14			
Block	4	2271.54	567.88	3.34	0.0179
Season	1	5682.90	5682.90	33.46	<0.0001
Treatment	5	3308.23	661.65	3.90	0.0052
Season*Treat.	5	2181.85	436.37	2.57	0.0400
Error	20	7473.62	169.85		

Appendix 3. Effects of agronet cover and companion planting on whitefly population (no /plant) at 28 DAT

Sources	df	ss	ms	F ratio	Prob >F
Total	29				
Block	4	1063540	265885	2.25	0.0794
Season	1	1660007	1660007	14.02	0.0005
Treatment	5	3256730	651346	5.50	0.0005
Season*treat.	5	691065	138213	1.17	0.3404
Error	20	5210114	118412		

Appendix 4. Effects of agronet cover and companion planting with basil on whitefly (no. /sticky trap) at 28 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	11881455.33			
Block	4	1063539.67	265884.92	2.25	0.0794
Season	1	1660006.67	1660006.67	14.02	0.0005
Treatment	5	3256730.13	651346.03	5.50	0.0005
Season*Treat.	5	691065.33	138213.07	1.17	0.3404
Error	20	5210113.53	118411.67		

Appendix 5. Effects of agronet cover and companion planting with basil on plant height (cm) at 70 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	111.8			
Block	4	2.14	0.53	1.18	0.33
Season	1	7.13	7.13	15.72	0.0003
Treatment	5	71.79	14.36	31.64	<0.0001
Season*Treat.	5	10.85	2.17	4.78	0.0014
Error	20	19.97	0.454		

Appendix 6. Effects of agronet cover and companion planting with basil on number of branches (No/plant) at 56 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	108.60			
Block	4	4.44	1.11	3.44	0.0157
Season	1	13.24	13.24	41.05	<0.0001
Treatment	5	72.21	14.44	44.76	<0.0001
Season*Treat.	5	4.51	0.90	2.80	0.0281
Error	20	14.20	0.32		

Appendix 7. Effect of agronet cover and companion planting with basil on number of trusses (no. /plant) at 63 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	1690.41			
Block	4	48.80	12.20	0.83	0.5149
Season	1	17.64	17.64	1.20	0.2801
Treatment	5	918.54	183.71	12.46	<0.0001
Season*Treat.	5	56.64	11.33	0.77	0.5780
Error	20	648.79	14.75		

Appendix 8. Effects of agronet cover and companion planting with basil on number of flowers (no/plant) at 63 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	57830.49			
Block	4	1266.51	316.63	1.16	0.3434
Season	1	7440.41	7440.41	27.15	<0.0001
Treatment	5	35025	7005.10	25.56	<0.0001
Season*Treat.	5	2041.35	408.27	1.49	0.2125
Error	20	12056.74	274.02		

Appendix 9. Effects of agronet cover and companion planting with basil on number of fruits (No/plant) at 112 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	424.67			
Block	4	63.49	15.87	3.0	0.0530
Season	1	172.61	172.61	32.57	<0.0001
Treatment	5	84.35	21.09	3.98	0.0214
Season*Treat.	5	24.73	4.95	0.93	0.4871
Error	20	79.49	5.30		

Appendix 10. Effects of agronet cover and companion planting with basil on tomato fruit weight (gm/plant) at 120 DAT.

Sources	df	ss	ms	F ratio	Prob >F
Total	29	726458.86			
Block	4	118535.10	29633.77	2.25	0.1120
Season	1	313588.48	313588.48	23.82	0.0002
Treatment	5	59219.51	14804.88	1.12	0.3818
Season*Treat.	5	37682.57	7536.51	0.57	0.7200
Error	20	197433.20	13162.21		

Appendix 11. Effects of agronet cover and companion planting with basil on non-marketable fruit number (no/plant) at105 DAT.

Sources	df	ss	ms	F ratio	Prob > F
Total	29	67.77			
Block	4	4.47	1.12	1.76	0.1545
Season	1	0.068	0.068	0.11	0.7453
Treatment	5	27.18	5.43	8.54	<0.0001
Season*treat.	5	8.06	1.61	2.53	0.0424
Error	20	28.00	0.64		

Appendix 12.Effects of agronet covers and companion planting on fruit firmness (KgF) at 10 DAS.

Sources	df	ss	ms	F ratio	Prob >F
Total	17	10.10			
Block	2	0.02	0.01	0.14	0.8686
Season	1	7.09	7.09	105.36	<0.0001
Treatment	5	0.31	0.06	0.91	0.4930
Season*treat.	5	1.20	0.24	3.57	0.0160
Error	10	1.48	0.67		

Appendix 13. Effects of agronet cover and companion planting with basil on total soluble solids (^{O}Brix)) at 7 DAS.

Sources	df	ss	ms	F ratio	Prob >F
Total	17	5.03			
Block	2	0.23	0.11	1.29	0.2966
Season	1	0.42	0.42	4.75	0.0403
Treatment	5	2.12	0.43	4.78	0.0042
Season*Treat.	5	0.29	0.06	0.65	0.6620
Error	10	1.96	0.09		

Appendix 14. Effects of agronet cover and companion planting with basil on titratable acidity (%) citric acid at 7 DAS.

Sources	df	ss	ms	F ratio	Prob > F
Total	17	42.16			
Block	2	0.23	0.11	0.19	0.8272
Season	1	0.50	0.50	0.83	0.3725
Treatment	5	19.48	3.90	6.44	0.0008
Season*treat.	5	8.62	1.72	2.85	0.0394
Error	10	13.32	0.60		

Appendix 15. Effects of agronet cover and companion planting with basil on TSS/TA at 1 DAS.

Sources	df	ss	ms	F ratio	Prob >F
Total	17	10.40			
Block	2	0.28	0.14	1.54	0.2361
Season	1	0.69	0.69	7.48	0.0121
Treatment	5	6.27	1.25	13.64	<0.0001
Season*treat.	5	1.13	0.23	2.46	0.0650
Error	10	2.02	0.09		