DIPLOMA THESIS

Joel Ayebeng Adjei

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BUDAPEST

Assessment of the Effects of Pests and Diseases on Three Tomato (*Solanum Lycopersicum*) Genotypes' Yield Under the Hedgerow System in the Organic Farm

Joel Ayebeng Adjei

Department of Agroecology and Organic Farming

Collaborator department(s): Department of Vegetable and Mushroom Growing

Supervisors: Dr. Szalai Zita Magdolna

Supervisors: Mohammed Omer Mustafa (PhD) Student.

Reviewers:

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Head of Department Supervisor

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1. INTRODUCTION

Vegetables are a crucial part of agriculture, contributing significantly to global food security and giving many farmers a source of income (Rai *et al.*, 2019). Because of the expanding population, shifting lifestyles, and greater interest in eating healthily, the demand for vegetables has been rising. As a result, the world economy's vegetable business has grown to be a significant sector. During the past few years, the worldwide output of fresh fruits and vegetables has climbed by 30%. From 30 million tons to 60 million metric tons, it has grown. Vegetable farmers must control temperature, water, light, soil, pests, and diseases to achieve the best possible development and output of their crops (Wells *et al*., 2000).

Tomato (*Solanum lycopersicum*) is a widely cultivated fruit crop belonging to the Solanaceae or the nightshade family (Naika *et al*., 2005). It originated in South America and was domesticated for the first time around 500 years ago in Mexico. Being one of the most significant crops internationally in terms of both economic worth and nutritional relevance, tomatoes are now cultivated in virtually every country in the world (Peralta *et al*., 2008). The cultivation of tomatoes is mainly in the open field and greenhouses but tomato production alternatives that prioritize sustainability, soil health, and biodiversity preservation include organic farming systems (Altieri *et al*., 2015). The process involves soil preparation, irrigation, pest control, and hand harvesting. Successful production requires careful planning and management (Gatahi, 2020).

Agroforestry methods merge trees, shrubs, or other perennial plants with crops, while organic farmers employ natural inputs and stay away from synthetic fertilizers, pesticides, and genetically modified organisms (Montagnini and Nair, 2004). Although weed control, irrigation, and labour are difficult for farmers to manage, these systems have the potential to improve soil quality, conserve biodiversity, and have a smaller negative impact on the environment (Van Der Werf, 2020). In the organic field production of tomatoes, there are occurrences of several pests and diseases that affect yield and profitability for farmers. These plant protection problems affect the growth and final yield of the tomato plant and hence, reduce the economic value of the fruits (Kandel *et al.*, 2020). Organic farming uses natural methods to control pests and diseases (Singh, 2021).

The use of natural methods for pest and disease control, such as crop rotation, resistant varieties, cultural practices, biological control agents, and physical control methods, is an important aspect of organic farming. The use of natural methods for pest and disease control is an important strategy for promoting sustainable agriculture and protecting the environment (Faroque *et al*., 2017). Regular monitoring of the crop is necessary to detect any signs of pest or disease problems early, so that appropriate action can be taken to prevent them from becoming severe. This proactive approach helps to minimize the need for reactive measures such as the use of synthetic pesticides, which can have negative impacts on the environment and human health. The effects of pests and diseases could be devastating. This could lead to a partial or total loss of the plantation or to a total loss of investment to the farmer. Hence, the need to tackle pests and diseases issues with seriousness (Van Bruggen *et al*., 2016).

2. OBJECTIVES

The general research aims to evaluate the impact of microclimate conditions on the pest and disease problems of three tomatoes (Szentlőrinckáta, ACE55, and Roma) genotype in the final yields under hedgerow systems. To compare the performance of three tomato genotypes cultivated and exposed to the hedge's windy sides and protected sides. This study aims to contribute to sustainable farming practices by providing insight into the most effective approaches for managing pest and disease problems under organic tomato farms.

The specific objectives of the study:

- To assess the impact of insect damage on three different tomato fruit genotypes on both the windy and protected sides of the hedgerows caused by the potato beetle (*Leptinotarsa decemlineata*) and cotton bollworm (*Helicoverpa armigera*) insect.
- To determine the number of fruits damaged by fungal infections by *phytophthora infestans* and wild animals on the three tomato genotypes from both windy and protected sides.
- To evaluate the final yield of healthy fruits from the three tomato genotypes on both the windy and protected sides.

This study will provide insights into practical approaches for maximizing crop production and minimizing pest and other environmental damage.

3. LITERATURE REVIEW

3.1. History and Background of the Tomato Plant.

Tomato was originally named *Solanum lycopersicum* by Linnaeus in 1753. Previously, tomatoes have also been known as *L. esculentum*. The cultivated tomato (*Solanum lycopersicum*) and its 12 wild relatives are all native to western South America and comprise the tomato clade (section Lycopersicon, formerly known as the genus Lycopersicon) (Knapp and Peralta, 2016). Tomato cultivars can be found in different regions where their biological origin center coexists with their wild relatives and other closely related, early domesticated species. According to Harlan (1971), secondary centers are places that are geographically different from the crop's natural center of the distribution, also referred to as centers of trans-domestication. Tomatoes are believed to have first been domesticated in Mexico, with Peru serving as the hub of variation for species that are closely related. *Solanum lycopersicum cerasiforme* is thought to be the ancestor of the cultivated tomato, based on its wide presence in Central America and the presence of a shortened style length in the flower. However, recent genetic investigations have shown that the plants known as '*cerasiforme'* are a mixture of wild and cultivated tomatoes rather than being ancestral to the cultivated tomatoes (Nesbitt and Tanksley, 2002).

Tomato was introduced to Europe by Spanish conquistadors in the early 16th century. Despite initial skepticism, tomatoes eventually became a popular ingredient in European cuisine by the 18th century. In the United States, tomatoes were not widely consumed until the late 19th century when they became popular in condiments such as ketchup (Pilcher, 2017). Today, tomatoes are one of the most widely cultivated crops in the world, with major producers including China, India, the United States, and Mexico. The spread of tomatoes from South America to other parts of the world showcases human ingenuity and the importance of agricultural biodiversity. *Solanum Lycopersicum* has been identified as having its natural distribution, abundance, or origin in a narrow region of western South America between the Andes Mountain ranges and the Pacific coast (Chetelat *et al*., 2009). The red-fruited *S. galapagense* and *S. cheesmaniae*, which were found in the Galapagos Islands, are the three wild species that are most closely related to domesticated tomatoes, according to 2012 research by the Tomato Genome Collaboration (Menda and Mueller, 2013).

3.2. The Biology of The Tomato Plant

Although there are biennial and perennial varieties of the tomato, it is most frequently cultivated as an annual crop. Tomatoes are grown in open fields or greenhouses in temperate and tropical climes, respectively. For industrial-scale production, greenhouses are frequently employed. It takes around 45 days from germination to anthesis and 90–100 days to reach the commencement of fruit ripening in a warm region with the appropriate light intensity for growth (Nuez, 2001). The cultivars planted, the time of harvest, and the harvest procedures which can be manual or mechanical depend on whether the crop will be used for the processed market or the fresh market (Nuez, 2001). The plant may develop in a variety of ways, from indeterminate to determinate, and can grow as tall as 3 meters (Mngoma *et al*., 2022). The main root might extend several meters. The tomato plant has a fibrous root system with roots that can extend up to 60 cm deep in the soil (Hebbar *et al*., 2004). The stem is covered with small hairs and has a woody texture at the base. The leaves are simple, alternate, and ovate with a serrated margin. The flowers are typically yellow and have a five-lobed corolla, with stamens and pistils located in the center of the flower. The fruit of the tomato plant is a fleshy berry with a smooth, shiny skin that can range in color from green to red, yellow, or even purple (Everett, 1980).

The tomato plant is a self-pollinating plant, which means that the flowers are capable of self-fertilization. The flowers are pollinated by bees, wind, or by self-fertilization. Once the flower is pollinated, it develops into a fruit, which contains seeds for the next generation (Dingley *et al*., 2022). The tomato plant requires warm temperatures (above 10°C) and ample sunlight to grow and produce fruit. The plant grows best in well-drained, fertile soil with a pH between 6.0 and 6.8. The plant undergoes several stages of growth and development, including seed germination, vegetative growth, flowering, fruit development, and maturation. Tomato seeds germinate best in warm soil (around 25°C) and typically take 5-10 days to germinate. The seedlings emerge from the soil with two cotyledons, which provide the initial source of energy for the growing plant (Sobarzo-Bernal *et al*., 2021). During the vegetative growth stage, the tomato plant produces leaves, stems, and roots. The plant will continue to grow and produce new leaves and stems until it reaches maturity. The vegetative growth stage typically lasts for 6-8 weeks. Once the tomato plant reaches maturity, it will begin to produce flowers. The flowers typically develop on the ends of the branches and are followed by the development of the fruit (Hariyadi *et al*., 2019).

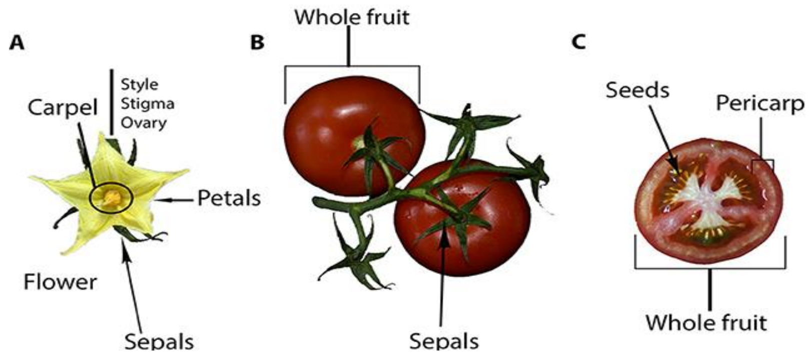

Figure 1. *The flower, fruit and cross section of the fruit of a tomato* (HTTP 1).

3.3. The Morphology of The Tomato Plant

The morphology of tomato plants can vary depending on the specific cultivar and growing conditions (Romero-Aranda *et al*., 2001). The root system of tomato plants can grow up to 2-3 feet deep and up to twice the size of the above-ground plant, which makes it an efficient system for nutrient uptake and water absorption. The stem of tomato plants is typically cylindrical in shape and can have a hairy or slightly rough surface. As the plant grows, it can reach heights of up to 3 meters, but it is usually trained to grow in a more compact form to make it easier to manage and harvest. This can be achieved by pruning the plant or by using a trellis or cage to support the stem (Mngoma, 2020). The stem of tomato plants has nodes where the leaves and flowers emerge. These nodes are spaced out along the stem at regular intervals and are important for the growth and development of the plant. The leaves of tomato plants are compound, meaning that they are made up of multiple leaflets. The leaves are arranged alternately on the stem, and each leaf typically has 5-9 leaflets. The leaflets are ovate in shape, which means they are wider at the base and narrower at the tip, and they have a serrated edge. The leaves can range in size from 4-10 cm in length, depending on the cultivar and growing conditions (Pan *et al*., 2023). The leaves are important for photosynthesis, which is the process by which the plant produces energy from sunlight, carbon dioxide, and water.

The flowers of tomato plants are typically yellow and have five petals. The flowers are arranged in a cyme inflorescence, which is a type of flower cluster where the main stem ends in a flower and the lateral branches produce additional flowers. The inflorescence of tomato plants can produce up to 50 flowers, although the exact number can vary depending on the cultivar and growing conditions (Menda *et al*., 2004). Each flower of the tomato plant has both male and female reproductive parts, which means it is self-pollinating. The male reproductive parts consist of the stamen, which produces pollen, while the female reproductive part is the pistil, which contains the stigma, style, and ovary. When the pollen from the stamen comes into contact with the stigma, it travels down the style and fertilizes the ovules in the ovary, leading to the formation of the fruit (Tanda, 2022). The fruit of the tomato plant is a berry that can vary in size, shape, and color depending on the cultivar. Tomatoes come in a wide range of sizes, from tiny cherry tomatoes to large beefsteak tomatoes, and they can be round, oblong, or even irregularly shaped. The color of the fruit can range from green to red, yellow, orange, or even purple, depending on the cultivar (Rivero *et al*., 2022). The fruit of the tomato plant typically has two to three chambers filled with seeds, although the exact number can vary. The flesh of the fruit is juicy and contains high levels of vitamins and minerals, including vitamin C, vitamin K, and potassium. The seeds are surrounded by a gel-like substance that is rich in antioxidants and has been shown to have health benefits (Haroon, 2014).

3.4. The Taxonomical Classification of The Tomato Plant

The tomato crop belongs to the Solanaceae family, which comprises 2,280 species and many of which are valuable commercially as food and medicinal plants (Knapp and Peralta, 2016). The family is quite diversified, including species of annual and perennial herbaceous plants, and it lives in a variety of terrestrial habitats, including deserts and rainforests. While having members all over the world, the tropical parts of South America, where over 40 species are endemic, are where the Solanaceae family is most prevalent. Tomato classification has been the subject of much discussion and the diversity of the genus has led to reassessment of earlier taxonomic treatments (Knapp, 2002). *Solanum pimpinellifolium* and *Solanum cerasiforme* are the two wild ancestor species from which tomato (*Solanum lycopersicum*) is derived. The 12 wild members of the Lycopersicum clade exhibit a significant degree of morphological and genetic variety, as well as a wide range in mating and reproductive biology. The taxonomy of tomatoes has been seriously contested, and the genus' diversity has caused many to re-evaluate earlier taxonomic theories. Tomatoes were previously known as *Lycopersicon esculentum*, but a recent study has revealed that they belong to the genus Solanum and are now often referred to as *Solanum Lycopersicum*. For breeding disease resistance, improved color, and desired quality features, other wild species are helpful. One way to improve disease resistance in tomato is to incorporate genes from wild tomato species into cultivated varieties. Wild tomato species, such as *Solanum pimpinellifolium*, *Solanum habrochaites*, and *Solanum pennellii*, are known to possess genes that confer resistance to various pathogens, including viruses, bacteria, and fungi., color, and other desired qualities (Peralta, 2008).

The current classification of the crop is as followed:

Kingdom: Plantae

Order: Solanales

Family: Solanaceae

Genus: Solanum

Species: S. Lycopersicum

Binomial name: *Solanum Lycopersicum* L.

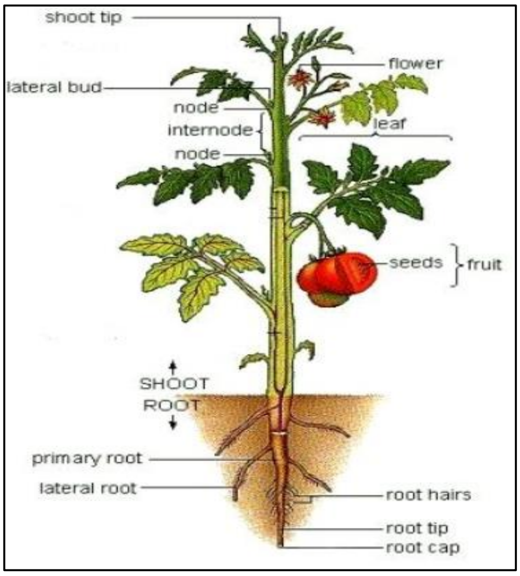

Figure 2. *A full tomato plant* (HTTP 2)

3.5. The World Production of Tomato

Table 1. *Tomato production quantity around the world* (reports FAOSTAT, 2023).

Country	Production (tons per hectare)
China	67 636 724
India	21 181 000
Turkey	13 095 258
United States of America	10 475 265
Italy	6 644 265

3.6. The Economic Importance of Tomato Production

Tomatoes are one of the most widely cultivated vegetables globally, with a global production of over 182 million tons in 2023. The production of tomatoes creates employment opportunities for millions of people in the agricultural sector, which helps to drive economic growth in many countries (Khalid *et al.,* 2023). Tomatoes are a highly valuable crop that generates significant revenue for farmers, traders, and processors and processing of tomatoes create employment opportunities for millions of people worldwide (Hellin *et al.,* 2019). Tomatoes are used in a wide range of food products, including sauces, soups, juices, and canned products. The food industry is a significant contributor to the global economy, and the use of tomatoes in food products generates significant revenue for food manufacturers (Sibomana *et al.,* 2016). Tomatoes are a highly traded commodity, with many countries importing and exporting them. Countries that are major producers of tomatoes, such as China, India, and the United States, generate significant revenue from tomato exports, which helps to boost their economies (Mohammad, 2011).

The color, shape, and size of tomatoes intended for the fresh market might vary; tomatoes intended for the processing business are often machine harvested, and they should have an intense red color and high solids content suited for making paste, ketchup, or sauce. Therefore, conserving the quality of these products is paramount for consumer safety. Fresh tomato costs are more variable than processed tomatoes, with the shipment chain paying one-fourth of the ultimate price (Samoggia *et al*., 2021). Tomatoes are grown in temperate, subtropical, and tropical climates worldwide and are the world's second most productive horticultural crop. Controlled conditions certify tomato production by using artificial lighting, increased temperature, and fertigation increases the production of the tomatoes for economic gains (Blanca *et al.,* 2012).

3.7. The Tomato Varieties

3.7.1. Roma VF

A specially bred plum tomato that is ideal for preserving and making ketchup, tomato juice, and soups (Markam, 2014). Tomato 'Roma VF' produces fleshy, juicy, almost seedless fruits with a deliciously different flavor which makes it an excellent variety for eating fresh too (Nipa *et al*., 2020). This semi-bush variety is very heavy cropping and has good resistance to verticillium and fusarium wilt. A versatile variety that can be grown outside or in the greenhouse. As a determinate plant (Abrha *et al*., 2015), it was originally introduced in 1963 by the Joseph Harris Seed Company of Rochester, New York, which crossed a Roma tomato with a California Red Top VR 9. The vines are compact and yield copious amounts of 3-inch-long fruits that come out either pear- or plum-shaped. Set in a sunny location and get ready for a large harvest. Roma tomato plants produce a high yield with their fruits (Nipa *et al.,* 2020). Your tomato plant will produce about 15 cherry red tomatoes per cluster, offering around 200 fruits per plant every growing season. The appropriate soil PH is about 5.5-7. It has a germination time of about 7-14 days after sowing and it features days to maturity between 75-95 days (Afzal *et al*., 2019).

Figure 3. *The Roma tomato genotype* (HTTP 3).

3.7.2. Szentlőrinckáta

According to the idea of landraces by Camacho Villa *et al.* in 2005, Szentlőrinckáta can be said to be a Hungarian landrace originating from the landscape district Szentlőrinckáta. It has a greater capacity to tolerate early blight (*Alternaria solani*), but it is vulnerable to late blight in unfavourable conditions (Booziné-Pullai *et al*., 2021). The growing type of the landrace is determinate with bush-like growth habits. The weight of the fruits is 45-95g. The taste of the fruits is traditional tomato-like taste, sour and sweet. It produces a lot of fruit and is resistant to early blight and has intense shoot sprouting. It helps the plant recover even after a severe *P. infestans* infection (Boziné-Pullai *et al*., 2021). Under open-field circumstances, it yields more provided that no *P. infestans* infection or frost occurs in the autumn. The skin of the fruit/berry is thin but does not tend to crack. The texture of the berry is fleshy and juicy. The color of the berry is bright red and has a pear shape. The use of the tomato berry is eating, canning, and drying and the berry falls when overripe (Abdullahi *et al*., 2016).

Figure 4. *The Szentlőrinckáta Hungarian tomato genotype landrace* (Barbara Ferschl, 2018).

3.7.3. ACE55

Advantageous characteristics of the Ace 55 include low acid content and fracture resistance (Hassan *et al.,* 2020). The Ace 55 grows in a determinate manner. These tomato seeds mature in an average of 80 days, making them adaptable to most climatic conditions (Belhachemi *et al*., 2020). The fruits are round and smooth with a slightly flattened shape, and they typically weigh between 8 to 12 ounces. The thick and robust skin of Ace 55 tomatoes makes them resistant to illness and cracking. The fruits' flesh is meaty, juicy, and sweet, and they mature to a rich crimson hue. They are a great option for individuals who want a milder tomato flavor because they are low in acid. Early-season tomato seeds can be cultivated as a fall or winter crop depending on the zone or if planted inside and take 50 to 60 days to mature (Sfeir, 2019).

Figure 5. *The ACE55 tomato genotype* (HTTP 4).

3.8. The Nutritional Value of Tomato Fruit

In addition to vitamins, provitamins, minerals, and phytosterols, tomatoes are also high in secondary metabolites such as lycopene, flavonoids, sitosterol, and polyphenols (Luthria *et al*., 2006). These bioactive compounds have physiological actions that include anti-inflammatory, anti-allergenic, antimicrobial, vasodilatory, antithrombotic, cardioprotective, and antioxidant. Carotenoids and polyphenolic compounds improve tomatoes' nutritional value by boosting their flavor and functional qualities. In addition, tomatoes contain significant amounts of naturally occurring antioxidant vitamins C and E as well as metabolites such as sucrose, hexoses, citrate, malate, and ascorbic acid (Agarwal and Rao, 2000).

3.9. The Ecological Requirements

Temperature: Tomatoes grow best in warm climates and need ideal temperatures of 26°C and 12°C to develop vegetatively. Temperatures above 31°C slow down flower fertilization, plant growth, and fruit ripening. The tomato plant requires different temperatures at different developmental stages (Adams *et al*., 2001).

Table 2. *Temperature requirements of tomato at different stages* (Shamshiri *et al.,* 2018).

Developmental stage	Optimum Temperature (°C)
Germination	15-30
Vegetative growth	20-24
Fruit set night	14-20
Fruit set day	20-24
Red color development	20-24

Relative humidity: High relative humidity can result in decreased growth and yield, while high relative humidity can increase the risk of fungal and bacterial diseases, such as powdery mildew, botrytis, and leaf spot (Tournas, 2005). Low relative humidity during the flowering and fruiting stages can result in poor fruit quality, while low relative humidity can cause the plant to lose more water through transpiration. It is important to monitor humidity levels and make adjustments as necessary to ensure that tomato plants remain healthy and productive (Choudhury *et al*., 2022).

Soil: While they do well in many different types of mineral soil, tomatoes prefer deep, well-drained sandy loams. In dense soils of the clay kind, deep tillage enables root penetration. On soils with a pH between 6.5 and 6.9, tomato production is higher. Acidic soils result in smaller fruits, and either direct seeding or transfer is used to establish the plant (Coelho *et al*., 2022).

Nutrient requirements: Tomato crop nutrient needs are determined by variety, yield, and cultural techniques (Sainju *et al.,* 2003). Studies of the soil and tissue should be done throughout the growth and production season to ensure that essential nutrients are present in the proper amounts and ratios. The following dietary requirements are regarded as typical: 30 tons of organic matter per acre, 50 kilograms of nitrogen (N), 80–100 kilograms of phosphorus (P), and 200–250 kilos of potassium per acre (K). In greenhouse environments, nutrient doses can be raised to improve productivity. Due to expense, fertilizer use is restricted in conventional agriculture in some nations, and it is not allowed in organic agriculture (Singh *et al*., 2010).

Transplantation: The land where the seedlings will be planted must be wet and holes must be dug to deposit the seeds. In the northern hemisphere, transplanting of the seedlings takes place between May through June. The planting distance for tomato plants can vary depending on the cultivar, growing conditions, and production goals (Kaboosi and Kaveh, 2012).

Fertilization: In general, fertilizer is sprayed three times: once before transplanting, once after 60 days, and once after 100 days. In Europe, organic farming is regulated by Regulation (EU) 2018/848, which sets out specific rules and standards for organic production, labelling, and certification. Synthetic fertilizers and other inputs are restricted or prohibited to promote environmentally sustainable and ecologically balanced production practices (European Commission, 2021).

Irrigation: To delay maturity and increase plant yield, tomatoes require constant watering. Irrigation also aids in the reduction of salinization with optimal salt concentration (Hoffman and Shannon, 2007). Some sources recommend that soil moisture levels never exceed 0.2 bar, while others recommend a limit of 2 bar. The required degree of soil moisture for tomatoes varies depending on the cultivation method, variety, and environment. Erratic moisture conditions can lead to radial and concentric cracking, which renders afflicted tomatoes unmarketable and causes rapid degeneration. Polyethylene-mulched beds with drip watering allow for close nutrient monitoring and efficient use of water and fertilizer. Drip irrigation for tomatoes has grown in popularity since it saves water and permits the administration of fertilizers blended into the irrigation water (Massa *et al*., 2020).

Pruning and Training of the Plant: Leaf pruning provides increased plant growth, more efficient phytosanitary management, and greater quantitative and qualitative production. Plants can be supported by a trellis with cotton threads or galvanized metal wire to raise and support the plant and allow access for crop management and pest control (Thakur *et al*., 2018). Pruning is important for indeterminate tomato plants to manage their growth, increase productivity and yield. Suckers should be removed as soon as they appear, while avoiding removing too many leaves. It is also beneficial to prune the main stem after it has produced 4-6 fruiting branches to encourage bushier growth and larger fruit (Mbonihankuye, 2010).

Harvest: The maturity level at which fruits are picked is determined by the eventual production target. The days from sowing up to harvest can last between 60-100 days depending on variety. The stage of harvest depends on the production goal (Arah *et al*., 2015).

Table 3. *Harvest indicator of tomato* (Renquist and Reid, 1998).

Production goal	Harvest indicator
Local consumption	Turgid fruits with intense red color
Regional consumption	Pink fruits
Export	Green mature
Industry	Physiologic maturity

3.10. The Main Pests and Diseases of Tomato Cultivation

Disease control is a serious problem for organic agricultural operations. There are organic plant protection methods and allowed in organic farming. The traits that promote disease resistance are particularly advantageous to producers (Akino *et al.,* 2014). Infections in the field or during post-harvest processing are known to significantly affect tomato output and quality in today's world. The four most important fungi that damage tomatoes are Fusarium wilt, Fusarium crown, late blight, and Sclerotinia rot. Late blight, one of the most dangerous tomato diseases caused by *Phytophthora infestans*, causes significant economic loss of up to 70%. More than 200 pests and diseases have been identified in tomatoes, causing losses in their products directly or indirectly (Foolad *et al.,* 2008).

Pests are one of the major problems in tomato cultivation, either in greenhouses or open field cultivation. These prevent growth and yield from reaching their maximum capacity. It may also, in serious cases, cause a huge economic loss to growers. Pests may bore into the tomato fruits and lay their eggs. Their eggs develop into larvae and cause the most significant damage (Kumar *et al*., 2018). The bollworm, *Helicoverpa armigera*, is a highly polyphagous species and a pest of major economic importance on a wide range of crops, particularly cotton, soybeans, tobacco, chickpea, and pigeon pea (Mahmood *et al*., 2021). *Helicoverpa armigera* and the potato beetle are two of the important and key pests in tomato fields (Dhandapani *et al*., 2003). Larva of *Helicoverpa armigera* feeds inside of tomato fruit and causes significant damage to the fruit. Parasitic wasps, predatory bugs, birds, spiders, and microbial pathogens are all known to feed on *Helicoverpa armigera*. Parasitic wasps lay their eggs inside the larvae of *Helicoverpa armigera* and feed on the larvae, eventually killing them. Predatory bugs, birds, spiders, and microbial pathogens are used to control *Helicoverpa armigera* population (Wubneh, 2016).

Root-knot nematode causes the roots of tomato plants to form gall-like structures. Root-knot nematodes are microscopic roundworms that can cause significant damage to tomato plants. They invade the roots of the plants, forming galls or knots that restrict the uptake of water and nutrients, resulting in stunted growth, wilting, and reduced yield (Ralmi *et al*., 2016). Other notable diseases of tomatoes include early blight, late blight, bacterial canker and mosaic virus amongst others. These pests and diseases cause major losses to farmers causing a significant reduction in the economic situation of farmers (Clark *et al*., 1998).

Table 4. *Most important insect pests of tomatoes under field conditions* (Aloysius Sam *et al.,* 2014).

Scientific name	Common name	Virus transmitted
Helicoverpa armigera	Cotton bollworm	HearSNVP
Cotton bollworm	Potato Beetle	None
Frankliniella fusca	Tobacco thrip	TSWV, TSV
Heliothis armigera	Fruit worms	None
Keiferia lycopersicella	Tomato pinworm	None
Leptinotarsa decemlineata	Colorado potato beetle	None
Phthorimaea operculella	Potato tuberworm	None
Trioza spp.	Tomato psyllid	None

Figure 6. *Larva of Helicoverpa armigera (Cotton bollworm) feeding inside a tomato fruit feeding on tomato fruit* (HTTP 5).

Figure 7. *potato beetle damage to tomato leaf* (HTTP 6).

Table 5. *Most important nematodes of tomatoes under field conditions* (Tian *et al*., 2015).

Scientific name	Common name	Virus transmitted
Meloidogyne ssp	Root-knot nematode	None
Xiphinema Americanum	American dagger nematode	TRSV
Rotylenchulus reniformis	Reniform nematode	None

Figure 8. *Root-knot nematode infection caused by Meloidogyne ssp.* (HTTP 7).

Tomato diseases, which are the effects of pest infestation cause major problems for farmers. These diseases may lead to a total or partial loss of the plantation and in severe cases, causes serious economic loss to the farmer. Upon consumption, some diseases may have a deteriorating effect on consumers (Cebolla *et al*., 2007).

Table 6. *Important bacterial diseases in terms of economic losses* (Agrawal *et al*., 2012).

Scientific name	Common name
Clavibacter michiganense	Bacterial canker
Pseudomonas corrugate	Tomato pith necrosis
Ralstonia (Pseudomonas) solanacearum	Bacterial wilt
Pseudomonas syringae van Hall pv. tomato	Bacterial speck
Xanthomonas campestris Pammel	Bacterial spot

Figure 9. *Bacterial canker of tomato caused by Clavibacter michiganense* (HTTP 8).

Table 7. *Important fungi diseases of Tomato in terms of economic losses* (Babadoost, 2010).

Scientific name	Common name
Alternaria alternate	Tomato black mould
Alternaria alternata	Alternaria stem canker
Alternaria solani	Early blight
Colletotrichum ssp.	Anthracnose
Fusarium oxysporum f. sp. Lycopersici	Fusarium wilt
Sclerotium rolfsii Sacc.	Tomato southern blight
Phytophthora infestans	Late blight

Table 8. *Important viral diseases of tomatoes in terms of economic losses* (Hanssen *et al*., 2010).

Scientific name	Acronym
Tomato Mosaic Virus	ToMV
Tomato Ringspot Virus	TRSV
Tobacco Mosaic Virus	TMV
Potato Virus Y	PVY

Figure 10. *Late blight disease of tomato in cultivation caused by phytophthora infestans, a fungal pathogen* (HTTP 9).

Figure 11. *Tomato mosaic virus disease* (HTTP 10).

3.11. Organic Plant Protection

Pests and diseases are two common problems that can affect the health and productivity of plants (Duveiller *et al.*, 2007). Pests are living things that consume plants and harm the leaves, stems, roots, flowers, and fruits of those plants. Farmers on a pesticide treadmill now face increased expenditures as a result of rising application rates, higher crop losses, and resistance to insecticides, herbicides, and other pesticides (Khan *et al*., 2010). Rising health concerns for exposed populations of farmers, farmworkers, rural residents, and consumers are associated with increased pesticide use. Pesticides harm the health of the soil, the quality of the water, and the habitat of wildlife (Stehle and Schulz, 2015). These negative effects include non-market costs that can only be calculated, but they place a heavy burden on the world as a whole and this justifies the practice of organic agriculture (Muller *et al.*, 2017).

Organic plant protection involves managing pests, diseases, and weeds to minimize environmental impact and maintain ecological balance (Letourneau and Van Bruggen, 2006). The first step towards organic plant protection is to prevent the situation. Prevention of plant protection problems can be the selection of sites free from pests and the planting of resistant varieties to certain diseases (Agrios, 2005). Other farmers also adopt crop rotation methods to escape the growing season of certain pests. More so, soil management may also be useful in prevention methods. Biological control also involves using natural enemies of pests to control their populations, such as predators, parasitoids, and microorganisms and organisms that produce poisons, sometimes known as antibiosis or allelopathy (Flint, 2012). Natural biological control that occurs spontaneously, the traditional introduction and establishment of foreign agents, the release of either native or foreign agents to enhance populations, and the preservation or amplification of populations of either native or foreign agents are all examples of biological control. Physical and mechanical methods involve the use of physical barriers or mechanical means to prevent or remove pests from plants, such as netting, trapping, pruning, and hand weeding (Litsinger, 1994). Organic pesticides that are derived from natural sources and approved for use in organic farming, such as neem oil, pyrethrin, and *Bacillus thuringiensis* are also used (Doğanlar *et al.,* 2015). IPM is a comprehensive approach to pest management that utilizes a combination of methods tailored to the specific crop and pest situation. Organic farming, on the other hand, employs a holistic approach to pest management that heavily relies on the ecological functions and biodiversity of the agroecosystem. As a result, the majority of IPM strategies, tenets, and elements are compatible with organic agricultural techniques. The approach seeks to prevent pests from reaching economically harmful levels without endangering the environment (Mahmood *et al*., in 2016).

3.12. Alternative Production Systems of Tomato

3.12.1. Open Field Production

Tomatoes thrive in a variety of soil types (Madhavi and Salunkhe, 1998). Growing tomatoes in sandy soils that warm up earlier in the spring promotes early fruit output, while a semi-sheltered field location with a windbreak provides protection and speed maturity. Soils should be prepared early in the season by introducing organic matter and cover crops. In windy places, a cover crop can be strip-tilled to give standing cover crop strips to buffer wind around fresh transplants. In the commercial production of tomatoes, several cultural systems are used to determine the field design (Kondo and Ting, 1998). These include sowing techniques like direct or transplants, shaped beds, and plant spacing. The majority of commercial field-grown tomatoes are grown from transplants, but processing tomatoes and mechanically picked fresh-market tomatoes are sometimes direct seeded (Gitaitis *et al*., 1992). Direct sowing can be difficult to establish a robust tomato stand and requires more seed per acre, increasing seed expense. Fresh market tomatoes are often grown in raised beds with plastic mulch, which warms up earlier in the spring and can boost early yield. In dry situations, elevated beds may demand more water. Drip irrigation is generally put beneath the plastic mulch to increase water delivery to the plants. Beds are usually 3-8 inches in height and 30-36 inches broad (Clark *et al*., 1991).

3.12.2. Production in Agroforestry System

Agroforestry is the deliberate mixing of crops with woody vegetation, such as trees and shrubs, in a land management unit (Nair *et al*., 2021). Through beneficial interactions between the system's components, this integration aims to diversify production systems and produce advantages for the economy, the environment, and society (Atangana *et al*., 2014). Farmers have been proven to benefit financially from agroforestry, with higher incomes, better soil fertility, and lower labour expenses. Agroforestry systems, as opposed to monoculture systems, lowered labour expenses by up to 50%, according to Nair's (2012) study. Environmental advantages include enhanced soil fertility, greater biodiversity, and decreased greenhouse gas emissions. Farmers and communities have also gained socially, with food security, less vulnerability to climate change, and more cohesive communities. Agroforestry is a crucial strategy for managing sustainable land use and natural resources, but it must be implemented within supporting institutional and policy frameworks (Nuberg *et al*., 2009).

Vegetable agroforestry is a sort of agricultural technique that combines the growing of trees or other permanent plants with the cultivation of vegetables (Parreño-de Guzman *et al*., 2015). With this technique, the trees' shading helps to control the microclimate and lessen soil water loss. They can also provide additional benefits such as nutrient cycling, erosion control, and wildlife habitat (Tscharntke *et al*., 2011). The vegetables are typically grown in the understory of the trees or in the alleys between the tree rows. This arrangement can help to reduce competition between the vegetables and the trees for light and nutrients, as well as provide some protection from wind and rain (Tscharntke *et al*., 2011). Common techniques used in vegetable agroforestry include; alley cropping, which involves the planting of trees in rows with the alleys between the rows used for vegetable production, forest farming, which involves the cultivation of crops, including vegetables, in a forested setting, and silvopastoral systems, which combine livestock grazing with tree and vegetable production (Cubbage *et al*., 2012).

Schmidt *et al.* (2022) discovered in another study that cocoa agroforestry systems' tree presence improved soil qualities and crop yields. Despite the potential advantages of agroforestry, there are obstacles to its implementation, such as farmers' lack of awareness and expertise, restricted access to capital and markets, and conflicting land-use demands. An all-encompassing strategy that takes into account social, economic, and environmental considerations is needed to scale up agricultural systems, and legislative and institutional assistance is needed to increase awareness and knowledge among farmers (Coe *et al*., 2014).

3.12.3. Implemented Species in the Hedgerow

These hedgerows in agroforestry systems are characterized by a mixture of several plant species that may be native or introduced, employed for a variety of objectives such as agricultural production of fruit, wood extraction, native species conservation outside of reserves, and human well-being (Tscharntke *et al*., 2011). These hedges are home to beneficial organisms such as bees, butterflies, and wasps (Ndakidemi *et al*., 2016). These organisms also create natural biodiversity, being pollination agents and natural enemies to some insect pests on the field (Hajek and Eilenberg, 2018).

Hedges play an important role in agroforestry systems by providing a range of ecological services such as windbreaks, erosion control, nutrient cycling, and wildlife habitat (Jose, 2009). They can also serve as a source of forage, fuelwood, and other non-timber forest products (Gurung *et al.,* 2021). In sustainable agriculture, hedgerows serve as a habitat for beneficial organisms such as bees, wasps, and other insects. These beneficial organisms create biodiversity and also aid valuable ecosystem services such as pollination (Garbach *et al*., 2014).

On a farm scale, the combination of agroforestry plots with ephemeral crops like vegetables can certainly act as a habitat and a source of vital insects (Thevathasan *et al.*, 2018). The definition of the agroecological idea is the application of ecological concepts to agriculture so that farm management may utilize ecosystem benefits supplied by biodiversity protection rather than contrived external outputs. (Harterreiten-Souza *et al.*, 2014).

The applied species in the hedgerow of the research includes *Prunus spinosa* (sloe), *Sambucus nigra* (Black elder) *Corylus avellana* (Hazelnut*); Rosa canina* (Meadow rose); *Ligustrum vulgare* (Common sloe); *Cornus mas* (Fleshy cattail); *Cornus sanguinea* (Red-ring cattail); *Euonymus europaeus* (Spindle) *Crataegus monogyna* (Single seed hawthorn); *Acer campestre* (Field maple*); Malus sylvestris* (Wild apple); *Pyrus pyraster* (Wild pear). This selected species was determined by their occurrence in the region of the research and Experiment station in Soroksár. The arrangement of the species was 1.5 x 1.5 m distance in rows and 1.5 x 1.5 m between the rows. The species were implemented in 3 rows. In the middle line were trees, and on the two sides were bushes planted (Szalai, 2010).

Figure 12. *hedge in the Research and Experiment field of the Organic Unit in Soroksár Research and Experiment Station of Szent Istvan University* (Szalai, 2004).

3.12.4. Organic Farm Production

Organic farming is the oldest system of farming (Francis & Van Wart, 2009). The system mainly relies on farm inputs. The only resources used in this type of farming were rainwater for irrigation, soil organic matter, plant remnants, and animal dung as sources of plant nutrients, and living things as pest control agents (Mason, 2003). Organic farming blends science, innovation, and tradition to benefit the environment as a whole, establish just relationships, and enhance everyone's quality of life. Organic agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved (Nasim *et al*., 2012). Four fundamental principles regulate organic farming and guarantee that the environment is protected while food is produced. Meena *et al*. (2020), stated that four fundamental guiding principles drive organic farming and they are: health, justice, ecology, and care. These principles include, in brief, that the environment is protected, farmers and workers have equitable access to means of production and are paid fairly, and consumers have access to nutritious meals made up of high-quality food they can trust and purchase at fair rates. Organic tomato production involves the cultivation of tomatoes without the use of synthetic fertilizers, pesticides, and genetically modified organisms but instead, organic farmers use natural methods to control pests and diseases, enhance soil fertility, and promote plant growth (Altieri *et al.,* 2015). Organic tomato production can be challenging, but it offers benefits such as improved soil health, reduced pesticide residues, and increased biodiversity. Soil preparation, crop rotation, natural pest control, mechanical weeding, water management, and harvesting are all important steps in organic tomato production (O'Connell *et al.,* 2012).

The USDA's National Organic Program in the US and the organic farming laws of the European Union according to IFOAM provide guidelines for the use of organic inputs, care given to animals, and management of land and water resources. Organic farming is becoming increasingly popular due to growing worries about conventional agriculture's effects on the environment and possible health dangers (Yanakittkul and Aungvaravong, 2020).

Despite consumers enjoying poison-free, tastier, more nutritious foods, growers also face certain challenges in producing these foods. Challenges in organic field production includes the prevalence of pests and diseases, lacking highly skilled labor, high costs of production, low yield in extreme cases, and time-consuming compared to conventional farming (Armesto-Lopez, 2008).

3.13. The European Union Regulation on Organic Farming

The first regulation on organic farming in the European Union was Council Regulation (EEC) No. 2092/91, which was adopted in 1991. This regulation established the basic principles of organic farming and laid down rules for the product. The current regulation (EU) 2018/848 of the European Parliament and of the Council on May 30, 2018, on organic production and labelling of organic goods and was effective in the European Union as of January 2021 as it was replaced with the former rule (EEC) No. 834/2007.

The EU Organic Regulation lays forth the guiding principles, goals, and regulations for organic farming, addressing issues such as plant and animal production, processing, labelling, and controls. It strives to guarantee a high degree of environmental and human health protection and customer confidence in organic goods (Cahill *et al*., 2010). Essential requirements include the use of only approved inputs and techniques, the use of genetically modified organisms (GMOs), the creation of a system of certification and supervision, and the importation of organic goods from non-EU nations. The legislation also specifies rules for the importation of organic goods from non-EU nations and the acceptance of their equivalent organic production and certification frameworks. The EU Organic Regulation requires producers to receive certification from a reputable organization and regular inspections and checks to ensure the farm complies with the regulations (Siderer *et al*., 2005).

To identify their status as organic, items must be marked with certain emblems or markings, and imports and exports must adhere to the same criteria as locally produced goods (Huber *et al*., 2015). The most recent update to the EU Organic Regulation went into effect in 2021. The European Union rule is continually reviewed and modified to reflect the most recent advancements in organic farming and to adapt to changing consumer and producer demands (Bostan *et al*., 2019). The EU organic farming regulation is constantly evolving and being updated to reflect changes in scientific knowledge and consumer demand. The goal is to ensure that consumers can trust that products labelled as organic meet strict standards for environmental and health protection, while also promoting sustainable agriculture and rural development (Dabbert *et al*., 2004).

4. MATERIALS AND METHODS

4.1. Study area

The experiment was conducted between June and October 2022 at the Soroksar Experimental Research Farm's organic unit, of the Hungarian University of Agriculture and Life Sciences (MATE). The farm is located at Túri István út. 2, about 20.2 km northeast of Budapest, with coordinates of 47°23'34.6"N 19°08'53.7"E and an altitude of 99-110 meters above sea level. The main experiment was set up at coordinates N 47°24'40", E 19°7'48", covering an area of approximately 11 hectares of certified ecological land and soil type. The nearly flat and contiguous area is surrounded by a strip of forest on all sides, which has been in place for several decades to mitigate the impact of wind. A hedge made up of native woody plant species was planted in two stages in 1999 and 2000.

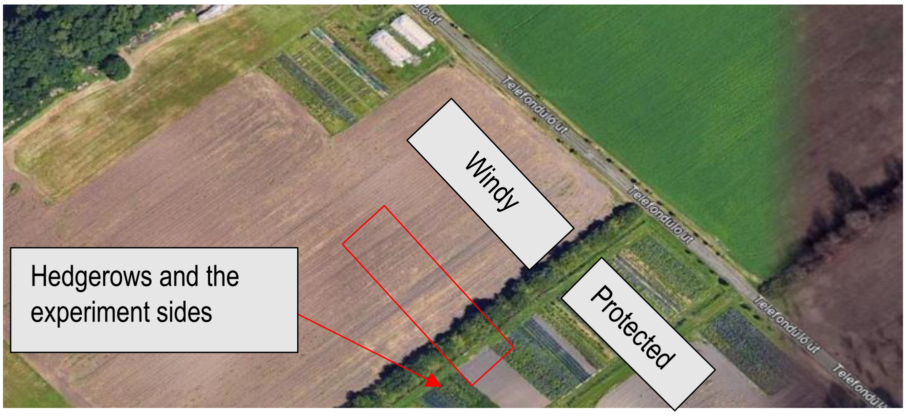

Figure 13. *Experiment site at The Organic Farming Department at the Soroksar Research Farm* (Google maps, 2023).

4.2. Materials

4.2.1. The Plant Materials used (Different tomato genotypes)

Szentlőrinckáta

Roma

ACE55

Figure 14. *The tomato genotypes which are used on the experiment.*

4.1.2. Preparations of seedlings of the three varieties

Seedlings were first sown at room circumstances at the Vegetable department of the Hungarian University of Agriculture and Life Sciences from the 18th of March to the 25th, of 2022. Seedlings were then transported to the glasshouse on the Buda Campus on the 4th of April, 2022 in six 40-celled trays using peat compost as the substrate. The varieties of seeds sown were ACE 55, Szentlőrinckáta, and Roma. Temperature, relative humidity, and lighting remained the same during the whole period.

Figure 15. *Glasshouse for production of seedlings* (Joel, 2022).

4.1.3. Experimental Layout and Land preparation

The open field experiment was conducted on both the protected and windy sides of a hedgerow, using a Randomized Complete Block Design (R.C.B.D.) with three replications and five plots for each replication. Each plot contained eight plants on both sides of the experiment, resulting in a total of 240 plants, that is; 120 plants on each side. The spacing between plants was 70 x 70 cm, and three tomato genotypes (Szentlőrinckáta, ACE55, and Roma) were used in the experiment.

The land was prepared for the open field by first removing weeds and debris. Stones and rocks were also removed, and smaller ones were broken down before ploughing began. Deep ploughing was carried out twice by a tractor with a harrow on both sides of the experiment. Plots were covered with agrotextil to reduce weeds and surfacing of certain insects, and to preserve moisture in the soil. On July 17th, 2022, a drip irrigation system was deployed to provide water to the roots of the tomato plants.

Figure 16. *The plants at the Organic Farming Unit in the experiment at the Soroksar Research Farm* (Mohammed, 2022).

4.2. Methods

4.2.1. Temperature and Relative Humidity

The temperature (**figure 17**) and air humidity were recorded during the experiment to show the microclimate conditions and the influence of the trees on the two experiment sites; the protected side and the unprotected side. The whole growth season was employed by the Voltcraft DL-181THP data collector for measurement. Three sensors in different spacing, 3, 6, and 9 for both sides. K windy and P protected, and H the hedgerow.

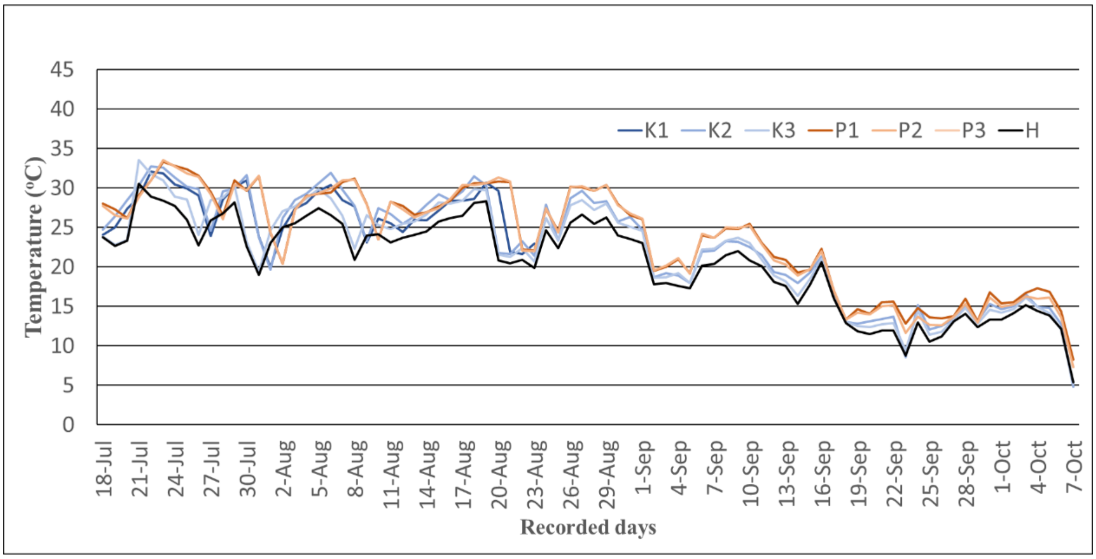

Figure 17. *The Voltcraft DL-181THP for monitoring the microclimate on both windy and protected sides.*

4.3. Crop Protection Data

4.3.1. Damage From Insect Damage

The number of fruits with holes created in them as a result of potato beetle insect attack or their larval feeding was recorded on the 10th of August 2022. Also, damage by *Helicoverpa armigera* was observed on the tomato fruits and data was duly taken on them on the 23rd of August and 30th.

Figure 18. *Insect damage by Potato beetle* (Joel, 2022).

4.3.2. Damage From Fungal Infection

On the 10th of August, 2022, data on the fungal attack was taken by observing and counting the number of infected fruits on the plants and that, which had fallen off the plant beneath. Those with fungal diseases such as early blight, late blight, and buckeye rot were counted and recorded.

Figure 19. *Fungal damage by phytophthora infestans* (Joel, 2022).

4.3.3. Physical Damage by Wild Animals

Data on animal damage on the protected and unprotected side was done by counting the number of fruits on the plants, or those that had fallen off the plant and had been eaten by animals that visited the sites on the 10th of August, 2022.

Figure 20. *Wild animals damage of fruit* (Joel, 2022).

4.4. Data on Harvested Fruits

4.4.1. Harvested Fruit Number and Weight

Fruits were harvested on the 5th of October and sorted into healthy green and healthy red fruits. Data on four (4) randomly selected middle plants were recorded. The harvest was then also graded into disease-free and diseased, fungal-free and fungal-infected fruits, and also those that are damaged by wild animals was counted.

- The number of healthy green fruits and healthy red ones was taken by direct counting.
- The weight of the healthy green and red fruits respectively taken with the use of a spring balance scale.

Figure 21. *Sorting of fruits after harvesting* (Joel, 2022).

4.5. STATISTICAL ANALYSIS

The experiment was arranged in a Randomized Complete Block Design (R.C.B.D.) with three (3) replications and 5 plots for each replication. The measured variables were divided into 3 groups: Damage-related variables observed at harvest (6 variables: Number and weight of potato beetle damage, fungal-damaged and animal-damaged fruits), *Helicoverpaa armigera* damage in summer (2 variables), and yield data at harvest (number and weight of green and red fruits).

Three-way multivariate analysis of variance (3-way MANOVA) was used to analyze a group of variables if the conditions of MANOVA were met. The main effects of variety, side, distance and all 2-way and 3-way interaction were included in the starting model. If MANOVA resulted in significant difference, the variables were analyzed separately with one-way ANOVA by using Bonferroni correction. If a main effect was significant, the pairwise comparison was performed with Tukey-HSD test. If the assumptions of MANOVA were not met, separate 3-way ANOVA was used for each variable of the group with Bonferroni-correction. If the 3-way interaction was significant, 2-way ANOVA containing main effects of side and distance and their interaction was performed for each variety, separately.

Pillai trace was used as test statistic for MANOVA. Normality was checked by boxplots; homogeneity of covariance matrices was checked by Box's M-test and two-variable scatterplots created for each variety-side-distance combination separately. To detect multivariate outliers, the Mahalanobis distance from the corresponding sample mean was calculated for each observation. The calculated Mahalanobis distance was compared against a chi-square distribution with degrees of freedom equal to the number of dependent (outcome) variables and an alpha level of 0.001. Calculations were carried out with R statistical language. Box's M test was performed with box(M) function from heplots package, Mahalanobis distance and the corresponding statistical test was performed with mahalanobis_distance function from rstatix package. Boxplot diagrams were created with ggplot2 package.

5. RESULTS

5.1. Insect-damaged Fruits by Potato Beetle (*Leptinotarsa decemlineata*)

The effect of variety, side, and distance on potato beetle damage's number and weight of the damage was evaluated after the harvest. In the factors observed, variety had the most significant effect on insect damage (for both number and weight: $p<0.0001$). Variety was a significant indicator of potato beetle damage, independent of side and distance as both factors proved not significant. The lack of significant interaction also indicated that the effect of variety on the insect damage was consistent across the sides and distances, and the relationship between the varieties and the insect damage was not influenced by the sides and distances.

Tukey test was carried out to compare the potato beetle damage between the varieties. As indicated in **Figure 22**, ACE55 had significantly fewer damaged fruits compared to both Roma ($p<0.001$) and Szentlőrinckáta ($p<0.001$). Hence the conclusion that there was a statistically significant difference in the levels of insect damage between ACE55 and the other two varieties. The difference between Roma and Szentlőrinckáta ($p=0.92$) was not significant. The side and distance interaction were significant (number: $p<0.001$; weight: $p<0.05$). The significant interaction between side and distance for insect damage is visually recognized in **Figure 22**, specifically distances R1 and R2. On the protected side at distance R1, more insect damage was observed, while on the windy side at R2, more insect damage was observed.

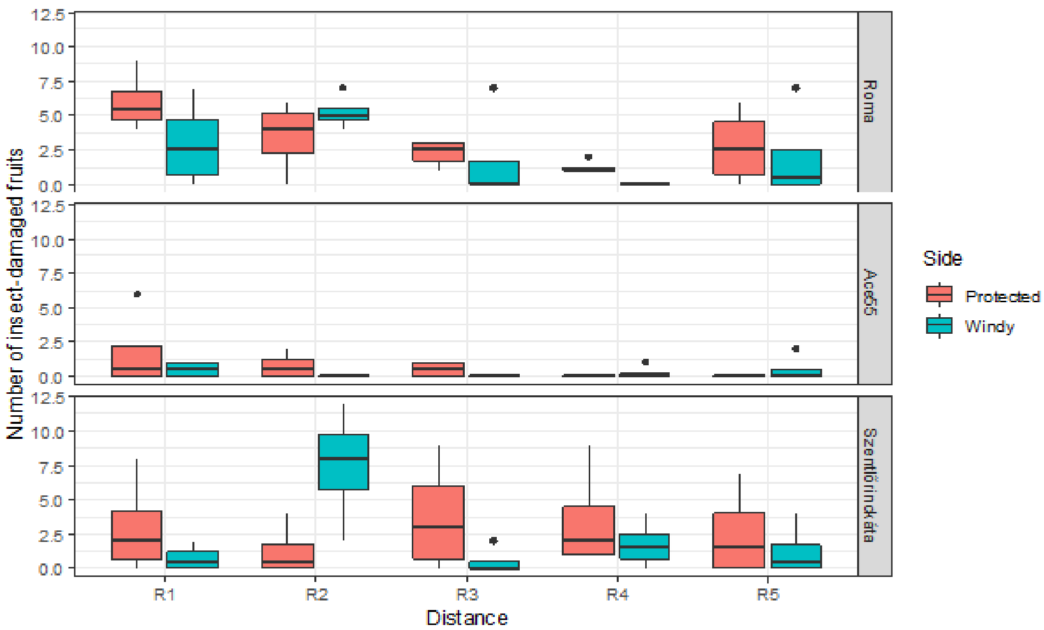

Figure 22. *Number of potato beetle damaged fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows potato beetle damage by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

5.2. Insect-damaged Fruits by *Helicoverpa armigera*

Helicoverpa armigera damage was measured on two different days as the insects were more prevalent on these days. All main effects and all interactions were significant for both dates, but the pattern of the interactions were different. This suggests that the interaction between variety, side and distance differed between the two dates. At the earliest survey on the 23rd of August 2022, there were significantly more damaged plants for the Szentlőrinckáta variety compared to ACE55 and Roma varieties with p-values less than 0.001. This finding suggests that, the Szentlőrinckáta variety was more susceptible to *Helicoveropa armigera* damage. There were no significant difference ACE55 and Roma which suggests that they exhibited similar levels of resistance to the damage.

In case of the Roma, neither side nor distance had a significant effect. The main effect of side was significant for the ACE55 variety, with a p-value of 0.009. More damage was observed in the protected side as shown in **figure 23**. Also, the main effects of side and distance, as well as their interaction were significant for Szentlőrinckáta. Specifically, the p-values for main effect of side and distance were both $p<0.001$, indicating a highly a highly significant effect. And the p-value of their interaction was also less than 0.001.

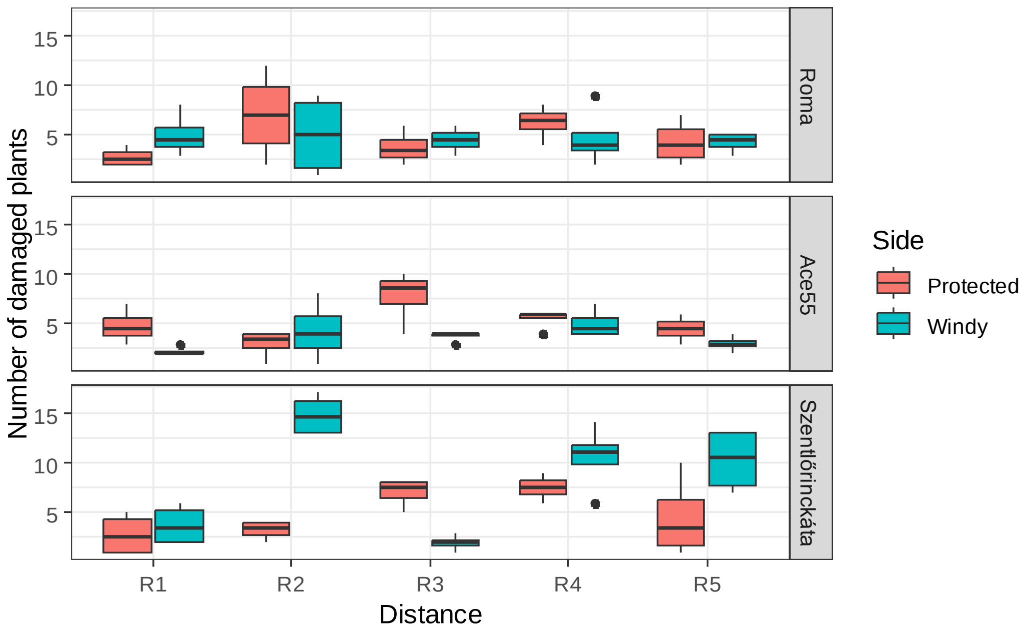

Figure 23. *Number of Helicoverpa armigera damaged fruits by variety, side, and distance represented by R, where R means the replications (23rd August 2022). Box-plot diagram shows Helicoverpa armigera damage by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

At the second survey on the 30th August 2022, there was a significant difference in the damaged plants between Roma and Szentlőrinckáta, with $p<0.001$. For Roma variety, both the main effect of side ($p<0.001$) and distance ($p<0.001$), as well as their interaction ($p<0.001$) were significant. In distance at R1, R2, R3, and R4, there were more damaged plants on the windy side, while at larger distances on the protected side (**figure 24**). The direction of the wind may have had a significant impact on the level of damaged observed in particularly at shorter distances from the hedge.

In the case of ACE55, neither the side nor the distance had a significant effect on the level of damage observed in the plants. This suggests the susceptibility of ACE55 to the *Helicoverpa armigera* damage is more uniform across different sides and distances from the hedge. For Szentlőrinckáta, both the main effect of the side ($p<0.001$) and distances ($p<0.001$), as well as their interaction ($p<0.001$), were found to be significant with p-value less than 0.001. Side and distance had a significant effect on the level of damage observed in the Szentlőrinckáta plant and these effects were not independent of each other. This means that, the effect of distance on damage may be different for plants on the protected side and the windy side or the effect of side may be different for different distances from the hedge. The level of damage in Szentlőrinckáta was relatively even at closer distances and decreased at further distances. This finding suggested that, Szentlőrinckáta may be less susceptible to *Helicoverpa armigera* damage on the protected side, particularly at larger distances from the hedge.

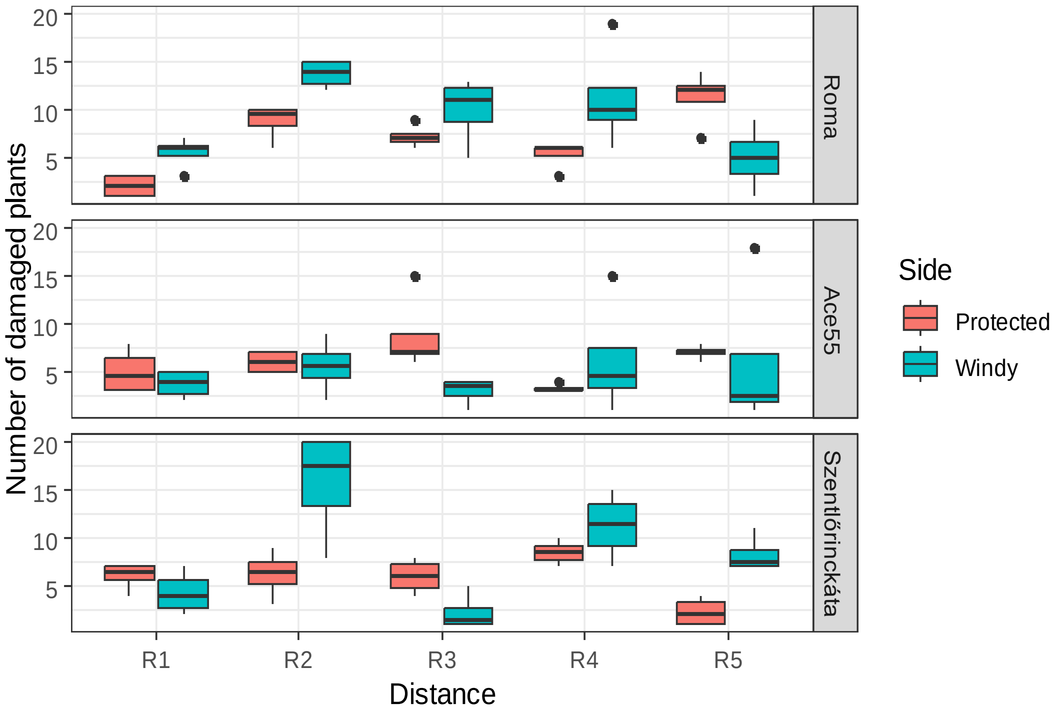

Figure 24. *Number of Helicoverpa armigera damaged fruits by variety, side, and distance represented by R, where R means the replications (30th August 2022). Box-plot diagram shows Helicoverpa armigera damage by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

5.3. Fungal Damaged Fruits

None of the main effect and none of their interactions were significant ($p<0.005$). This suggests that the tomato varieties planted did not have a significant effect on the fungal damage and that, the varieties were equally susceptible to fungal damage under the circumstances of the experiment. The absence of significant difference between the interaction of side and distance ($p<0.005$) containing the variety suggests that variety, side and distance did not have an impact on the level of fungal damage observed in the tomato plants. More specifically from the statistical analysis, the impact of either of the variables did not depend on the level of another variable. In this case, the impact of variety on fungal damage was same regardless which side and distance the plants were (**figure 25**).

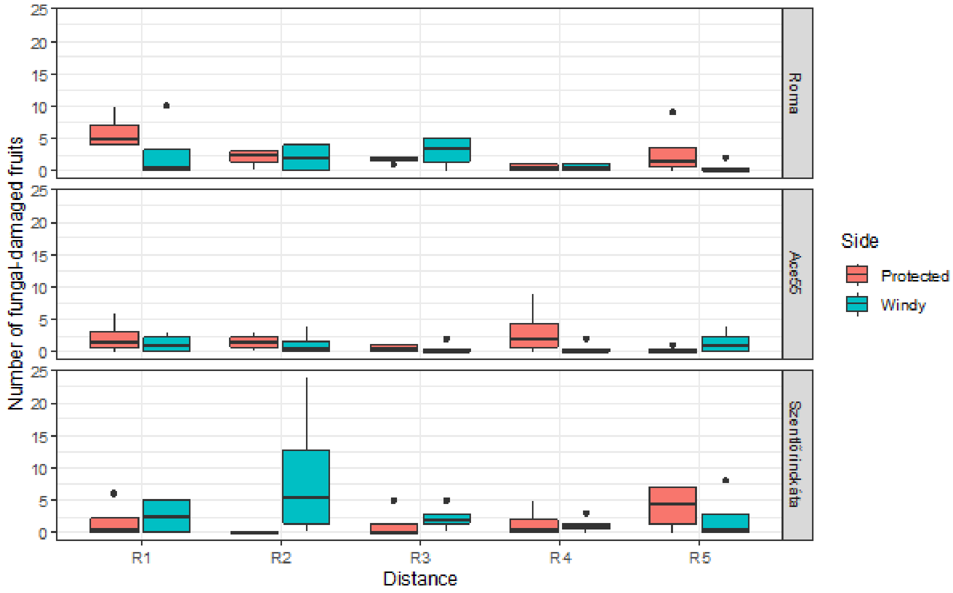

Figure 25. *Number of fungal damaged fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows fungal damage number by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

5.4. Wild Animal Damage

The main effects of distances were highly significant (number: p<0.00001; weight: p<0001) and the side and distance interaction (number: p=0.001; weight p=0.002) was also significant. This suggested that distance has a strong relationship with animal damage both in terms of number and weight. A larger number of damaged fruits by animals was observed at larger distances.

There was a significant interaction between distances at R1, R3, and R4 for both windy and protected sides in terms of animal-damaged fruits. The pattern of fruit damage by animals varied depending on both the distance and side. Specifically, as indicated in **Figure 26**, distances at R1 observed more damage on the protected side, whiles in the distances at R3 and R4, more animal-damaged fruits were observed on the windy side. Tomato variety did not have a significant effect on the amount of animal damage observed in the study.

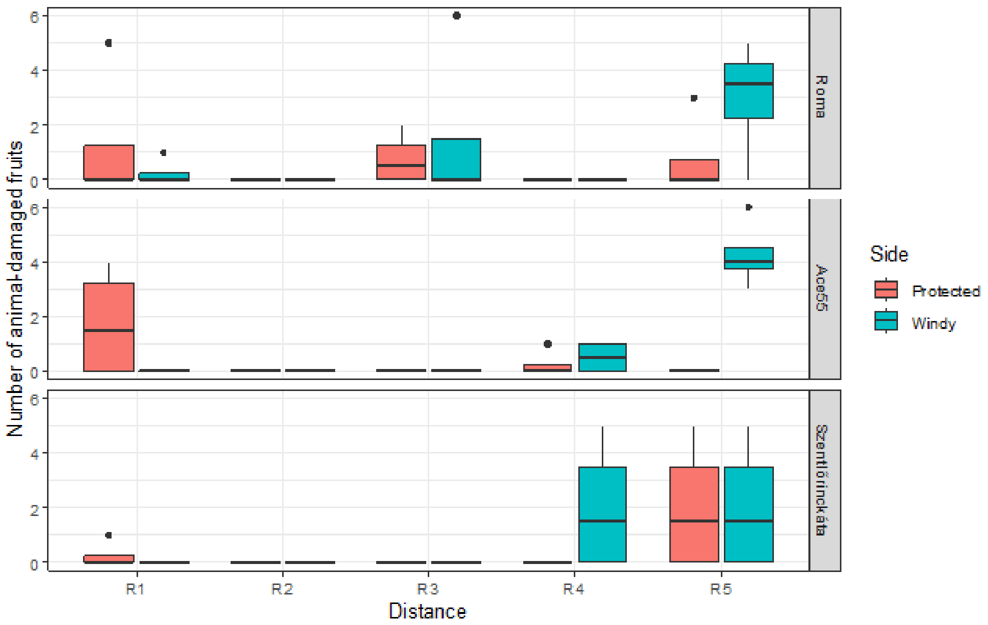

Figure 26. *Number of wild animal-damaged fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows wild animal damage by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

5.5. Number and Weight of Healthy Green Fruits Harvested

The main effect of variety was found to be significant for the number of healthy green fruits harvested ($p<0.00001$), which suggested that, the different varieties of tomatoes planted has a significant impact on the number of green fruits produced. Additionally, the side and distance interaction were also found to be significant ($p<0.001$), which implies that both sides and their distances within them had an interaction effect on the number of green fruits harvested. In contrast, for the weight of the healthy green fruits harvested, only side and distance were found to be significant ($p=0.006$). This finding implies that, the location of the plant and the distance had a significant impact on the weight of the healthy green fruits produced but the effect of variety was not significant as shown in **figure 29**. Significantly fewer green fruits were harvested from variety ACE55 than Roma ($p=0.005$) and Szentlőrinckáta ($p=0.001$). This means that Roma and Szentlőrinckáta may be a more productive variety of plant for producing healthy green fruits than ACE55, as depicted in the **figure 28**.

Szentlőrinckáta ACE55 Roma

Figure 27. Healthy green Tomato Genotypes Fruit (Mohammed, 2022).

From the analysis, it was found that the side and distance interaction was more pronounced in the distance at R1 and R2. When comparing these two distances, the result showed that there were more green fruits harvested on the protected side in the distance at R1, especially for the Roma variety. On the contrary, in the distance at R2, there were more healthy green harvested fruits on the windy side, especially for the Roma and Szentlőrinckáta variety according to **figure 28**.

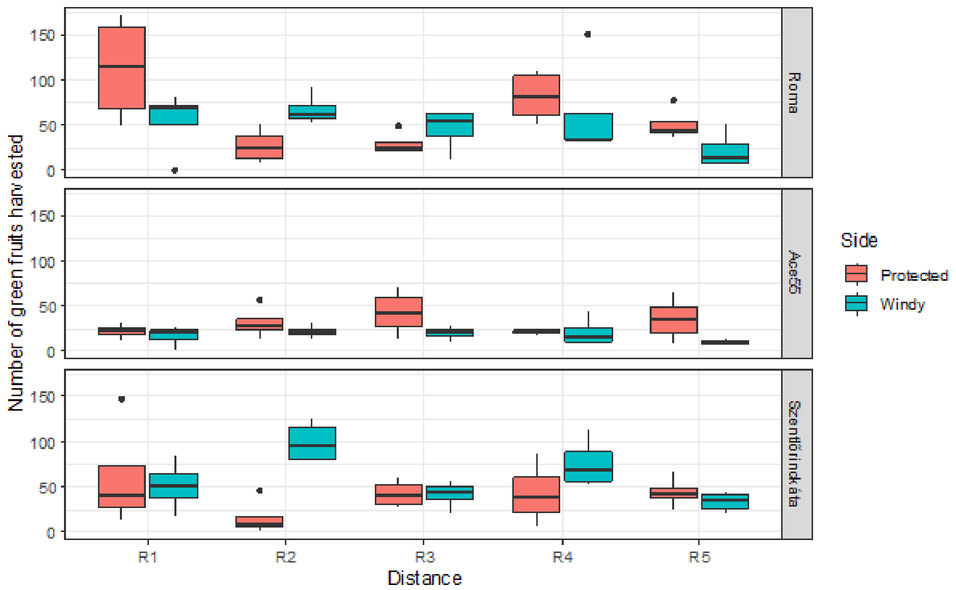

Figure 28. *Number of healthy green harvested fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows number of healthy green harvested fruits by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

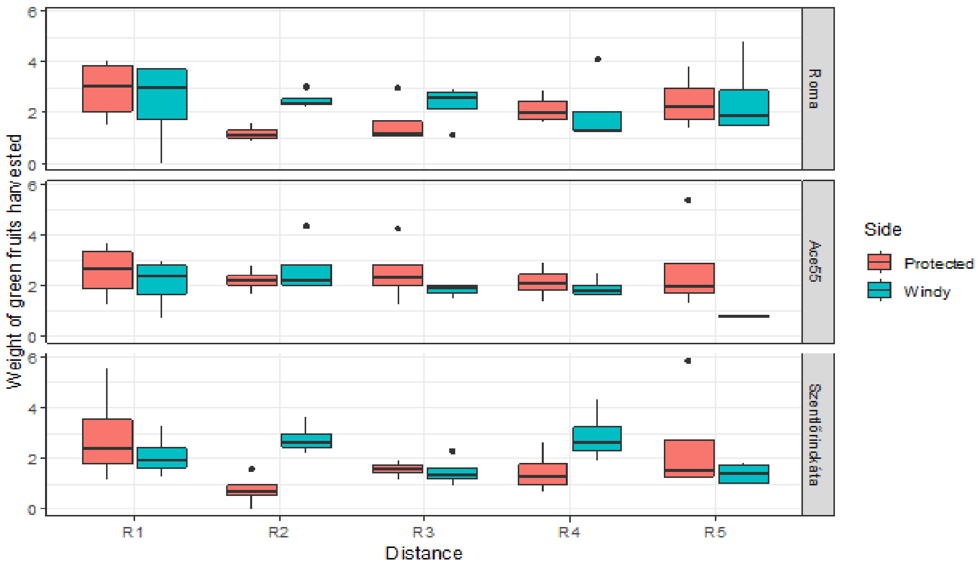

Figure 29. *Weight (kg) of healthy green harvested fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows weight (kg) of healthy green harvested fruits by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

5.6. Number and Weight of Healthy Red Fruits Harvested

The number and the weight of the healthy red fruits harvested showed similar results. The main effect of variety (MANOVA: P<0.000001, ANOVA for number: p<0.0001, ANOVA for weight: 0.00000001) and side (MANOVA: p=0.004, ANOVA for number: p=0.007, ANOVA for weight: p=0.003) were significant, while the main effect of the distance and all the interactions were not significant. More specifically, the variety had a significant effect on the number and weight of the harvested healthy red fruits, with variety ACE55 producing significantly fewer healthy red fruits compared to varieties Roma (number: p<0.00001, weight: p=0.00002) and Szentlőrinckáta (number: p=0.0001, weight: 0.0000001) as described in **figure 30** for the number of healthy red fruits produced and in **figure 31** for the weight of healthy red fruits produced accordingly. Statistical analysis of the data did not find a significant difference between the number and weight of fruits produced by the two varieties Roma and Szentlőrinckáta as shown in **figure 30** and **figure 31**. The observed differences between Roma and Szentlőrinckáta were not large enough to be considered statistically significant. In addition, the side variable had a significant effect on the number and weight of the harvested fruits, with the protected side producing significantly more red fruits compared to the windy side.

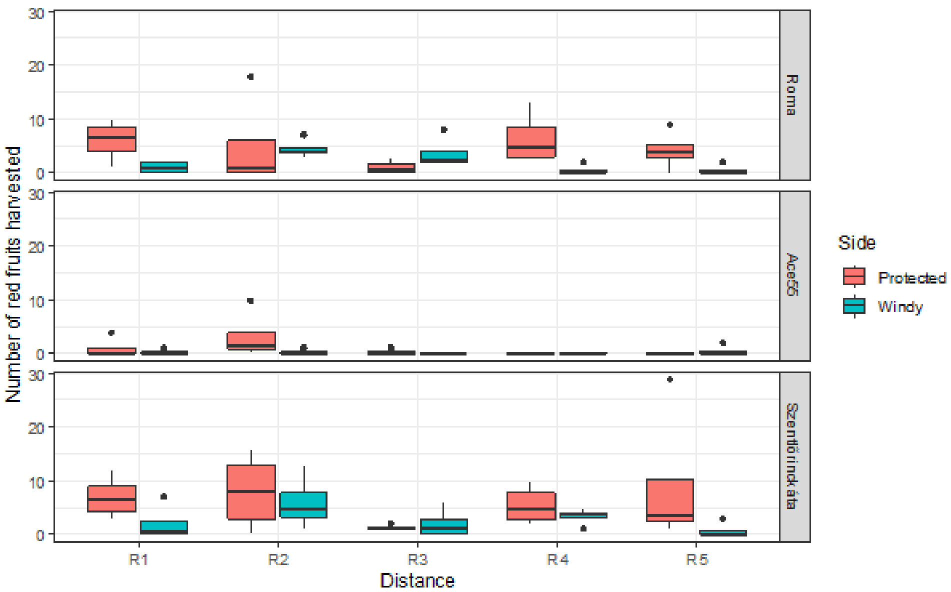

Figure 30. *Number of healthy red harvested fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows number of healthy red harvested fruits by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

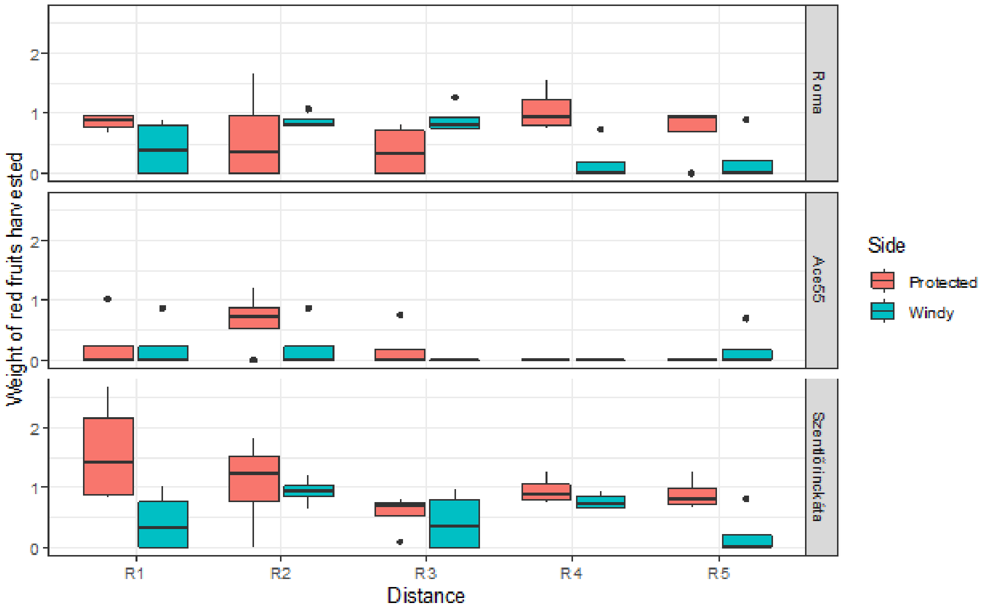

Figure 31. *Weight (kg) of healthy red harvested fruits by variety, side, and distance represented by R, where R means the replications. Box-plot diagram shows weight (kg) of healthy red harvested fruits by variety, side and distance. The segment inside the box represents median, whiskers above and below the box represents the maximum and minimum damage by numbers, and dots represents outliers.*

Szentlőrinckáta ACE55 Roma

Figure 32. *Healthy RedTomato Genotypes Fruit (*Mohammed, 2022).

6. CONCLUSION

The research has focused on the effect of variety, side (windy and protected), and distance from a hedgerow in organic field production of different tomato genotypes in an agroforestry system of different microclimates on insect damage by potato beetle (*Leptinotarsa decemlineata*) and Cotton bollworm (*Helicoverpa armigera*), fungal damage by *phytophthora infestans* and wild animal damage on the final yield of the tomato genotypes cultivated. Three tomato varieties were selected for the study, namely: ACE55, Roma, and Szentlőrinckáta. Plant protection measures were applied according to the standards and regulations of the European Union organic farming.

This study shows that variety is the most significant factor affecting potato beetle damage, regardless of the side and distance. Variety ACE55 was found to have significantly lower levels of insect damage than the other two varieties tested, Roma and Szentlőrinckáta. Furthermore, the side and distance interaction were significant, indicating that the relationship between insect damage and distance varies depending on the side of the field. Specifically, more damage was observed on the protected side at distance R1, while on the windy side at distance R2. In regards to damage caused by cotton bollworm, *Helicoverpa armigera*, suggest that the level of susceptibility to *Helicoverpa armigera* damage varies among the three tomato varieties tested. The Szentlőrinckáta variety was found to be the most susceptible to the damage, while ACE55 and Roma exhibited similar levels of resistance. Additionally, the pattern of interaction between variety, side, and distance differed between the two survey dates (23rd August 2022 and 30th August 2022), indicating the importance of considering the timing of the survey when assessing the damage. For ACE55, the level of damage was relatively uniform across different sides and distances from the hedge, while for Roma and Szentlőrinckáta, the effects of side and distance on damage were significant and not independent of each other. These findings have important implications for tomato growers in terms of selecting the appropriate variety and considering factors such as wind direction when managing *Helicoverpa armigera* damage as it agrees with the investigation of Patil *et al.* (2017).

The results of the study suggest that there is no significant difference in the susceptibility of tomato genotypes to fungal damage in the experiment. Additionally, neither the side nor the distance of the plants from the hedge had a significant impact on the level of fungal damage observed. Other factors, such as proper sanitation and cultural practices, may be more effective in reducing the incidence and severity of fungal damage in tomato plants (Thresh, 1982). The study found that distance has a significant effect on wild animal damage in terms of both the number and weight of damaged fruits. The interaction between distance and side was also significant, with larger distances leading to a greater number of damaged fruits by animals. Additionally, the pattern of fruit damage varied depending on both the distance and side, with more damage observed on the protected side at R1 and on the windy side at R3 and R4. Tomato variety did not have a significant effect on the amount of animal damage observed in the study. By this, the findings suggest that farmers should consider the distance from animal habitats when planting tomatoes and take appropriate measures to protect their crops from animal damage.

This study demonstrated that the different varieties of tomatoes planted had a significant impact on the number of healthy green and healthy red fruits produced. Specifically, ACE55 produced significantly fewer healthy green and healthy red fruits than Roma and Szentlőrinckáta. The side and distance interaction were also found to be significant. In contrast, for the weight of the healthy green and healthy red fruits harvested, only the side and distance variables were found to be significant. These findings suggest that the choice of variety and location of the plant should be carefully considered when aiming to optimize fruit production and agrees with the research of Osei *et al*. (2018) on the Genotype and Environment interaction being a prerequisite for tomato production. This study provides important insights into the factors that influence fruit production in tomatoes and may have practical implications for growers looking to maximize their yields and therefore produce healthy tomato fruits.

Based on the results, it can be concluded that the highest amount of healthy red fruits was harvested on the protected side from all tomato genotypes when cultivated under the hedgerow agroforestry system. In terms of the number of healthy green fruits harvested, the effect of variety and the side and distance interaction were significant, indicating that different varieties of tomatoes and their placement on the experimental side had a significant impact on the number of healthy green fruits produced. The weight of the healthy green fruits harvested was also affected by the side and distance interaction, with location having a significant impact.

For healthy red fruits, both the number and weight were significantly affected by variety and the location of the plant. Significantly fewer healthy red fruits were produced by variety ACE55 compared to varieties Roma and Szentlőrinckáta. In terms of location, the protected side produced significantly more healthy red fruits compared to the windy side. In addition, the experiment showed that insect damage was more severe on the protected side, but the amount of healthy red fruits harvested was significantly higher on the protected side. This suggests that the protected side was more favourable for the establishment and growth of healthy marketable crops, despite being more susceptible to insect damage. The protected side proved to be a better location for producing healthy red and green fruits, especially for varieties Roma and Szentlőrinckáta.

Further research could investigate additional factors that may contribute to potato beetle (*Leptinotarsa decemlineata*), cotton bollworm (*Helicoverpa armigera*), fungal damage, and damage from wild animals to explore potential strategies for reducing its impact on tomato crop yield.

7. SUMMARY

Tomato (*Solanum lycopersicum*) is a widely cultivated fruit crop belonging to the Solanaceae. The cultivation of tomatoes in organic and agroforestry systems comes with interference of pests and diseases. Agroforestry methods merge trees, shrubs, or other perennial plants with crops, while organic farmers employ natural inputs and stay away from synthetic fertilizers, pesticides, and genetically modified organisms. This study intends to evaluate how insect damage, fungal infection, and wild animals affect the yield of three different tomato genotypes; Szentlőrinckáta, ACE55 and Roma in a windy and protected cultivation side in an organic farming system. The experiment took place at the Department of Agroecology and Organic Farming Unit at the Hungarian University of Agriculture and Life Sciences, Soroksar Experimental and Research Farm.

The study investigated the effects of variety, side, and distance on insect damage, fungal damage, animal damage, and yield in tomato plants. The results showed that variety had the most significant effect on potato beetle damage, with ACE55 being more resistant to potato beetle damage than Roma and Szentlőrinckáta. The side and distance had a significant impact on potato beetle damage, with more damage observed on the protected side at distance R1 and on the windy side at distance R2. On 23rd August 2022, the Szentlőrinckáta variety showed a higher susceptibility to *Helicoverpa armigera* damage compared to ACE55 and Roma varieties. However, on the same date, ACE55 showed more damage on the protected side. On 30th August 2022, the Roma variety showed more damage on the windy side, especially at shorter distances from the hedge and at larger distances from the protected side. There was no significant difference in resistance levels between ACE55 and Roma on this date. In terms of fungal damage, neither the variety nor the side or distance had a significant impact. The distance had a significant effect on wild animal damage, with the interaction between distance and side also being significant. The tomato variety did not have a significant effect on animal damage. The choice of tomato variety and the location of the plant significantly impacted fruit production, with ACE55 producing significantly fewer healthy green and healthy red fruits compared to Roma and Szentlőrinckáta. The protected side was found to be a more favourable location for producing healthy red and healthy green fruits, especially for varieties Roma and Szentlőrinckáta, despite being more favourable for insect damage.

In conclusion, the data for insect damage, in general, was higher on the protected side and lower on the windy side, as the results were mixed and varied depending on the specific insect and survey date. However, the study confirmed that the location of the plant significantly impacted healthy fruit production, with the protected side being more favourable for producing healthy red and healthy green fruits and agrees with the research by Nordey *et al*. (2017) on protected cultivation of vegetable crops in sub-Saharan Africa. Based on the results, the use of the protected side in the organic production of tomatoes is recommended for the production of more healthy, disease-free, and infection-free tomato fruits.

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10. APPENDIX

Application of *Bt* (*Bacillus thuringiensis*) Spray During the Growing Season

In this experiment, *Bt* spray was applied to control insect pests when their population was at its peak. The population of insect pests was monitored regularly to determine the peak of their population. Once the peak was reached, *Bt* spray was applied according to label directions and best practices for minimizing impacts on non-target organisms and the environment.

Data was taken of the insect number and damage prior to the *Bt* spray application. The effectiveness of the *Bt* spray was monitored by checking the population of insect pests in the treated area. *Bt* spray was effective in reducing the population of insect pests. The population of insect pests in the treated area was significantly lower than in the control area. The reduction in population was observed for a period of time after the *Bt* spray was applied.

Applying *Bt* spray when the population of insect pests is at its peak can help to reduce the damage caused by the pests and protect crop yields. However, it's important to use *Bt* spray appropriately and follow label directions and best practices for minimizing impacts on non-target organisms and the environment (Gill and Garg, 2014).

Bt sprays contain a naturally occurring bacterium called *Bacillus thuringiensis* (*Bt*) (Sanchis, 2011). This bacterium produces a protein that is toxic to certain insects, such as caterpillars, but is not harmful to humans, pets, or beneficial insects. *Bt* sprays can be used as a biological control method to reduce pest populations in agricultural and horticultural settings, as well as in residential gardens. *Bt* sprays are effective against several pests, including the European corn borer, tomato hornworm, and cabbage looper (Cranshaw, 2003). The specific formulation of BT sprays may vary depending on the manufacturer, but generally, they contain a concentration of the *Bt* protein, as well as other inert ingredients to aid in application and adherence to plant surfaces.

Bt proteins are allowed in organic farming as an insecticide because they are considered natural and non-toxic to humans and other non-target organisms. *Bt*-based products have been extensively tested and found to have minimal impact on non-target organisms, including humans, wildlife, and beneficial insects. It's always a good idea to consult with a local extension agent, crop advisor, or other expert before using any pesticide or pest control product, including *Bt* spray, to ensure that it is appropriate and effective for your specific situation (McGaughey, 1992).

The timing and frequency of *Bt* spray applications are critical for their effectiveness. *Bt* sprays should be applied when the pest is in the vulnerable larval stage, before it has caused significant damage to the plant. Multiple applications may be necessary to ensure that the pest is completely controlled. Environmental conditions can also affect the effectiveness of *Bt* sprays. The bacteria in *Bt* sprays can be degraded by sunlight and high temperatures, so it is important to apply the spray during cool, overcast conditions, or in the early morning or late evening. Rain can also wash away the spray, reducing its effectiveness.

European Union Regulation on Organic Farming (Crop Protection Aspect of the Regulations)

Producing organically means respecting the rules of organic farming. These rules are designed based on general and specific principles to promote environmental protection, maintain the biodiversity of Europe, and build consumer trust in organic products. The rules cover all stages of production, preparation, and distribution (from primary production to storage, processing, transport, distribution, and supply to the final consumer). One of the objectives in organic production is to reduce the use of external inputs. Any substance used in organic agriculture to fight pests or plant diseases must be pre-approved by the European Commission.

The use of plant protection products should be significantly restricted. Preference should be given to measures to prevent damage by pests and weeds through techniques that do not involve the use of plant protection products, such as crop rotation. The presence of pests and weeds should be monitored to decide whether any intervention is economically and ecologically justified. However, the use of certain plant protection products should be allowed if such techniques do not provide adequate protection and only if those plant protection products have been authorized in accordance with Regulation (EC) No 1107/2009, after having been assessed and found to be compatible with the objectives and principles of organic production, including where those products have been authorized subject to restrictive conditions of use, and consequently have been authorized in accordance with this Regulation.

Where plants cannot adequately be protected from pests by measures provided for in point or in the case of an established threat to a crop, only products and substances authorized pursuant to Articles 9 and 24 for use in organic production shall be used, and only to the extent necessary. Operators shall keep records proving the need for the use of such products.

In relation to products and substances used in traps or in dispensers of products and substances other than pheromones, the traps or dispensers shall prevent the products and substances from being released into the environment and shall prevent contact between the products and substances and the crops being cultivated. All traps, including pheromone traps, shall be collected after use and shall be safely disposed of.

DECLARATION

Me, as the undersigned…Joel Ayebeng Adjei…(DIHXW5) declare, that the Diploma Thesis entitled **Assessment of the Effects of Pests and Diseases on Three Tomato (*Solanum Lycopersicum*) Genotypes' Yield Under the Hedgerow System in the Organic Farm** submitted on 3rd May, 2023 is my own intellectual property.

I hereby acknowledge that the presentation of my thesis in the Dean's Office according the schedule does not mean at the same time the acceptance of my dissertation from professional and content related aspects.

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