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Prospects of Cropping with Polysaccharides Producing Microbes Under Drought Stress

Kuraklık Stresi Altında Polisakkarit Üreten Mikroorganizmalarla Ekim İmkânları

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ABSTRACT

Drought and water stress are the major abiotic stresses that limit plant growth. Plant growth-promoting rhizobacteria, well known for their growth-promoting attributes, produce extracellular polysaccharides that form rhizosheath around the roots, thereby protecting them from desiccation for a longer duration. Arbuscular mycorrhizae, one of the key determinants of soil quality, secrete glomalin protein, which shows soil aggregation properties and helps in increasing water stability, thereby overcoming drought conditions. Increasing extracellular polysaccharide-producing plant growth-promoting rhizobacteria and mycorrhizal fungi density in the rhizospheric soil can be a means to improve the survival of plants during water stress periods. The present review highlights the role of microbes producing extracellular polysaccharides in the maintenance of soil health and plant growth under drought.

Keywords: Drought stress, extracellular polysaccharides, glomalin, PGPR, AMF, microbes

ÖZ

Kuraklık/Su stresi, bitki büyümesini kısıtlayan önemli bir abiyotik strestir. Büyümeyi teşvik edici özellikleriyle iyi bilinen bitki büyümesini teşvik eden rizobakteriler (PGPR), köklerin etrafında kuraklık süresince onları daha uzun süre kuraklığa karşı koruyan hücre dışı polisakkaritler (EPS'ler) üretirler. Toprak kalitesinin temel belirleyicilerinden biri olan arbusküler mikorizalar, toprağın topaklanma özelliklerini gösteren ve su stabilitesinin arttırılmasına ve böylece kuraklık koşullarının aşılmasına yardımcı olan glomalin proteinini salgılar; bu protein, toprak agregasyon özelliklerini gösterir ve dolayısıyla kuraklık koşullarını aşarak su stabilitesini artırmaya yardımcı olur. Rhizosferik toprakta EPS üreten PGPR ve mikorizal mantar yoğunluğunu artırmak, bitkilerin su stresi dönemlerinde hayatta kalma şansını artırmak için bir yol olabilir. Bu derleme, EPS üreten mikroorganizmaların kuraklık altında toprak sağlığının ve bitki büyümesinin korunmasındaki rolünü vurgulamaktadır.

Anahtar Kelimeler: Kuraklık stresi, ekstrasellüler polisakkaritler, glomalin, PGPR, AMF, mikroorganizmalar

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Introduction

Agriculture is the art of domesticating plants for food, fiber, biofuel, medicinal purposes, and other products used to sustain and improve human life. Agriculture in the past century has seen large rises in productivity due to innovative human ideas on mechanization, synthetic fertilizers, biofertilizers, pesticides, and selective breeding. However, the world populace is thriving quickly and is relied upon to achieve 10 billion by the year 2050. The increasing population has exerted serious pressure on the existing agricultural land, demanding intensified crop production. Abiotic stresses like soil sodification, soil salinization, soil pH, drought, and environmental temperature are adding further constraints. Abiotic stress straightforwardly damages the farmable area, affecting the crop yield. Of all the 20th century climate risks, water stress brought on the greatest negative impact, and decreased rainfall was the major climatic factor affecting crop growth.

The natural soil microbial assembly dwelling in the rhizosphere and on the surface of the plant roots, which execute beneficial effects on the overall welfare of the plants, is categorized as plant

growth-promoting rhizobacteria (PGPR). Generally, about 2–5% of rhizosphere bacteria are PGPR. Majority of credible groups of PGPR belong to genera belonging to *Agrobacterium*, *Acinetobacter*, *Azotobacter, Arthobacter*, *Azospirillum, Burkholderia, Bradyrhizobium, Frankia, Serratia, Rhizobium, Thiobacillus, Pseudomonas,* and *Bacillus*. Plant growth-promoting rhizobacteria have mostly been studied for their abilities to improve plant growth by direct mechanisms, like enhancing nutrient content and phytohormone, extracellular polysaccharide (EPS) production, or indirect mechanisms, like siderophore production and protecting plants against pathogen attack by HCN production (Hakim et al., 2021). Adopting PGPR's can be an effective strategy for cropping under drought stress, as the EPSs secreted by the rhizobacteria in the soil along with the adjacent mineral particles form a sheath around the plant roots, which protects them from desiccation under the declining water conditions (Prasad et al., 2022). Polysaccharide-producing PGPR have also been reported to help in maintaining high water content in the rhizosphere in sandy soils (Khan et al., 2017; Zheng et al., 2018). They also help in the formation of macroaggregates, which improve soil structure. Extracellular polysaccharides can have an imperative role in ecosystem management as they exhibit multifaceted roles like protection of plants from desiccation, microbial aggregation, plant–microbe interaction, surface attachment, and bioremediation, which can help in ecosystem establishment.

Arbuscular mycorrhizal fungi (AMF), the other microbial group forming symbiotic association with the roots of higher plants, have profound effects on host plant physiology, soil engineering, and ecological interactions. Arbuscular mycorrhizal fungi well recognized for nutrient mobilization in plants (Miller & Jastrow, 2000) also help in encountering drought by secreting glomalin protein which shows soil aggregation properties (Rillig, 2004) thereby improving soil water stability. Understanding control over glomalin production and its mechanism of production can help maximize the contributions of arbuscular mycorrhizal mycelium to soil aggregation and water stability. Arbuscular mycorrhizal fungi colonization increases host growth rates during droughts by increasing water use efficiency and affecting soil enzymatic activity, which increases nutrient acquisition. Understanding the rhizospheric microbiome and maintaining the density of EPS-producing microbes can be helpful in overcoming the water stress responses in plants.

Besides PGPR and AMF, several other EPS-producing bacteria, algae, fungi, and yeasts are much worked upon for their industrial exploitation and biofilm properties but less studied for their plant growth-promoting attributes. Extracellular polysaccharides are one of the principal components involved in the formation of the extracellular biofilm matrix, which protects microorganisms from the adversities of pH, temperature, antibiotics, host immune defenses, and so on. The past decade has witnessed an increase in exploring natural polymers in areas of chemistry, medicine, and the food industry. Because of their unique structure and composition, they have an inherent ability to increase holding water, which makes them widely used as viscous, stabilizing, and emulsifying agents in the food industry and to improve the rheological properties, texture, and sensibility of bread and fermented milk products such as yogurt and cheese. In addition, EPSs also have potential health benefits such as antioxidant, anticancer, anti-inflammatory, antiviral, and cholesterol-lowering effects (Nguyen et al., 2020). Among EPS-producing bacteria, lactic acid bacteria (LAB) have captured much attention from researchers due to their strong ability to produce EPS. Introducing EPS-producing microbes in rhizosphere engineering can be helpful in improving plant growth, disease, and stress resistance by artificially reconstructing the plant-root microbiome and overcoming the barriers to intensive cropping under adversity.

Drought Response in Plants

Stress in general limits the growth of plants for some period of time until either the stress is removed or the plant is able to adjust its metabolism to overcome the stress. Soil drought often prompts an atmospheric drought, and if both combine, it becomes disastrous. Plants struggle more against soil drought than against atmospheric drought. A plant is stressed when there is a reduction in some physiological rate (water or nutrient absorption, photosynthesis, respiration, growth, development, reproduction, or others) below the maximum possible rate expressed under optimal conditions. Stress obstructs the plants from attaining genotypic potential, which severely affects productivity. In response to environmental stress, alterations in the levels of several compatible solutes like proline, sugar, polyamines, polyhydric alcohols, betaines, amino acids, and quaternary ammonium compounds are observed. Antioxidants are the principal defense system against oxidative damage in plants. These antioxidants, comprising superoxide dismutase, peroxidase, catalase, and many nonenzymatic compounds like carotenoids and ascorbate, get enhanced in response to water stress (Nadeem et al., 2021; Prasad and Raghuwanshi, 2022).

Water performs the main role of absorbing nutrients from the soil and transporting them to different parts of the plant. Morphologically, drought injury is evident as stunted growth, a decrease in the growth of the lateral root, and enhanced waxy deposition of epidermal and cortical cells, thereby decreasing intercellular space, which maximally affects growth, development, and plant productivity. Physiological characterization of plants subjected to drought reveals that the stress has several unique aspects, including high respiration with low photosynthesis, closed stomata, and high leaf temperature. Roots are the area where a plant first faces water stress and likely responds to stress conditions. Under limited water availability, the root–shoot ratio of plants increases because roots are less sensitive than shoots to growth inhibition by low water potential (Latif et al., 2022). Thus, to make plants drought-tolerant, better rhizo-engineering is always advisable. Microorganisms residing in the rhizosphere encode more genes than the host plants and form a stable community structure through collaboration and competition, which is crucial for growth, development, and resistance against adversities (Bai et al., 2022).

Bacterial Extracellular Polysaccharides

Extracellular polysaccharides can be referred to as those polysaccharides that are synthesized and then secreted in the external environment. Many times EPSs are synthesized extracellularly by the cell wall-anchored enzymes of bacteria and archaea. The term exopolysaccharide was proposed by Sutherland (Sutherland, 1977) for these EPS which is often used interchangeably. Extracellular polysaccharides is a heterogeneous mixture of polysaccharides, proteins, nucleic acids, and lipids in the form of long chain molecules, with a molecular weight of 10–30 kDa. Although bacteria synthesize only a few intracellular polymers, the range of extracellular polymers is vast (Rehm, 2010). Four major classes of polymers produced by bacteria are

polysaccharides, polyesters, polyamides, and inorganic polyanhydrides such as polyphosphatases (Rehm, 2010).

The diverse bacterial polysaccharides are categorized based on their chemical structure, functionality, molecular weight, and linkage bonds. Based on the chemical composition, EPS that is monomeric, i.e., only one type of monosaccharide, is classified as homopolysaccharide, while heteropolysaccharides have a polymeric composition. Heteropolysaccharides can have repeating units varying in size from disaccharides to heptasaccharides. Homopolysaccharides and heteropolysaccharides also differ in their sites of synthesis and their synthetic enzymes. The precursors of heteropolysaccharides are formed intracellularly inside the bacterium, and isoprenoid glycosyl carrier lipids then help in the translocation of the precursors across the membrane for further polymerization extracellularly (Nielsen & Jahn, 1999), whereas in the case of homopolysaccharides, synthesis requires a specific substrate such as sucrose. Mostly EPS are neutral, but they may also be polyionic due to the presence of uronic acid (D-galacturonic acid, D-glucuronic acid, and D-mannuronic acid), ketal-linked pyruvate groups or inorganic parts like sulfate and phosphate, which may impart the EPS a polyionic nature (Sutherland, 1977). Extracellular polysaccharides are water-soluble in nature. Sorptive EPSs involved in cell–surface interactions are composed of charged polymers whose function is sorption by other charged molecules. Exopolymers obtained from *Streptococcus epidermidis* strains were polycationic in nature (Prajapati et al., 1998). Functional groups like the hydroxyl group, carboxyl group, and phosphoric acid make the EPSs an acidic polymer, thereby showing high affinity toward metal ions (Concórdio-Reis et al., 2020). Besides affinities toward metal ions, the enzymatic activities of EPSs also help in heavy metal transformation and degradation of organic recalcitrant. In vitro studies have shown that the amounts of EPS produced not only depend on the bacteria species but are also affected by physicochemical factors like pH, temperature, incubation period, and medium grown (Ercole et al., 2007). High carbon and low nitrogen ratios favor the production of EPS by bacteria (Kimmel & Roberts, 1998).

Extracellular polysaccharides are the important component of the extracellular matrix and account for 40–95% of the bacterial weight. Bacteria may produce EPS in either the slime EPS form or the capsular EPS form. The EPSs serving architectural purposes in the matrix formation facilitate water retention and cell protection. Surface active EPSs involved in biofilm comprise molecules of amphiphilic nature having varied chemical structures and surface properties. Bacterial EPSs have 97% water in their polymer matrix, making them a suitable tool to provide protection against desiccation. Numerous studies have also reported the unusual antimicrobial activities of various EPS against a wide variety of human pathogenic microbes (bacteria, viruses, and fungi) (Abdalla et al., 2021). The various roles exhibited by bacterial EPS, which help in ecosystem establishment and soil health management under abiotic and biotic stress, are depicted in Figure 1.

Multifaceted interactions of bacterial EPSs with plants are helpful in ecosystem establishment. Extracellular polysaccharides are also found in the matrix of microalgal biofilms and share a lot of similarities with bacterial ones with respect to the components made up of proteins, phospholipids, polysaccharides, nucleic acids, humic substances, uronic acids, and some functional groups, such as phosphoric, carboxylic, hydroxyl, and amino groups. Early colonization and replication of microalgal biofilms are facilitated by the organic molecules present in the matrix. It is interesting to note that the microalgal biofilms comprise of 90% EPS and only 10% algal cells. Extracellular polysaccharides protect them from dehydration and reinforce the adhesion of the cells to the surface (Schnurr & Allen, 2015).

Biofilm Formation over Plant Roots by Extracellular Polysaccharide-Producing Bacteria

Bacterial population in the rhizosphere of healthy soils are normally 100–1000 times higher than in the bulk soil, mostly because bacteria possess metabolic versatility to adapt and utilize root exudates proficiently. The microbial population also covers 15% of the total root surface (Goswami et al., 2016). About 5–30% of the plant photosynthetic product is secreted by roots as different sugars, which in turn is utilized by microbial populations. The rhizosphere harboring microbial communities are the perfect place

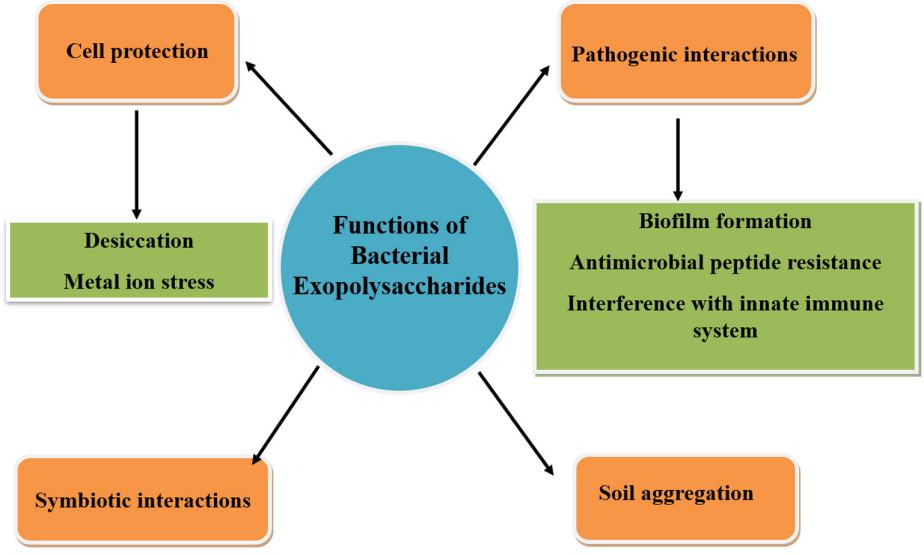

Figure 1.
Multi-Faceted Role of Bacterial Exopolysaccharide During Plant Interaction.

for the formation of biofilms as they have adequate soil moisture and nutrients, some of which are delivered by the plants, which promotes biofilm formation (Rodríguez-Navarro et al., 2007). Biofilm formation depends upon the bacterial density and diversity that reside inside the polymeric matrix, i.e., EPSs formed by bacteria themselves.

Extracellular polysaccharide-producing bacteria initially attach to the plant root as the first step in the process of biofilm formation. This attachment of bacteria to plant roots, which is the first phase, is reversible and involves an unspecific binding. In this process, three components are involved: are lectin protein, rhicadhesin (Ca12-binding protein), and bacterial polysaccharides. Lectin proteins are present at the tip of legume root hairs that recognize specific carbohydrates present on the bacterial surface and bind to them (Isken & Bont, 1998). The second step of attachment is irreversible in nature, in which the synthesis of bacterial cellulose fibrils happens after 8–16 hours of bacterial inoculation and is intervened by the surface polysaccharides of bacteria. Among the diverse plant factors that mediate the process of bacterial attachment, the most significant is plant lectin, which functions as receptors for the bacterial EPS attachment (Rodríguez-Navarro et al., 2007).

The EPSs produced by *Planomicrobium chinense* and *Bacillus cereus* were shown to have profound effects on plant growth and drought tolerance, as the rhizospheric soil moisture content was improved following PGPR inoculation up to 77% over control (Khan & Bano, 2019). Plants inoculated with EPS-producing bacteria showed a higher accumulation of proline, sugars, and free amino acids under water deficit stress (Khan & Bano, 2019; Naseem et al., 2018). Seed bacterization of maize with EPS-producing bacterial strains improved soil moisture contents, plant biomass, root and shoot length, leaf area, leaf protein, and sugar contents under drought stress conditions (Naseem et al., 2014). Khan et al., (2019) reported similar results in wheat plants grown under rainfed conditions. A novel bacterial surface polysaccharide isolated from R. 1. bv. viciae RBL5523 (Laus et al., 2006), mainly composed of glucose and mannose, galactose, and rhamnose, showed high binding affinity to the lectins of *Pisum sativum* and *Vicia sativa*. Some surface polysaccharides produced by bacterial strain R. 1. bv. viciae RBL5523 (Laus et al., 2006) have been shown to contain lipopolysaccharides, EPSs, cyclic glucans, and capsular polysaccharides. More research on bacterial attachment and factors affecting biofilm formation can be helpful in extending the applications of EPS-producing bacteria in agriculture and beyond.

Survival Mechanism of Extracellular Polysaccharide-Producing Bacteria Under Drought Stress

Bacterial response to drought stress depends upon stress intensity, bacterial species and their growth stages, and the duration of stress exposure. Physiological changes accounting for microbial survival under abiotic stress conditions include the formation of cysts, flock formation, melanin production, synthesis of poly-β-hydroxybutyrate, synthesis of EPS, and protection by ectomycorrhizal spore caps. Polysaccharides, being hygroscopic, uphold a higher water content compared to bulk soil, which ensures bacterial survival in their microenvironment under the decreasing water potential scenario. Rhizobacteria are reported to show enhanced EPS production with an increase in drought stress conditions compared to normal conditions indicating a response to be triggered by drought stress (Roberson & Firestone, 1992). Under water stress conditions, amount and composition of EPSs are reported to change as capsular polysaccharides of *Azospirillum brasilense* sp245 contained high-molecular weight carbohydrates, lipopolysaccharide–protein, and polysaccharide-lipid complexes that showed protection against extreme drought. Extracellular polysaccharide-producing bacteria ensure their survival under drought stress not only by producing exopolysaccharides (Sandhya et al., 2009), which protect them from desiccation, but also by regulating the diffusion of organic carbon under drought stress (Latif et al., 2022). Studies have shown that, besides EPS, the greater release of soluble carbohydrates by PGPR into the plant rhizospheric soil improves the survival efficiency of microorganisms under water-deficit conditions. Soil bacteria adopt different strategies to overcome soil desiccation, like they modify the structure of their membrane or synthesize EPS in order to ensure their existence during the conditions of low external water potential.

In a study done by Ilyas et al. (2020), 24 bacterial strains were tested, out of which *Bacillus subtilis* and *A. brasilense* producing good amounts of EPSs and osmolytes improved drought tolerance in wheat by retaining 97% water in the matrix, which protected the bacteria as well as plants from desiccation. Colonization of EPS-producing bacteria like *Azospirillum* and *Pseudomonas* has shown a growth promotion effect on wheat and maize seedlings and other plants under low soil water content (Alvarez et al., 2008; Sandhya et al., 2009). *Pseudomonas putida* strain GAP-P45, an EPS-producing bacteria, is reported to form biofilm on sunflower root surfaces and confer drought tolerance. *P. putida* strain GAP-P45 showed extensive soil aggregation, and such plants whose root adhered soil had high relative water content in leaves (Sandhya et al., 2009). Few studies done on cowpea plants inoculated with *Bradyrhizobium* strain under drought conditions have correlated the amounts of EPS produced to the level of tolerance observed under drought conditions (Skvortsov & Ignatov, 1998).

Many microbes and plants survive up to 99% water loss during long durations of desiccation (Welsh, 2000), as these microbes form nodules under desert conditions. Literature is well documented with free-living rhizobia (saprophytes) capable of surviving under low water potential (Vardharajula et al., 2011). Most of the drought-resistant plants have shown deeper root penetration, heavier roots, and numerous primary and secondary roots, which indicate a greater rhizosphere volume that can hold a higher microbial population enduring drought tolerance. The ratio of root/shoot increases under drought conditions as roots are less vulnerable to water deficiency than shoots (Wu & Xia, 2006). Extracellular polysaccharides-producing microbes can be exploited to increase the drought tolerance capacity of plants by increasing their population density in the rhizospheric zone of plants.

Drought stress is generally accompanied by salinity and nutrient imbalance, thereby adversely affecting plant growth and crop production in cultivated areas worldwide. Plant productivity under such conditions is considerably reduced due to osmotic stress, membrane destabilization, and the partial closure of stomata. Soil salinity and drought together considerably reduce plant growth, photosynthetic capacity, protein synthesis, energy and lipid metabolism, and the total nitrogen contents (Upadhyay et al., 2011).

Extracellular polysaccharides-producing plant growth-promoting rhizobacteria can significantly enhance the volume of soil macropores and rhizosphere soil aggregation, resulting in increased water and fertilizer availability to inoculated plants. Extracellular polysaccharides producing PGPR also bind cations, including Na^+. Therefore, an increase in the population density of EPS-producing bacteria in the root zone is advantageous as it reduces the content of available Na^+ for plant uptake and in so doing alleviates salt stress in plants growing in saline environments (Upadhyay, 2011).

Mechanisms of Microbial Extracellular Polysaccharides on Soil Restructuring and Drought Tolerance

The tripartite interactions among the soil, plant roots, and bacteria in the rhizosphere lead to changes in soil physicochemical and structural properties (Berg & Smalla, 2009). Extracellular polysaccharide-producing microorganisms residing in soil contribute immensely in maintaining soil health and quality, as these polysaccharides attach to the particles of soil, forming macroaggregates of diameter >250 µm and micro aggregates of <250 µm (Oades, 1993). Bacterial EPSs have been studied extensively in the rhizosphere for their function in moisture retention. Slime materials and capsular EPSs released by microbes in soil may be adsorbed through the clay surfaces via cation bridges, the van der Waal's force, hydrogen bonding, and the anion absorption process, thereby providing a protective barrier surrounding soil aggregates. Furthermore alginate, a tiny polysaccharide existing as a biofilm, helps to maintain a hydrated microenvironment by water retention and drying at a slower pace than the surrounding environment, thus protecting plant roots and microorganisms from desiccation (Fadiji et al., 2022). Crops primed with bacteria capable of producing EPSs show enhanced resilience to moisture stress (Ojuederie et al., 2019). Treatment of the bacteria strain *B. subtilis* strain UD1022 increased soil water retention and reduced unsaturated hydraulic conductivity and evaporation, as measured through the HYPROP measurements and neutron radiography imaging. Scanning electron microscope and light microscope imaging of the control sand particles showed clean surfaces, whereas rod-shaped bacteria cells were found distributed in a continuous and thick layer of dried biofilm covering UD1022-treated sand particles. Bridier et al., (2013) observed in SEM images that bacterial cells of *B. subtilis* were embedded in mucoid-like structures in a hydrated matrix, and upon gradual dehydration, the cells were connected by a dense and oriented network of fibers. The mucus material and the fibrous skeleton under dehydrated conditions were identified as EPS (Branda et al., 2006; Kumar et al., 2012). Volk et al. (2016) also reported a reduction in both saturated and unsaturated hydraulic conductivity in soil samples after incubation with *Pseudomonas*. Mathematical models have been developed to take into account the effects of EPS or mucilage on soil water retention and hydraulic conductivity. In a composite model treating soil phase and EPS as separate media, the water content or hydraulic conductivity at any given potential was found as a linear superposition of that in each phase (Rockhold et al., 2002). Rosenzweig et al., (2012) found that the dominant mechanism for increased water retention was EPS' distinct water holding capacity. Kroener et al. (2018) observed that mucilage occupies small pores and creates additional potential during drying, so that water retention increases, especially under dry conditions. Carles Brangarí et al. (2017), in a more complex model, found that the swelling properties of EPSs lead to soil pore size change. All these modeling results indicate that small amounts of EPS or mucilage could lead to significant changes in water retention and hydraulic properties. The cross-linked and compact EPS matrix behaves like a sponge and is capable of absorbing water at an amount of tens (xanthan or pure bacterial EPS) or hundreds (root mucilage of maize) of times its dry weight (Zheng et al., 2018). Pure xanthan can hold 50–70 g of water per gram of xanthan while maintaining structural coherence (Chenu & Roberson, 1996). Flemming and Wingender (2010) reported that EPSs are hygroscopic and can retain water entropically rather than through specific water-binding mechanisms. Soils with different textures responded to bacterial EPSs or mucilage treatment differently, indicating that other mechanisms might have also played a role in increasing soil water retention (Benard et al., 2019). Filament networks formed by EPSs in between soil particles not only creates additional surface area but also increases the surface roughness, and it is important to note that surface roughness increases water film thickness. As EPSs are generally composed of polymeric substances, they exhibit a larger viscosity compared to water, thus increasing flow resistance. The viscous biofilm produced by Strain 3610 *B. subtilis* cells measured at an air–liquid interface was 200 times higher than pure water (Angelini et al., 2009). Overall, it has been estimated that the effect of EPSs on water retention and hydraulic conductivity is twofold, as the retained water is less mobile due to higher viscosity, and as a result, there are more saturated soil pores at the same potential due to reduced surface tension (Zheng et al., 2018). Network bridging of the soil pore space through EPSs is a universal strategy for plants and bacteria to engineer their own soil micro-hydrological niches where stable conditions for life can be preserved under drought (Benard et al., 2019).

Biofilm formation involving the transportation of EPS components from the microbial cell to the surface is regulated by quorum sensing. Quorum sensing process regulates cell–cell communication through specific gene expression in a cell density-dependent manner (Dutta et al., 2022). The process may, however, differ in the diverse bacterial forms. Maintenance of adequate soil structure and porosity is important as it aids in root growth, helping the plant explore a greater soil volume for nutrients and water. The EPSs produced by the rhizobacteria help in the formation of biofilm or sheath around the roots, which not only helps in holding the soil but also provides an active site for microbial interactions leading to nutrient recycling and its availability along with the flow of water to the plants (Kohler et al., 2008). Soil water potential acts as a key parameter in determining the availability of water, oxygen, and soil nutrients to the plants as well as microorganisms residing in the soil. Relative water content (RWC) in leaves is a measure of plant water status. Decreased RWC causes closure of stomata, leading to decreased CO_2 assimilation in plants, resulting in poor growth. While ample literature is focused on plants' physiological and yield parameters affected by EPS, studies lag on quantifying the effects of microbial EPSs on the RWC of leaves.

Mycorrhizal Interactions with Plants and Its Significance

Arbuscular mycorrhizal fungi forming symbiotic association with the root systems of 80% of terrestrial plants belong to the phylum Glomeromycota. Several mechanisms are involved in this symbiotic association that helps plant to survive even under stressful conditions, like enhanced growth through nutrient uptake, prevention of oxidative damage, reduced ion toxicity, and improving photosynthesis through osmotic adjustments. Arbuscular

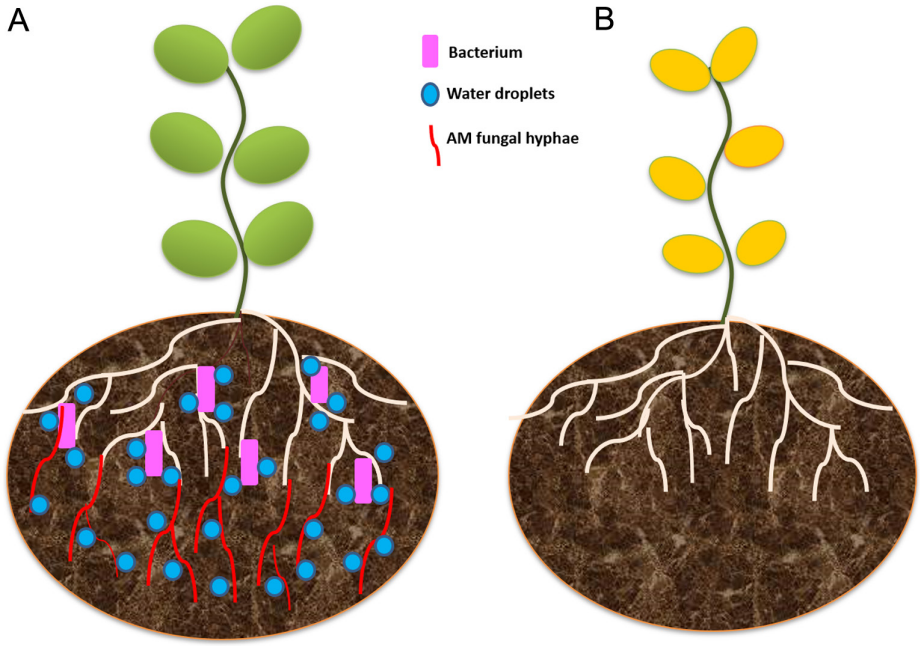

Figure 2.
Water Status in Rhizospheric Soil. (A) In the Presence of Microbes. (B) In the Absence of Microbes.

mycorrhizal fungi are key determinants of soil quality and are well recognized in processes of nutrient cycling and soil aggregation (Miller & Jastrow, 2000). The commonly occurring genera of AMF are *Glomus*, *Gigaspora*, *Scutellospora*, *Acaulospora,* and *Entrophospora*. Arbuscular mycorrhizal fungi inside the root form the intraradical mycelium, consisting of hyphae and other fungal structures, such as arbuscules, which are the sites of nutrient and carbon exchange between the symbionts, and vesicles, which help in fungal lipid storage. This intraradical mycelium is well extended outside the root, as is the extraradical mycelium in the soil, where it forms spores. The intraradical mycelium of soil mycorrhizal fungi inserted into the root cortex of the host plants assists in improving water relations, photosynthesis rates, and drought responses. It is the extraradical mycelium that plays a central role in contributing to soil quality. Arbuscular mycorrhiza formation results in an ecological niche for roots to be more accessible to water resources, as the fungal hyphae can penetrate soil pores inaccessible to the root hairs. They result in altering the root architecture, resulting in increased water uptake even at low soil moisture levels. The extraradical fungal hyphae is also capable of exploring water and nutrients beyond the depletion zone, as depicted in Figure 2.

Arbuscular mycorrhiza symbiosis not only enhances the acquisition of major plant nutrients like phosphate, nitrogen, and sulfur but even trace elements like zinc and copper. Arbuscular mycorrhiza colonization is also corelated with an increase in the activities of certain enzymes that help in the hydrolysis and mobilization of nutrients. In alkaline soils, phosphorus (P) often forms complexes with Ca and Mg, rendering P unavailable for uptake by plants. Higher acid phosphatase in the mycorrhizosphere as compared to the rhizosphere of non-arbuscular mycorrhiza plants enables the hydrolysis and mobilization of P, which is easily taken up by the plants. Higher soil acid phosphatase activities in the mycorrhizosphere were also observed to be positively correlated to soil water content. Thus, an increase in soil acid phosphatase activity due to mycorrhiza partially alleviates plant drought stress in plants (Wu et al., 2006). Arbuscular mycorrhiza symbiosis increases the units of photosynthesis, increasing the rates of photosynthetic storage and export in the plants. After infection in host plants, arbuscular mycorrhiza symbiosis incites a more powerful ROS scavenging system, which reduces the destruction of biomolecules at the cellular level under water stress conditions. Arbuscular mycorrhiza symbiotic plants exposed to water stress have been reported to show lower lipid peroxidation than nonmycorrhizal plants. Arbuscular mycorrhizal fungi protect host plants against oxidative damage through increase in enzymatic and nonenzymatic antioxidants. Increased enzymatic antioxidants, i.e., peroxidase and catalase, and alleviating ROS breakage are some of the methods of protecting arbuscular mycorrhiza plant organisms from oxidative bursts under water stress (Li et al., 2019).

Mycorrhizal Glomalin in Shaping Soil Structure

The soil structure reflects the soil biota to a large extent. Soil structure and biota are important aspects of the biogeochemical cycling process, even offering resistance to soil erosion. Soil aggregation is a complex process in which numerous microorganisms secreting various binding agents play a vital role (Miller & Jastrow, 2000). Arbuscular mycorrhizal fungi are ubiquitous soil organisms, and their relatively persistent hyphae and their products make AMF important contributors as longer-term aggregate stabilizers (Miller & Jastrow, 2000). Among all soil factors, AMF hyphae have a direct effect on soil aggregation through the production of glomalin protein, which helps in soil binding. The role of AMF in soil engineering has mostly been studied with respect to soil aggregation, as these aggregates physically protect the carbon inside and contribute to the soil carbon pool. Soil organic matter, which is related to carbon content, has a multifarious influence on soil quality, including water-holding capacity and nutrient storage capacity. The various roles of AMF in plant well-being, soil engineering, and ecosystem establishment is depicted in Figure 3.

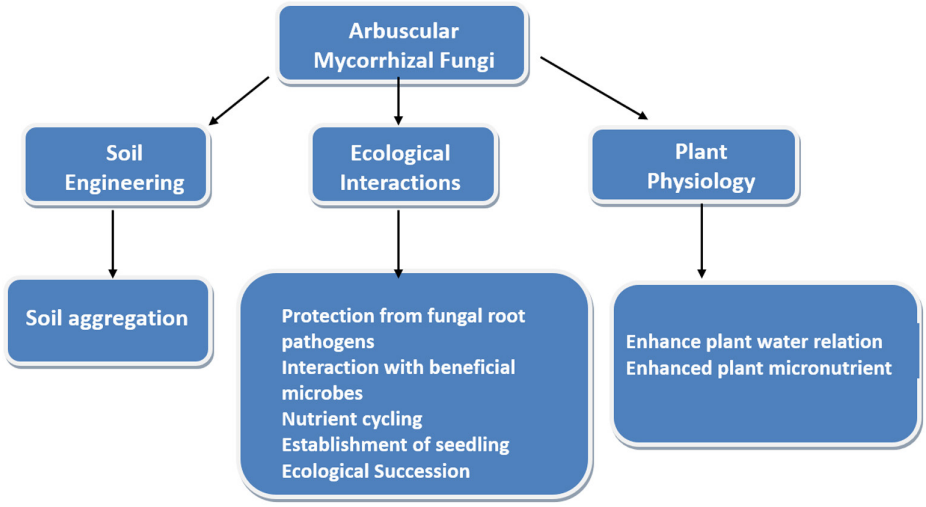

Figure 3.
Role of Arbuscular Mycorrhizal Fungi in Soil Engineering and Ecosystem Establishment.

Concentration of glomalin-related soil protein (GRSP) in soil has been positively correlated with aggregate water stability (Rillig, 2004). As GRSP has a slow turnover rate, it immensely contributes to soil aggregation in the long term. However, few studies done through conventional disintegrating forces show that GRSP concentration is positively correlated with soil aggregate water stability only to an extent and beyond a certain saturation level; additional deposition of GRSP does not remarkably increase the soil aggregate water stability (Kemper & Rosenau, 1986). Further, when talking of large-scale managed agroecosystems where water stability is quite low, the addition of low levels of GRSP shows a linear relationship to water stability (Wright & Upadhyaya, 1998). A path analysis experiment done in California grassland showed AMF hyphae and its products, i.e., glomalin, as significant contributors to soil aggregate water stability (Rillig, 2004). Of the soil protein pool, GRSP shows a slow turnover time, which makes it an important compound in soil aggregation. Few data suggest that glomalin is retained in the hyphal or spore wall instead of being secreted in the soil (Driver et al., 2005). It is only after the hyphal turnover that it gets deposited into the soil. Glomalin-related soil protein remained after >400 days in soil under lab incubation conditions in an experiment conducted on Ohio, USA, soils. A study conducted in western Montana grassland on seasonal variation in GRSP concentrations exhibited minor temporal coefficient variations, but some GRSP fractions showed statistically significant changes (Lutgen et al., 2003). Revealing the molecular biology of glomalin can be of great help in tracing the trajectory of this important soil-binding protein. Many studies have reported AMF as a determining factor in plant species diversity (van der Heijden et al., 1998) at the ecosystem level. In agroecosystems AMF diversity and performance are greatly influenced by tillage, application of biocides, cropping sequences (nonmycorrhizal hosts), fertilization, and genotype. It has been clearly demonstrated that the soil GRSP pools are negatively affected by agricultural practices like crop rotation and tillage (Wang et al., 2011). Glomalin-related soil protein pools are also sensitive to environmental factors like elevated atmospheric CO_2 concentration which increases the level of GRSP, or warming, which brings down the GRSP concentration in the soil (Rillig, 2004). A recent critical review on the occurrence and functioning of AMF in agroecosystems (Ryan & Graham, 2002) has concluded the negative influence of modern agroecosystem management practices on diversity and functional aspects of AMF. More research done on the role of GRSP in soil aggregation beyond the 1- to 2-mm size class can help in better understanding.

Managing GRSP concentration in soil can be a promising approach to improve soil structure and quality, not only in agricultural soil but also in degraded ecosystems. Preliminary research indicates that glomalin amounts in soils can be manipulated by changing the composition of the arbuscular mycorrhiza community or altering the arbuscular mycorrhiza physiology, which is well correlated with the physiological status of the host species (Rillig, 2004). Arbuscular mycorrhizal fungi clearly differs in many of their life history traits, and it has been observed that different AMF species produce varying amounts of GRSP, a character that can be explored to increase the utility of marginal lands and bring them under agricultural purpose by inhabiting AMF species with a high GRSP production rate.

Conclusion

Plants can be made more tolerant to drought stress by increasing EPSs and producing microbial population density in the root zone. Extracellular polysaccharide-producing PGPR and AMF are important biotic factors that influence soil quality and plant growth through their direct effects on soil structure and indirectly through their effects on host physiology and ecological interactions. Glomalin, a hyphal product, contributes to soil aggregation and water stability across different types of soils, and thus the AMF community is an important regulator helpful in soil engineering. Managing an appropriate microbial consortium in soil can be promising in overcoming the adverse effects of deficit irrigation in cropping.

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Profit Efficiency of Paddy Rice Marketing in Kaduna State, Nigeria: Implications for Food Security and Poverty Alleviation

Nijerya'nın Kaduna Eyaletinde Çeltik Pirinç Pazarlamasının Kâr Verimliliği: Gıda Güvenliği ve Yoksulluğun Azaltılmasına Yönelik Etkiler

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ABSTRACT

This study evaluated the profit efficiency of paddy rice marketing in Kaduna State, Nigeria, with implications for food security and poverty alleviation. A multi-stage sampling technique was adopted. A total sample size of 180 paddy rice marketers was selected. Primary data were obtained using a well-structured and well-designed questionnaire. The data were analyzed using descriptive and inferential statistics. The result shows that the mean ages of producers, wholesalers, and retailers that are involved in rice marketing were 46, 44, and 41 years old. Paddy rice marketing is profitable. The producers had the highest marketing margin and the lowest operating ratio of 85.82% and 0.12, respectively. The retailers had the highest marketing efficiency of 20.92%. The rates of return on investment for producers', wholesalers, and retailers involved in paddy rice marketing were 5.54, 4.27, and 3.78, respectively. The purchase price, transportation cost, labor cost, and fees were the significant factors influencing the profit efficiency of the actors involved in paddy rice marketing. The significant socioeconomic factors influencing the profit inefficiency of paddy rice marketing among actors were age, gender, educational level, access to credit, and membership of cooperatives. The mean profit efficiency score for actors was 0.46, leaving a gap of 0.54 for improvement. The study identified transportation, finance, roads, and market infrastructure as the major problems associated with paddy rice marketing. The study recommended that credit facilities should be provided and made accessible; also, investment in market and road infrastructure is necessary to create an enabling environment for effective and efficient marketing.

Keywords: Profit effiency, stochastic profit efficiency frontier model, paddy rice marketing, Nigeria

ÖZ

Bu çalışma, Nijerya'nın Kaduna Eyaleti'nde çeltik pirinç pazarlamasının kârlılık etkinliğini, gıda güvenliği ve yoksulluğu hafifletme açısından değerlendirmiştir. Çalışmada çok aşamalı bir örnekleme tekniği benimsenmiştir. Toplamda 180 çeltik pirinç pazarlamacısından oluşan bir örneklem büyüklüğü seçilmiştir. İlk veriler, iyi yapılandırılmış ve tasarlanmış bir anket kullanılarak elde edilmiştir. Veriler, tanımlayıcı ve çıkarımsal istatistikler kullanılarak analiz edilmiştir. Sonuçlar, pirinç pazarlamanın karlı olduğunu göstermektedir. Üreticilerin pazarlama marjının en yüksek olduğu ve işletme oranının en düşük olduğu (sırasıyla %85,82 ve 0,12) tespit edilmiştir. Perakendecilerin en yüksek pazarlama etkinliğine (%20,92) sahip olduğu belirlenmiştir. Üreticilerin, toptancıların ve perakendecilerin çeltik pirinç pazarlamasına katılanların yatırım getirisi sırasıyla %5,54, %4,27 ve %3,78'dir. Çeltik pirinç pazarlamasında yer alan aktörlerin karlılık etkinliğini etkileyen önemli faktörler arasında alım fiyatı, taşıma maliyeti, işçilik maliyeti ve ücretler yer almaktadır. Çeltik pirinç pazarlamasındaki aktörler arasında karlılık etkinliğini etkileyen önemli sosyo-ekonomik faktörler arasında yaş, cinsiyet, eğitim düzeyi, kredi erişimi ve kooperatif üyeliği bulunmaktadır. Aktörler için ortalama kârlılık etkinlik puanı 0,46 olarak belirlenmiş olup, iyileştirme için 0,54'lük bir boşluk bulunmaktadır. Çalışma, çeltik pirinç pazarlamasıyla ilişkilendirilen ana sorunları taşımacılık, finans, yol ve pazar altyapıları olarak tanımlamıştır. Çalışma, kredi olanaklarının sağlanması ve erişilebilir hale getirilmesi, ayrıca etkili ve verimli pazarlama için uygun bir ortam yaratmak için pazar ve yol altyapılarına yatırım yapılmasını önermektedir.

Anahtar Kelimeler: Kârlılık etkinliği, stokastik karlılık etkinlik sınır modeli, çeltik pirinç pazarlama, Nijerya

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Introduction

Rice (*Oryza sativa*) is a staple food consumed globally by a large population of people, both in urban and rural areas of Nigeria. Nigeria is the largest producer of rice in Africa, and it is the largest consumer, with a consumption per capita of 32 kg. Nigeria's demand for rice is about 7.9 million metric tons per year, out of which an average of about 2 million metric tons are imported; the country has spent between $500 million and $1 billion on rice importation per year since 2002 (Ejoha, 2019). Rice is crucial to the food security of many developing nations, such as Nigeria (Yusuf, 2022). It is one of the multivalue chain crops that plays a significant role in national food security and employment sustenance, generates income, and serves as a source of raw material for agro-allied industries (Ejoha, 2019; Okoro et al., 2015). Rice is an increasingly important crop for Nigeria's economic growth and food security; it is the most common cereal crop in Nigeria (Okello et al., 2019). Rice is grown in virtually all the ecological zones in Nigeria due to its significant importance. Rice paddy production in Nigeria has increased by 2.08%, from 8.17 million tons in 2020 to about 8.34 million tons in 2021 (Rice Farmers Association of Nigeria, RIFAN, 2022). Rice has maintained its position as one of the most promising commercial crops for food security, economic growth, and poverty alleviation (Hounge and Nonvide, 2020). Rice marketing encompasses all the activities involved in moving rice from the point of production to where it is needed by the final consumers in the desired form and at the appropriate time (Abah et al., 2015a; Bassey et al., 2013). Agricultural marketing plays an important role in stimulating production and consumption and in accelerating economic development (Alabi et al., 2020). An efficient marketing system promotes economic development by encouraging specialization and leading to output enhancement (Ejoha, 2019). According to Bassey et al. (2013), increasing production of rice without a corresponding efficient marketing strategy being put in place to ensure its accessibility would not stimulate farmers to embrace practices that would enhance production since the excess would be wasted through post-harvest loses/lower prices. Improving the performance of rice marketing will require proper planning and decision-making that is dependent on adequate empirical knowledge of the market structure and the behavior of the various actors in the marketing system (Ejoha, 2019). According to Abah et al. (2015a), marketing ought to provide, among other things, access to irrigated land, appropriate farm inputs, and market information, including agricultural best practices and pricing needed to transform the Nigerian rice market. Nigeria is the leading importer of rice in Africa (Ojo et al., 2020). Relying on imported rice on global markets not only stimulates domestic inflation but also affects small-scale farmers in Nigeria, displacing their local production and fueling the already rising unemployment rate (Mark et al., 2019). Nigerians' preference for imported rice is a sign of the deteriorating state of nations' agricultural and technological development, inefficiency in profit among farmers and in the use of resources, low production, the use of traditional technology by small-scale farmers, and an inconsistent macroeconomic policy environment.

Objectives of the Study

This study evaluated the profit efficiency of paddy rice marketing in Kaduna State, Nigeria, with implications for food security and poverty alleviation. The specific objectives were:

1. Determine the socioeconomic characteristics of paddy rice marketers.
2. Analyze the prevailing prices, gross margin, and net income of paddy rice marketing.
3. Estimate the marketing margin and marketing efficiency of paddy rice and evaluate the factors influencing the profit efficiency of paddy rice marketing.
4. Evaluate the socioeconomic factors influencing the profit inefficiency of paddy rice marketing.
5. Determine the profit efficiency scores of paddy rice marketers.
6. Determine the constraints facing paddy rice marketers in the study area.

Methods

This research study was conducted in Kaduna State, Nigeria. Kaduna State lies between longitudes 06° 15′ and 08° 50′ east of the prime meridian and latitudes 09° 02′ and 09° 02′ north of the equator. The state has a total land area of 4.5 million hectares. The population of Kaduna as of 2021 was 8.9 million people. They are involved in agricultural activities. Crops grown include pepper, maize, ginger, sorghum, rice, yam, cassava, millet, and tomatoes. Animals reared include cattle, goats, sheep, rabbits, and poultry. A descriptive cross-sectional research design was employed in this study. A multistage sampling technique was adopted for this study. Sampling frame of 213 paddy rice marketers wcomprising 71 producers of paddy rice marketers, 71 wholesalers of paddy rice marketers, and 71 retailers of paddy rice marketers. A proportionate and simple random sampling technique was used to select the desired sample size of 180 paddy rice marketers (60 paddy rice marketers each). This study employed the formula advanced by Yamane (1967) in the determination or estimation of the sample size. The formula is stated thus:

$$n = \frac{N}{1+N\left(e^2\right)} = 180 \quad (1)$$

where

n = desired sample size.

N = finite size of the population.

e = maximum acceptable margin of error as determined by the researcher.

Method of Data Analysis

The data for this study were collected through the use of a well-structured and well-designed questionnaire. Data were analyzed using econometric tools in addition to descriptive and inferential statistics as follows:

Gross margin analysis: The gross margin and net farm income analysis of paddy rice marketing were estimated using the models as follows:

$$GM = \sum_{i=1}^{n} P_i Q_i - \sum_{j=1}^{m} P_j X_j \quad (2)$$

$$NFI = \sum_{i=1}^{n} P_i Q_i - \left[\sum_{j=1}^{m} P_j X_j + \sum_{k=1}^{k} GK \right]. \quad (3)$$

where

P_i = Price of paddy rice  ,

Q_i = quantity of paddy rice (Kg),

P_j = price of variable inputs  ,

X_j = quantity of variable inputs (units),

TR = total revenue obtained from sales of paddy rice (N),

TVC = total variable cost (N),

GK = cost of all fixed inputs (Naira),

NFI = net income (Naira),

The gross margin analysis was used to analyze the profitability of paddy rice marketing as stated in specific objectives two (ii) and three (iii).

Financial analysis: According to Alabi et al. (2020), gross margin ratio is defined as follows:

$$\text{Gross margin ratio} = \frac{\text{Gross margin}}{\text{Total revenue}}. \quad (4)$$

According to Olukosi and Erhabor (2015), operating ratio is defined as follows:

$$\text{Operating ratio} = \frac{TVC}{GI} \quad (5)$$

where

TVC = total variable cost (Naira),

GI = gross income (Naira),

The rate of return per Naira invested (RORI) in paddy rice marketing is stated as follows:

$$RORI = \frac{NI}{TC} \quad (6)$$

where

NI = net income from paddy rice marketing (Naira),

TC = total cost (Naira),

The financial analysis was used to analyze the profitability of paddy rice marketing as stated in specific objectives two (ii) and three (iii).

Marketing Margin

Marketing margin (MM) according to Olukosi and Erhabor (2015) is defined as follows:

$$MM\ in(\%) = \frac{PR_t - FP_t}{PR_t} = \frac{SP - PP}{SP} \quad (7)$$

where

PR_t = retail price (Naira),

FP_t = farm gate price (Naira),

SP = selling price (Naira),

PP = purchasing price (Naira),

This was used to estimate MM of paddy rice marketing as stated in specific objective three (iii).

Marketing Efficiency

Marketing efficiency (ME), according to Olukosi and Erhabor (2015), Babatunde and Oyatoye (2005), is defined as follows:

$$ME = \frac{VAM}{CMS} \times 100 = \frac{TC}{TR} \times 100 = \frac{TC - TR}{TC} \times 100 \quad (8)$$

where

VAM = value added by marketing (Naira),

CMS = cost of marketing services (Naira)

TC = total cost incurred (Naira)

TR = total revenue (total value of products sold) (Naira)

This was used to estimate the ME of paddy rice marketing as stated in specific objective three (iii).

Depreciation of Assets

The straight-line depreciation of assets according to Olukosi, Erhabor, and Isitor (2015) is stated as follows:

$$D = \frac{P - S}{n} \quad (9)$$

where

D = straight-line depreciation (Naira).

P = purchasing price (Naira).

S = salvage value (Naira).

n = number of years of life of the assets.

Stochastic Profit Efficiency Frontier Model

The stochastic profit efficiency frontier model according to Alabi et al. (2022); Sadiq and Singh (2015); and Ejoha (2019) is stated as follows:

$$Ln\pi^* = \beta_0 + \sum_{j=1}^{6} \beta_i lnX_{ij} + \beta_k lnX_k + v_j - \mu_i. \quad (10)$$

where

π^* = normalized profit (Naira),

X_i = vector of variable input prices faced by ith marketers (Naira/kg),

X_k = vector of fixed factors of the ith marketers (Naira/unit),

ln = natural log,

$\beta_0 - \beta_6$ *and* β_k = parameters to be estimated,

X_1 = purchase price of paddy rice (Naira/kg),

X_2 = transportation cost (Naira),

X_3 = labour cost (Naira),

X_4 = rent (Naira),

X_5 = fees (Naira)

X_k = cost of land and machines (Naira),

V_i = statistical disturbance term (two-sided random error),

U_i = profit inefficiency effects of the *i*th marketers (one-sided half normal error).

$$U_i = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_5 Z_5 + \alpha_6 Z_6 + \alpha_7 Z_7. \quad (11)$$

where

Z_1 = age (years),

Z_2 = gender (dummy: 1, male; 0, otherwise),

Z_3 = level of education (years),

Z_4 = household size (number),

Z_5 = access to credit (1, access; 0, otherwise),

Z_6 = memberships of cooperative association (1, membership; 0, otherwise),

Z_7 = years of experience (years),

α_0 = constant term,

$\alpha_1 - \alpha_7$ = parameters to be estimated,and

U_i = error term due to technical inefficiency.

This was used specifically to achieve objectives four (iv), five (v), and six (vi).

Principal Component Analysis

The constraints facing paddy rice marketers were subjected to the principal component model. This was used to specifically achieve objective seven (vii).

Results, Discussion, Conclusion and Recommendations

Socioeconomic Characteristics of Paddy Rice Marketers

The summary statistics of the socioeconomic profiles of paddy rice marketers under consideration were age, gender, marital status, level of education, household size, and marketing experience (Table 1). The mean ages of paddy rice marketers for producers, wholesalers, and retailers were 46, 44, and 41 years old, respectively. This implies that paddy rice marketers are active and within the productive workforce. This result is in line with the findings of Ben-Chendo et al. (2017). In terms of gender analysis, about 80% of rice producer marketers were male, while 20% were female. Also, 42% of wholesalers were male, while 58% were female. Furthermore, 35% of paddy rice retailers were male, while 65% were female. This shows that women were the main participants in the wholesale and retail of paddy rice in the study area. This shows that women play a greater role in rice marketing since the majority of men are mainly involved in farming. About 85.93% of the producers, 60.97% of the wholesalers, and 58.50% of the retailers were married. This is in Amolegbe and Adewumi (2016), who observed that the majority of the actors in the rice value chain were married. Averagely, rice paddy producers', wholesalers', and retailers' marketers had 12, 13, and 12 years of education, respectively. This

Table 1.
Summary Statistics of Socioeconomic Profiles of Paddy Rice Marketers

Variables	Summary Statistics		
	Producer	Wholesaler	Retailer
Age (years)	46	44	41
Gender (% male)	80.00	42.00	35.00
Marital status (% married)	85.93	60.97	58.50
Level of education (years)	12	13	12
Household size (number)	6	5	5
Marketing experience (years)	10	12	11
Sample size (*n*)	60	60	60

Source: Field Survey (2022).

Table 2.
Marketing Margin, Marketing Efficiency, and Profitability Analysis of Paddy Rice Marketing for Producers

Items	Amount (Naira)	% of Total Cost
Production cost		
Seeds	7343.87	05.95
Fertilizers	35,716.43	28.94
Herbicides	6129.17	04.97
Insecticides	4694.18	03.80
Labour	24,813.37	20.10
Total production cost (TPC)	78,697.02	63.76
Marketing Cost	14,463.14	11.72
Processing	5224.26	04.23
Packaging	9872.10	07.99
Transport	2309.23	01.87
Storage	2094.67	01.70
Loading and off-Loading	1087.96	0.88
Cost of empty jute bags, sacks, thread, sowing	35,051.36	28.40
Total marketing cost (TMC)	113,748.38	92.16
Total variable cost (TVC)	7667.43	06.21
Fixed cost	2004.21	01.62
Land cost	9671.64	07.84
Depreciation	123,420.02	100.00
Total fixed cost (TFC)	32.3409	
Total cost (TC)	24,957.29	
Yield/100 kg/ha	807,141.22	
Selling price/100 kg	683,721.2	
Total revenue (TR)	693,392.84	
Net income (NI)	920,243.09	
Gross margin	0.86	
Gross income (estimated from survey) + gift + home consumption	0.12	
Gross margin ratio (GMR)	5.54	
Operating ratio (OR)	85.82	
Rate of Return on investment (RORI)	15.29	
Marketing margin (MM) (%)	86.07	
Marketing efficiency (ME) (%)		
Producer share (%)		

Source: Field Survey (2022).

result agrees with the findings of Abah et al. (2015b), who reported that paddy rice producers and marketers have attained some level of formal education and can read and write.

Marketing Margin, Marketing Efficiency, and Profitability Analysis of Rice Paddy

Marketing for Producers

Table 2 presents the marketing margin, marketing efficiency, and the various costs and returns involved in paddy rice marketing for producers. The various costs involved and revenue obtained were based on the prevailing market price at the time of the survey. The result shows that the farmers obtained 683,721.20 Naira as total revenue from sales of paddy rice per hectare. This shows that paddy rice marketing for producers was profitable. The operating ratio of 0.12 implies that the farmers used 12.0% of the total revenue to offset the operating cost of producing and marketing paddy rice per hectare. The rate of return on investment was estimated at 5.54; this implies that the farmer earned over 5.5 Naira per 1.00 Naira invested in paddy production and marketing per hectare. This result is in line with the findings of Osawe et al. (2017). The producers received a marketing margin of 85.82%, which implies that the farmer earns 0.85% from marketing paddy rice. The coefficient of marketing efficiency for the farmers was 15.29%; this signifies that 15.29% of the sales revenue of the producers' marketers is taken up by costs. This result is in line with the findings of Ejoha (2019). The producer's share among actors along the rice value chain was estimated at 86.07%.

Marketing Margin, Marketing Efficiency, and Profitability Analysis of Paddy Rice

Marketing for Wholesalers and Retailers

Table 3 presents the marketing margin, marketing efficiency, and the various costs and returns involved in paddy rice marketing for wholesalers and retailers. The various costs involved and revenue obtained were based on the prevailing market price at the time of the survey. The total revenue obtained from sales of paddy rice for wholesalers and retailers was 8816,547.56 Naira and 6,166,700.54 Naira, respectively. The wholesalers got an average gross margin of about

7385,194.61 Naira, for the period under examination, while the net income stood at 7,143,710.98 Naira. The gross margin accrued to the retailers was 4,999,851.53 Naira, and the net income amounted to 4,876,546.04 Naira. This shows that paddy rice marketing by wholesalers and retailers was profitable. The operating ratio shows that the retailers spent about 19% of their total revenue on the operating costs of retail rice marketing, while the wholesalers spent 16% of their revenue on the operating costs. Every one Naira invested in wholesale paddy marketing yields about 4.27 Naira in returns, while retailers earn about 3.78 Naira per one Naira invested in paddy rice marketing. The wholesalers and retailers share amounted to 10.48% and 03.45% among the actors across the rice value chain, respectively. This result is in consonance with the findings of Chidi et al. (2015) and Nwibo et al. (2013). The wholesalers and retailers got 10.74% and 03.44% marketing margin per 100 kg bag of paddy rice; this implies that the wholesalers and retailers received 0.11 and 0.03 Naira, respectively, for every one Naira spent on 100 kg bag of paddy rice. The coefficients of marketing efficiency for wholesalers and retailers were 18.97% and 20.92%, respectively. This signifies that 18.97% and 20.92% of the sales revenue of the marketers were taken up by the costs. This result is in consonance with the findings of Okwo (2009).

Table 3.
Marketing Margin, Marketing Efficiency, and Profitability Analysis of Paddy Rice Marketing for Wholesalers and Retailers

	Wholesalers		Retailers	
Items	Amount (Naira)	% of Total Cost	Amount (Naira)	% of Total Cost
Purchasing price (100 kg)	24,990.10		27,998.27	
Transport	333,567.81	19.94	252,236.66	19.55
Labour	285,219.671	17.05	184,382.21	14.29
Processing	–	04.38	68,775.32	05.33
Packaging	73,257.628	08.91	116,168.55	09.00
Storage	149,072.864	09.39	126,337.80	09.79
Fees	157,073.94	21.58	241,741.60	18.73
Handling	361,067.92	09.27	124,460.70	09.65
Loading and offloading	155,112.76	04.43	52,746.17	04.09
Cost of empty bags, thread, sowing	74,054.22	85.56	1,166,849.01	90.44
Total marketing cost	1,431,352.95	13.99	117,787.53	09.13
Fixed cost	234,126.36	00.44	5517.96	0.43
Land/shop rentals	7,357.27	14.43	123,305.49	09.56
Depreciation cost	241,483.63	01.67	28,996.57	90.44
Total fixed cost (TFC)	27,996.15	0.02	212.67	100.00
Supply price (100 kg)	314.92	85.56	1,166,849.01	
Number of bags sold (100 kg)	1,431,352.95	100.00	1,290,154.5	
Total variable cost (TVC)	1,672,836.58		6,166,700.54	
Total cost (TC)	8,816,547.56		4,876,546.04	
Total revenue (TR)	7,143,710.98		4,999,851.53	
Net income (NI)	7,385,194.61		6,020,213.01	
Gross margin	8,821,228.29		0.81	
Gross income (estimated from	0.84		0.19	
survey) + gift + home	0.16		3.78	
Consumption	4.27		03.44	
Gross margin ratio (GMR)	10.74		20.92	
Operating ratio (OR)	18.97		03.45	
Rate of return on investment (RORI)	10.48			
Marketing margin (MM) (%)				
Marketing efficiency (ME) (%)				
Wholesaler/retailer share (%)				

Source: Field Survey (2022)

Estimates of Stochastic Profit Efficiency Frontier Model of Paddy Rice Marketing

The maximum likelihood estimates of the stochastic frontier function of the factors influencing the profit efficiency of paddy rice marketing in the study area are presented in Table 4. The estimated coefficients of the parameters of the normalized

Table 4.
Maximum Likelihood Results of the Stochastic Profit Efficiency Frontier Model

Variables	Parameters	Coefficient	Standard Error	Z-Value
Constant	β_0	0.8702***	0.0069	125.09
Purchase price	β_1	–1.3304***	0.0091	–147.07
Transportation cost	β_2	–0.4206***	0.1081	–3.89
Labour cost	β_3	2.1704***	0.1807	12.01
Rent	β_4	–1.3075	0.7387	–1.77
Fees	β_5	3.4201***	0.6151	5.56
Inefficiency component				
Constant	α_0	–5.7034**	2.2279	–2.56
Age	α_1	–0.0723**	0.0354	–2.04
Gender	α_2	–0.8230**	0.3995	–2.06
Educational level	α_3	–0.0452**	0.0199	–2.27
Household size	α_4	0.0209	0.0535	0.39
Access to credit	α_5	–0.5609***	0.1833	–3.06
Membership of cooperatives	α_6	–0.4509	0.4335	–1.04
Years of experience	α_7	–0.4509***	0.1523	–2.96
Diagnostic statistics (variance parameters)	σ^2	0.002117		
Total variance	γ	0.8409***		
Variance ratio $\left(\frac{\sigma_u^2}{\sigma^2}\right)$		1056.90		
Log-likelihood		0.0000		
Prob > Chi		97.07***		
F-test value				

Source: Data Analysis (2022)
Note: *Significant at $p < .10$. **Significant at $p < .05$. ***Significant at $p < .01$.

stochastic profit frontier function were negative, as expected, except for the cost of labor and fees. This implies that a unit decrease in the purchasing price, transportation cost, labor cost, and rental values will lead to an increase in the normalized profit realized from the marketing of paddy rice. The coefficients of purchasing price, transportation cost, labor cost, and fees were statistically significant at ($p < .01$). With respect to the inefficiency component of the model, the signs and significance of the estimated coefficient have important economic implication on profit efficiency of the paddy producers and marketers. The variables with positive signs are those for profit inefficiency, while the coefficients with negative signs are those for profit efficiency. The result on level of the education shows an expected negative sign. The level of education was statistically significant at $p < .05$. This implies that education contributes positively to profit efficiency; an increase in the number of years of education brings about a decrease in inefficiency and increases the chances of enhancing profit efficiency. This could be due to the effect of education in exposing marketers and producers to modern technologies. Marketers and producers who can write and read have the likelihood of being aware of productivity-enhancing technologies, and they are also likely to take advantage of opportunities that improve the lives of many marketers and producers, such as participation in training programs and the formal credit market. Years of experience had a negative coefficient and was statistically significant at $p < .01$. Farming and marketing experiences enhance the human capital of marketers and producers by equipping them with the required skills and knowledge, which increase the efficiency of production and marketing. This result is consistent with the findings of Ogundari (2016), Alabi et al. (2020), Amesimeku and Anang (2021), and Yusuf (2022). The estimated value of gamma (γ) of 0.8409 was statistically significant ($p < .01$). This signifies that inefficiencies exist in the rice production marketing in the study area. The result implies that 84.09% of the variations in profit level among the producer marketers were due to differences in farmers' and marketers' practices, and 15.91% of the variations in the

Table 5.
Summary Statistics of Profit Efficiency Scores

Efficiency Score	Frequency	Percentage
0.00–0.20	57	31.67
0.21–0.40	32	17.78
0.41–0.60	27	15.00
0.61–0.80	19	10.56
0.81–1.00	45	25.00
Total	180	
Mean	0.46	
Standard deviation	0.3194	
Minimum	0.08	
Maximum	0.96	

Source: Field Survey (2022)

Table 6.
Principal Component Model of Constraints Encountered by Paddy Rice Marketers

Constraints	Eigenvalue	Difference	Proportion	Cumulative	Rank
Lack of credit facilities	2.9957	0.7873	0.1709	0.1709	First
Lack of storage facilities	2.2074	0.299	0.1506	0.3215	Second
Grading and standardization	1.9084	0.0178	0.1609	0.4824	Third
Lack of power infrastructure	1.8906	0.1701	0.1661	0.6485	Fourth
Poor market infrastructure	1.7205	0.1599	0.1669	0.8154	Fifth
High transportation cost	1.5606	0.2004	0.1005	0.9159	Sixth
Bartlett test of sphericity					
Chi-square	934.09***				
Kaiser-Meyer-Olkin	0.8802				
Rho	1.00000				

Source: Field Survey (2022), ***Significant at 1% Probability Level

level of profit among the producer marketers were due to random shocks outside the producers' and marketers' control. The variance parameters were statistically significant ($p < .01$), which means that the data are a good fit.

Distribution of Profit Efficiency Scores among Actors of Paddy Rice Marketing

Table 5 depicts the profit efficiency scores among the actors in paddy rice marketing, which include the producer marketers, the wholesalers, and the retailers. The results show that 49.45% of paddy rice marketers had a profit efficiency score of less than 40%, while 50.55% had a profit efficiency score above 40%. The mean profit efficiency score was 46%, with a minimum profit efficiency score of about 8% and a maximum profit efficiency score of 96%. The mean profit efficiency score of 46% shows that the paddy rice producer marketers will be able to increase profit further by 54% by adopting improved techniques and technology to attain the profit efficiency level of 1. The producer marketers' inability to attain 100% profit efficiency could be attributed to limited usage of available technology and also to external shocks such as poor environmental conditions that affect efficiency and productivity. This result is in line with the findings of Yusuf (2022) and Anang and Shafiwu (2022).

Constraints Associated with Paddy Rice Marketing Activities in the Study Area

The constraints facing paddy rice producers' marketers were subjected to analysis using the principal component model (Table 6). Constraints with eigenvalues greater than 1 were retained by the model. Lack of credit facilities (eigenvalue = 2.9957) was ranked first, and this explained 17.09% of all constraints retained by the model. Lack of storage facilities (eigenvalue = 2.2074) was ranked second, and this explained 15.06% of all constraints retained by the model. Grading and standardization (eigenvalue = 1.9084) was ranked third, and this explained 16.09% of all constraints retained by the model. This is based on the perceptions of the actors along the rice value chain. The constraints retained by the model explained 91.59% of all constraints included in the model. The chi square value of 934.09 and the Kaiser-Meyer-Olkin (KMO) value of 0.8802 were statistically significant ($p < .01$). This confirmed the justification of the data for the principal component analysis.

This study has established that the paddy rice marketing among the actors was profitable. The majority of the paddy rice marketers were young, energetic, and within the active age group. The wholesale and retail marketing of paddy rice was dominated by females. The shares of the producers are higher than those of wholesalers and retailers along the rice value chain. The profit margin of the producer marketers is relatively higher than that of the wholesalers and retailers. The operating ratio of producer marketers is higher than that of wholesalers and retailers. The wholesalers and retailers have higher operation ratios due to various marketing functions performed by them in the course of paddy rice marketing. The farmers got the highest marketing margin, while the retailers got the lowest marketing margin. The producers are more efficient than the wholesalers and retailers in paddy rice marketing. Farmers have the highest rate of return per Naira invested in paddy rice production and marketing compared to wholesalers and retailers. Purchase prices, transportation costs, labor costs, and fees were significant factors influencing the profit efficiency of paddy rice marketing among actors along the value chain. Age, gender, educational level, access to credit, and years of experience were significant factors influencing the profit inefficiency of paddy rice marketing among actors along the value chain. The mean profit efficiency score for paddy rice producers' marketers was 46%, leaving an inefficiency gap of 54%. The recommendations are as follows:

(i) Agricultural empowerment programs of the government should be focused on the youth, particularly young women, being active participants in the rice value chain.
(ii) Actors along the rice value chain should form cooperative organization; through cooperative organization, they can have easy access to credit facilities, share ideas and knowledge, buy farm inputs in groups, and sell their rice produce in bulk.
(iii) There is a need for efficient transport and market infrastructure, which includes the massive construction and maintenance of feeder roads. This will enhance efficient and effective movement of paddy rice to nearby markets.
(iv) Actors of paddy rice marketing need proper training on handling, packaging, storage, and marketing along the rice value chain.
(v) Credit facilities should be provided and easily accessible at a low interest rate to actors of paddy rice marketing along the rice value chain.

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New Additions to the Aphid (Hemiptera: Aphididae) Fauna of Turkey from Erzurum Province

Türkiye Afit (Hemiptera: Aphididae) Faunasına Erzurum'dan Katkılar

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ABSTRACT

This study was conducted to have an idea about the aphid species of Erzurum province. Thirty aphid species and one subspecies were identified on 26 host plants. Among these species, four species were new records for the Turkey aphid fauna which are *Callipterinella tuberculata* (von Heyden, 1837); *Cinara* (*Cinara*) *sitchensis* Hottes, 1958; *Colopha graminis* (Monell, 1882); and *Macrosiphum* (*Macrosiphum*) *venaefuscae* Davis, 1914. With these new records, the number of the aphid species in Turkey aphid fauna was increased to 675 species. Furthermore, *Dysaphis* (*Dysaphis*) *crataegi aethusae* (Börner, 1950) was also determined as new subspecies records for the aphid fauna of Turkey.

Keywords: Aphid, Erzurum, new record, Turkey

ÖZ

Bu çalışma Erzurum ilinin yaprakbiti türleri hakkında fikir sahibi olmak amacıyla yapılmıştır. 26 konak bitki üzerinde 30 afit türü ve 1 alttür tespit edilmiştir. Bu türler arasında *Callipterinella tuberculata* (von Heyden, 1837); *Cinara* (*Cinara*) *sitchensis* Hottes, 1958; *Colopha graminis* (Monell, 1882) ve *Macrosiphum* (*Macrosiphum*) *venaefuscae* Davis, 1914 olmak üzere 4 tür Türkiye afit faunası için yeni kayıttır. Bu yeni kayıtlarla birlikte Türkiye afit faunasındaki afit türlerinin sayısı 675'e yükselmiştir. Ayrıca *Dysaphis* (*Dysaphis*) *crataegi aethusae* (Börner, 1950) alttürü de Türkiye afit faunası için yeni kayıt olarak belirlenmiştir.

Anahtar Kelimeler: Afit, Erzurum, yeni kayıt, Türkiye

Introduction

Aphid species are considered as an obligatory phytophagous insect because they cannot survive without the host plant; they feed on plant sap and are host specific. They cause a large amount of crop losses by feeding on plant sap directly, transmitting almost 60% of the plant viruses and causing fumagine indirectly. Aphids feeding on the host plant has a significant negative effect on the physiology, growth, flowering rate and appearance of host plants, thus causing an average of 35–40% product loss (Ruberson, 1999). Their unique life cycles and polyphenism, as well as their reproductive abilities, make this species an important group of insects to study insect–host plant relations and ecological result of global warming effects in terms of insect–host plant interactions (Vilcinskas, 2016).

Erzurum is one of the provinces with the highest altitude (1900 m) in Turkey. Erzurum has a harsh continental climate effect that is directly related with geographical location; the annual average temperature is around 6°C (Anonymous, 2023). Due to both the climatic conditions of Erzurum and the lack of adequate studies, the study will contribute to the aphid fauna. Studies conducted in recent years in Turkey (Görür et al., 2020; Kök & Özdemir, 2021; Patlar et al., 2021; Şenol et al., 2021) made significant contribution the number of aphid fauna of Turkey and is currently represented by 671 species (Görür et al., 2023a).

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Methods

This study was conducted in Erzurum provinces (Aziziye, Palandöken, Tortum, Uzundere, and Yakutiye districts) in September 2022, sampling were carried out during whole days of the month as much as possible to take samples from all host plants. During these field studies, 50 population (any colony on any host plant is called population) were sampled on 26 different plant species. Apterae, alatae, and immature individuals were taken with soft and fine-tipped brushes gently. Samples were preserved in Eppendorf tubes containing 96% alcohol. Any host plant sampling carried on that was brought into the laboratory pressed between two cartons. The preparations of the samples were made according to the principles stated in Martin (1983). Specimens on the permanent slides were identified with Olympus BX51 microscope according to key by Blackman and Eastop (2023) and current taxonomical status was checked by Favret (2023). Measurements of some common distinguishing characters were made for the identified species: body length (BL), sixth antennal segment processus terminalis/sixth antennal segment base (PT/BASE), length of rostrum segment VI+V/hind tarsus II segment length (RIV+V/HTII), and siphunculi length/cauda length (SIPH L/cauda). The voucher samples were stored at the Biotechnology Department of the Nigde Ömer Halisdemir University.

Results and Discussion

As a result of the evaluation of the aphid population were sampled on 26 plants, 30 aphid species and 1 subspecies were determined from the study area. Four species were new records for the Turkey aphid fauna.

Acyrthosiphon* (*Acyrthosiphon*) *malvae (Mosley, 1841); eight adult aptera individuals (♀) were green. Collected from leaves of *Cirsium* sp. Mill. (Asteraceae) from Erzurum/Aziziye/Börekli district on 13.09.2022. It is distributed all over the world (Blackman & Eastop, 2023; Holman, 2009). Recorded from Bitlis, Çanakkale, Rize, Samsun, and Van in Turkey (Kök & Özdemir, 2021).

Anoecia* (*Anoecia*) *corni (Fabricius, 1775); six adult aptera individuals (♀) were pale green, alatae individuals were black and attended by ants. Collected from leaves of *Cornus* sp. L. (Cornaceae) from Erzurum/Tortum/Pehlivanlı village on 14.09.2022. In Europe, North America, Asia, Africa, and Argentina (Blackman & Eastop, 2023). Recorded from Ankara, Bitlis, Çanakkale, Diyarbakır, Gümüşhane, Istanbul, Içel, Kayseri, Rize, Samsun, Trabzon, and Tekirdağ in Turkey (Kök & Özdemir, 2021).

Aphis* (*Aphis*) *gossypii Glover, 1877; 15 adult aptera individuals (♀) were yellow. Collected from under of leaves of *Cucurbita* sp. L. (Cucurbitaceae) and *Catalpa* sp. Scop. (Bignoniaceae) from Erzur um/Aziziye/Börekli district and Erzurum/Atatürk University Campus on 13.09.2022. It is distributed all over the world (Blackman & Eastop, 2023; Holman, 2009). It shows a wide distribution in Turkey (Kök & Ozdemir, 2021).

Aphis* (*Aphis*) *sambuci Linnaeus, 1758; ten adult aptera individuals (♀) were dark green and attended by ants. Collected from under of leaves of *Sambucus* sp. L. (Adoxaceae) from Erzurum/Atatürk University Campus on 9.09.2022. In America, Japan, Korea, and North Africa (Blackman & Eastop, 2023). Recorded from Afyonkarahisar, Ankara, Artvin, Bolu, Çanakkale, Erzurum, Giresun, İstanbul, İzmir, Kahramanmaraş, Kastamonu, Konya, Niğde, Rize, Sakarya, Samsun, Trabzon, and Yalova in Turkey (Kök & Özdemir, 2021).

Aphis* (*Aphis*) *spiraecola Patch, 1914; 16 adult aptera individuals (♀) were green and attended by ants. Collected from under of leaves of *Malus* sp. Mill. (Rosaceae) from Erzurum/Atatürk University Campus on 09.09.2022, and Erzurum/Tortum/Kaledibi district on 14.09.2022. It is distributed all over the world (Blackman & Eastop, 2023; Holman, 2009). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Aphis* (*Aphis*) *pomi De Geer, 1773; ten adult aptera individuals (♀) were green and attended by ants. Collected from petiole and under of leaves of *Prunus* sp. L. (Rosaceae) from Erzurum/Atatürk University Campus on 12.09.2022, and Erzurum/Uzundere on 14.09.2022. In Europe, North Africa, America, and Asia (Blackman & Eastop, 2023; Holman, 2009). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Callipterinella tuberculata (von Heyden, 1837); determined as a new record for the aphid fauna of Turkey. Eight adult aptera individuals (♀), collected from on leaves of *Betula* sp. L. (Betulaceae) (Fig 1.a) from Erzurum/Atatürk University Campus on 09.09.2022. In Europe, East Siberia, and China (Blackman & Eastop, 2023).

Description: Aptera individuals were pale green with brownish-red bands on the abdomen and attended by ants. Antenna has VI segment (Figure 1E). BL: 1.33 mm (Figure 1B). PT/BASE: 1.8 mm. HTI/HTII: 0.3 mm (Figure 1C). RIV+V: 0.10 mm (Figure 1D).

Cavariella* (*Cavariella*) *theobaldi (Gillette & Bragg, 1918); six adult aptera individuals (♀) were green-yellow and attended by ants. Collected from petiole and on leaves of *Salix* sp. L. (Salicaceae) from Erzurum/Atatürk University Campus on 11.09.2022. In Europe, Eastern Siberia and Western Siberia, Kazakhstan, Iran, North Africa, and Northeastern United States (Blackman & Eastop, 2023; Holman, 2009). Recorded from Ankara, Bolu, Erzincan, Kütahya, Malatya, Niğde, Uşak, and Trabzon in Turkey (Kök & Özdemir, 2021).

Chaitophorus parvus Hille Ris Lambers, 1935; eight adult aptera individuals (♀) were black. Collected from under of leaves of *Salix* sp. L. (Salicaceae) from Erzurum/Dadaşkent on 09.09.2022. In Northern Europe and Spain (Blackman & Eastop, 2023). Record is being only given from Muğla in Turkey (Görür et al., 2022).

Chaitophorus populeti (Panzer, 1801); eight adult aptera individuals (♀) were green and attended by ants. Collected from on leaves of *Populus* sp. L. (Salicaceae) from Erzurum/Atatürk University Campus on 12.09.2022. In Mediterranean region, Afghanistan, and Western Siberia (Blackman & Eastop, 2023). Recorded from Afyon, Ankara, Artvin, Bartin, Bursa, Edirne, Erzurum, İstanbul, Izmir, Kütahya, Samsun, and Tekirdağ in Turkey (Kök & Özdemir, 2021).

Chaitophorus populialbae (Boyer de Fonscolombe, 1841); ten adult aptera individuals (♀) were green and attended by ants. Collected from on leaves of *Populus* sp. L. (Salicaceae) from Erzurum/Atatürk University Campus on 09.09.2022. In the Palearctic region, Africa, and North America (Blackman & Eastop, 2023). Recorded from Ankara, Artvin, Bartın, Istanbul, Icel, Isparta, Konya, Rize, and Samsun in Turkey (Kök & Ozdemir, 2021).

Cinara* (*Cinara*) *pinea (Mordvilko, 1895); six adult aptera individuals (♀) were dark brown and attended by ants. Collected from on the branch of *Pinus* sp. L. (Pinaceae) from Erzurum/Atatürk University Campus on 13.09.2022. In Europe, Georgia, Kazakhstan, eastern Siberia, China, and North America (Blackman &

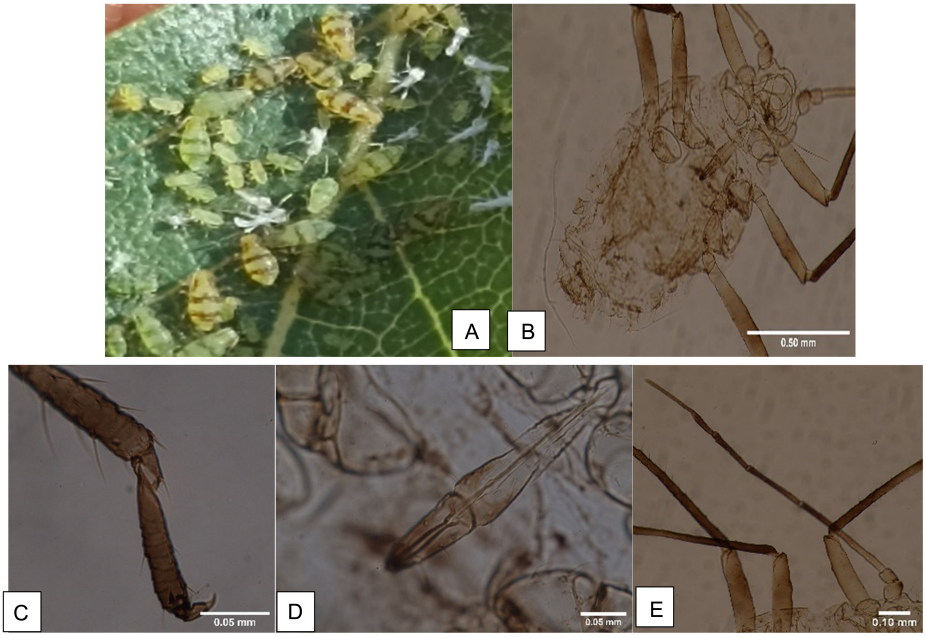

Figure 1.
(A) Callipterinella tuberculata on Betula sp. (B) Body of aptera female. (C) HTI and HTII of aptera female. (D) RIV+V of aptera female. (E) Whole antenna of aptera female.

Eastop, 2023). Recorded from Ankara, Antalya, Artvin, Bolu, Giresun, İstanbul, Isparta, Kastamonu, and Tekirdağ in Turkey (Kök & Özdemir, 2021).

Cinara* (*Cinara*) *pinivora (Wilson, 1919); four adult aptera individuals (♀) were grey wax with black head. Collected from at the tip of the branch of *Pinus* sp. L. (Pinaceae) from Erzurum/Atatürk University Campus on 13.09.2022. In Australes, the eastern United States, Canada, Argentina, Brazil, and Africa (Blackman & Eastop, 2023). Recorded from Artvin, Afyon, Kütahya, and Uşak in Turkey (Kök & Özdemir, 2021).

Cinara* (*Cinara*) *sitchensis Hottes, 1958; determined as a new record for the aphid fauna of Turkey. Eight adult aptera individuals (♀) collected from on the branch of *Picea* sp. L. (Pinaceae) (Figure 2A) from Erzurum/Atatürk University Campus on 13.09.2022. In America (Blackman & Eastop, 2023).

Description: Aptera individuals were brown, slightly wax-dusted and attended by ants. Appearance in life specified for the first time. BL: 2.02 mm (Figure 2B). PT/BASE: 0.5 mm. SIPH diameter 0.13 mm (Figure 2C). Antenna has VI segment (Figure 2D). ANT VI: 0.15 mm. ANT V: 0.15 mm. HTII: 0.2 mm (Figure 2E).

Cinara* (*Cupressobium*) *tujafilina (Del Guercio, 1909); ten adult aptera individuals (♀) were brown and attended by ants. Collected from on branch of *Thuja* sp. L. (Cupressaceae) from Erzurum/Palandöken on 14.09.2022. It is distributed all over the world (Blackman & Eastop, 2023). Recorded from Artvin, Ankara, Adana, Adıyaman, Afyonkarahisar, Çanakkale, İstanbul, Konya, Malatya,

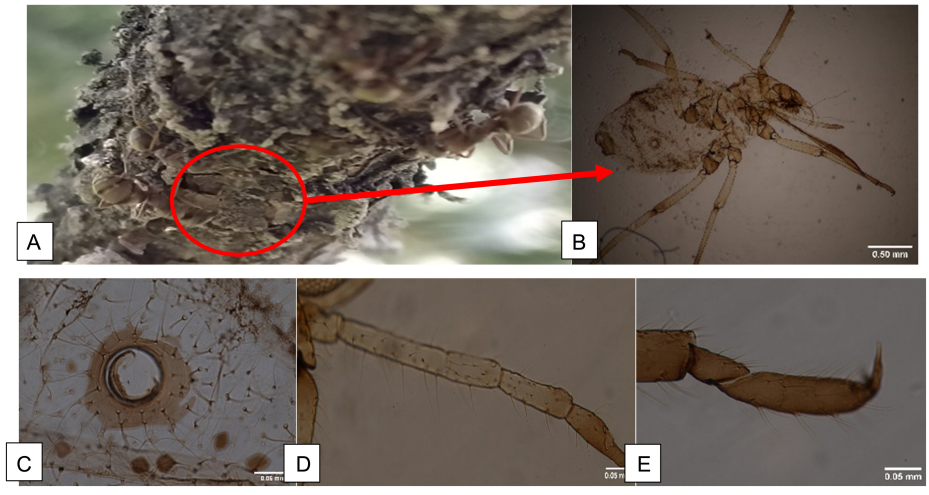

Figure 2.
(A) Cinara (Cinara) sitchensis on Picea sp. (B) Body of aptera female. (C) SIPH of aptera female. (D) Whole antenna of aptera female. (E) HTI and HTII of aptera female.

Niğde, Samsun, Şanlıurfa, and Trabzon in Turkey (Kök & Özdemir, 2021).

Cinara* (*Schizolachnus*) *pineti (Fabricius, 1781); six adult aptera individuals (♀) were grey wax. Collected from on needles of *Pinus* sp. L. (Pinaceae) from Erzurum/Atatürk University Campus on 12.09.2022. In Europe, Kazakhstan, Eastern Siberia, and China (Blackman & Eastop, 2023). Recorded from Artvin, Ankara, Afyonkarahisar, Bolu, Giresun, Istanbul, Kütahya, Malatya, Muğla, Trabzon, Rize, Samsun, and Uşak in Turkey (Kök & Özdemir, 2021).

Colopha graminis (Monell, 1882); determined as a new record for the aphid fauna of Turkey. Ten adult aptera individuals (♀) collected from roots of *Setaria* sp. L. (Poaceae) (Figure 3A) from Erzurum/Tortum/Kaledibi district on 14.09.2022. In North America (Blackman & Eastop, 2023).

Description: Aptera individuals were yellow. Antenna has V segment (Figure 3E). Tarsi 1-segment (Figure 3D). BL: 1.22 mm (Figure 3B). PT/BASE: 0.25 mm. RIV+V/HTI: 1.25 mm. RIV+V: 0.10 mm (Figure 3C).

Eucarazzia elegans (Ferrari, 1872); eight adult aptera individuals (♀) were pale green and attended by ants. Collected from under of leaves of *Mentha* sp. L. (Lamiaceae) from Erzurum/Aziziye/Börekli district on 13.09.2022. In the Mediterranean area, Madeira, Middle East, Central Asia, Pakistan, northern India, southern Poland, Australia, Africa south of the Sahara, and America (Blackman & Eastop, 2023). Recorded from Ankara, Istanbul, Izmir, and Trabzon in Turkey (Kök & Özdemir, 2021).

Eulachnus thunbergii Wilson, 1919; six adult aptera individuals (♀) were green. Collected from on needles of *Pinus* sp. L. (Pinaceae) from Erzurum/Atatürk University Campus on 12.09.2022. In India, Vietnam, China, Japan, Korea, Siberia, Taiwan, Java, Philippines, and Australia (Blackman & Eastop, 2023). Recorded from Afyon and Kütahya in Turkey (Kök & Özdemir, 2021).

Hyalopterus arundiniformis Ghulamullah, 1942; 20 adult aptera individuals (♀) were green and attended by ants. Collected from under of leaves of *Prunus armeniaca* L. (Rosaceae) and *Prunus persica* (L.) Batsch (Rosaceae) from Erzurum/Dadaşkent on 09.09.2022; Erzurum/Atatürk University Campus on 12.09.2022; Erzurum/Tortum on 14.09.2022. Spain, Italy, Greece, Iran, Iraq, Georgia, China, Afghanistan, and Algeria (Blackman & Eastop, 2023). Recorded from Afyon, Kahramanmaraş, Kütahya, and Uşak in Turkey (Kök & Özdemir, 2021).

Hyalopterus pruni (Geoffroy, 1762); 12 adult aptera individuals (♀) were green. Collected from under of leaves of *Prunus armeniaca* L. (Rosaceae) and *Prunus domestica* L. (Rosaceae) from Erzurum/Dadaşkent; Erzurum/Atatürk University Campus on 10.09.2022. It is distributed all over the world (Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Macrosiphum* (*Macrosiphum*) *euphorbiae (Thomas, 1878); ten adult aptera individuals (♀) were dark brown. Collected from under of leaves of *Rumex* sp. L. (Polygonaceae) from Erzurum/Atatürk University Campus on 13.09.2022. It is distributed all over the world (Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Macrosiphum* (*Macrosiphum*) *venaefuscae Davis, 1914; determined as a new record for the aphid fauna of Turkey. Eight adult aptera individuals (♀) collected from under of leaves of *Rumex* sp. L. (Polygonaceae) from Erzurum/Atatürk University Campus on 13.09.2022. In eastern North America (Blackman & Eastop, 2023).

Description: Aptera individuals were dark brown. Antenna has VI segment. BL: 2.98 mm (Figure 4A). PT/BASE: 4.58 mm (Figure 4E). BASE/RIV+V: 0.8 mm. SIPH L/cauda: 2.32 mm (Figure 4C). Longest hair on ANT III/BD III: 1 mm. HTII: 0.14 mm (Figure 4D). RIV+V: 0.15 mm (Figure 4B).

Myzus* (*Myzus*) *cerasi (Fabricius, 1775); 16 adult aptera individuals (♀) were black and attended by ants. Collected from under of leaves of *Prunus avium* L. (Rosaceae) and *Amaranthus* sp. L. (Amaranthaceae) from Erzurum/Atatürk University Campus 12.09.2022 and Erzurum/Tortum/Kaledibi district on 14.09.2022. In Europe, Pakistan, Australia, New Zealand and North America

Figure 3.
(A) Colopha graminis on Setaria sp. (B) Body of aptera female. (C) RIV+V of aptera female. (D) HTI of aptera female. (E) Whole antenna of aptera female.

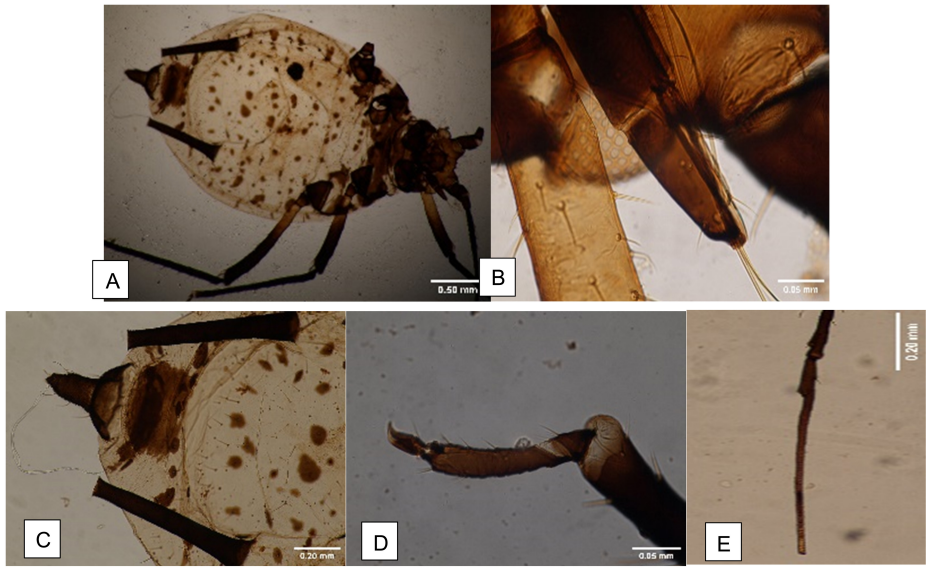

Figure 4.
(A) Body of aptera female. (B) RIV+V of aptera female. (C) SIPH and cauda of aptera female. (D) HTI and HTII of aptera female. (E) ANT VI (PT+BASE) of aptera female.

(Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Ozdemir, 2021).

Myzus* (*Nectarosiphon*) *persicae (Sulzer, 1776); 12 adult aptera individuals (♀) were black and attended by ants and wasp. Collected from under of leaves of *Prunus avium* L. (Rosaceae) Erzurum/Tortum on 14.09.2022. It is distributed all over the world (Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Paracletus bykovi (Mordvilko, 1921); ten adult aptera individuals (♀) were pale yellow-white. Collected from roots of *Poa* sp. L. (Poaceae) from Erzurum/Atatürk University Campus on 13.09.2022. In Poland, Ukraine, Transcaucasia, Kazakhstan, and Uzbekistan (Blackman & Eastop, 2023). Recorded from Izmir in Turkey (Çanakçıoğlu, 1975).

Pterochloroides persicae (Cholodkovsky, 1898); 15 adult aptera individuals (♀) were dark brown and attended by ants and bee. Collected from the branch and trunk of *Prunus* sp. L. (Rosaceae) (*P. domestica, armeniaca, salicina*) Erzurum/Atatürk University Campus on 11.09.2022; *Prunus armeniaca* L. (Rosaceae) from Erzurum/Tortum on 14.09.2022. In Southern Europe, North Africa, Central Asia, Romania, Tunisia, India, Pakistan, and Indonesia (Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Rhopalosiphum maidis (Fitch, 1856); seven adult aptera individuals (♀) were green and attended by ants. Collected from on leaves of *Zea* sp. L. (Poaceae) Erzurum/Aziziye/Börekli district on 13.09.2022. It is distributed all over the world (Blackman & Eastop, 2023). It shows a wide distribution in Turkey (Kök & Özdemir, 2021).

Tinocallis* (*Sappocallis*) *ulmicola (Matsumura, 1919); six adult aptera individuals (♀) were pale yellow. Collected from under of leaves of *Ulmus* sp. L. (Ulmaceae) Erzurum/Dadaşkent on 10.09.2022. In Japan, China, Korea, and eastern Siberia (Blackman & Eastop, 2023; Holman, 2009). Record is being only given from Antalya in Turkey (Görür et al., 2022).

Uroleucon* (*Uroleucon*) *murale (Buckton, 1876); eight adult aptera individuals (♀) were dark brown. Collected from on receptacle and petiole of *Crepis* sp. L. (Asteraceae) Erzurum/Uzundere on 14.09.2022. In Europe, eastward to Byelorussia, Ukraine, and Iran (Blackman & Eastop, 2023). Record is being only given from Adiyaman in Turkey (Görür et al., 2019).

Dysaphis* (*Dysaphis*) *crataegi aethusae (Börner, 1950); determined as a new subspecies for the aphid fauna of Turkey. Twelve adult aptera individuals (♀) collected from root and near the root of *Aethusa* sp. L. (Apiaceae) Erzurum/Uzundere on 14.09.2022.

Description: Aptera individuals were pale white. Antenna has VI segment. Cauda helmet-shaped (Figure 5C). No subracaudal process. BL: 1.40 mm (Figure 5A). RIV+V: 0.13 mm (Figure 5B). PT/BASE: 3.6 mm (Figure 5D).

Conclusion

Turkey is a country where aphid fauna is expected to be rich due to reasons such as being a transition region between continents, seeing different climate types, and the high number of endemic plant species. Recent studies added new records to the Turkey aphid fauna (Başer & Tozlu, 2020; Görür, 2022; Kök, 2021; Oğuzoğlu et al., 2023; Yayla, 2022; Özdemir, 2020), and it is currently represented by 671 species (Görür et al., 2023a). With this study conducted only in such a small area in Erzurum, the species *Callipterinella tuberculata* (von Heyden, 1837); *Cinara* (*Cinara*) *sitchensis* Hottes, 1958; *Colopha graminis* (Monell, 1882); and *Macrosiphum* (*Macrosiphum*) *venaefuscae* Davis, 1914 were determined as new records for Turkey. With these new records, the aphid fauna of Turkey increased to 675 species. *Dysaphis* (*Dysaphis*) *crataegi aethusae* (Börner, 1950) was also recorded as new subspecies records for the aphid fauna of Turkey, thus increasing to 28 subspecies. Findings presented here were derived from very small geographical locality in Erzurum; therefore, they do not reflect whole Erzurum province aphid composition. Recording four species and one subspecies as a new record for Turkey aphid fauna in such a small locality strongly indicated the importance of detailed studies to find out current composition of the Turkey

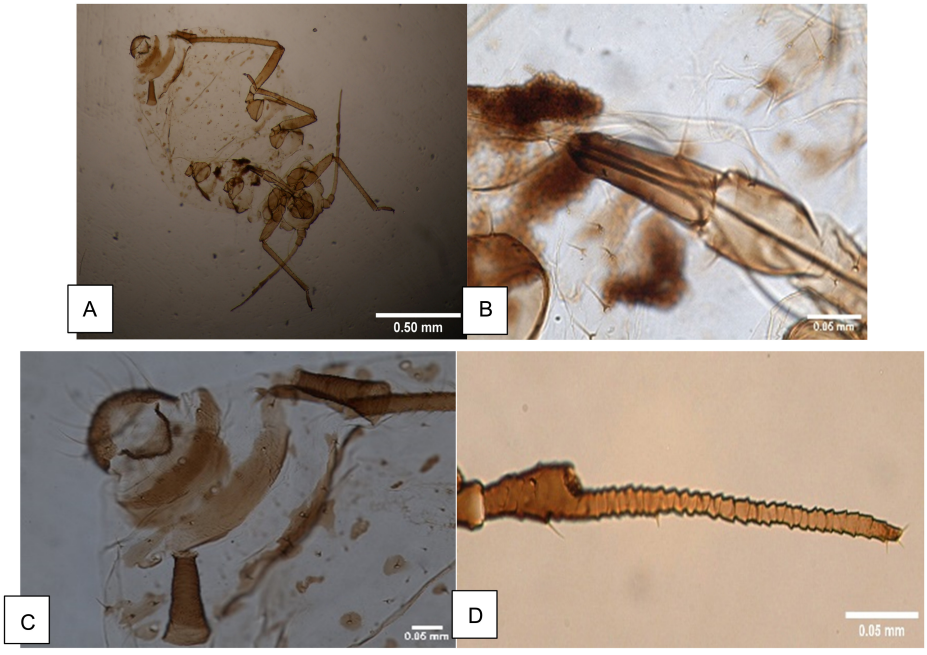

Figure 5.
(A) Body of aptera female. (B) RIV+V of aptera female. (C) SIPH and cauda of aptera female. (D) ANT VI (PT+BASE) of aptera female.

aphid fauna. In addition, recent climatic changes also provokes researchers to study Turkey aphid fauna since aphid might have an ability to produce two to six more generations and more damage to the host plants by turning global warming effects into the advantage (Görür et al., 2023b). Agricultural production in Turkey contributes in a large manner to the country's development; therefore, inventorying the Turkey aphid fauna plays an important role, as aphids are the one of the most important groups of insects recognized as severe pests around the world.

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Date Fruit Classification by Using Image Features Based on Machine Learning Algorithms

Makine Öğrenme Algoritmalarına Dayalı Görüntü Özellikleri Kullanılarak Hurma Meyvelerinin Sınıflandırılması

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ABSTRACT

The date fruit, scientifically known as *Phoenix dactylifera*, is a significant dietary component due to its high nutritional value and abundance of essential vitamins and minerals. The process of discerning the classification of this fruit, which exhibits a multitude of variations within its natural domain, needs a specialized skill set. The automated recognition of species based on images of agricultural goods has gained significant prevalence in recent times. In this objective, the present study employed machine learning algorithms to automatically identify seven types of date fruit. In the investigation, decision tree, K-nearest neighbor, artificial neural networks, and support vector machine through their different hyperparameters are employed for the purpose of classifying date fruit. The dataset was divided into ratios of 80% and 20% for training and testing, respectively, and the training process employed the five-fold cross-validation technique to avoid overfitting. In summary, the results indicate that the best algorithm is neural network with a layer size of 25. In this study, this proposed algorithm achieved a test accuracy rate of 93.85%. Given the absence of computational complexity in the investigation, it can be effortlessly incorporated into diverse tools, thereby facilitating the identification of the types of date fruit.

Keywords: Automatic detection, classification, date fruit, machine learning algorithms, neural networks

ÖZ

Bilimsel olarak *Phoenix dactylifera* olarak bilinen hurma meyvesi, yüksek besin değeri ve temel vitamin ve minerallerin bolluğu nedeniyle önemli bir diyet bileşenidir. Doğal ortamında çok sayıda varyasyon sergileyen bu meyvenin sınıflandırılmasını ayırt etme süreci, özel bir yetenek gerektirir. Tarımsal ürünlerin görüntülerine dayalı türlerin otomatik olarak tanınması son zamanlarda önemli bir yaygınlık kazanmıştır. Bu amaçla, mevcut çalışma, yedi tür hurma meyvesini otomatik olarak tanımlamak için makine öğrenme algoritmalarını kullandı. Araştırmada hurma meyvelerinin sınıflandırılması amacıyla farklı hiperparametreler ile karar ağaçları, K-En Yakın Komşu, yapay Sinir Ağları ve Destek Vektör Makinesi kullanılmıştır. Veri seti, eğitim ve test için sırasıyla %80 ve %20 oranında bölünmüştür ve eğitim sürecinde, fazla uydurmayı önlemek için 5 katlı çapraz doğrulama tekniği kullanılmıştır. Özetle, sonuçlar en iyi algoritmanın katman boyutu 25 olan Sinir Ağları olduğunu göstermektedir. Bu çalışmada önerilen bu algoritma %93,85'lik bir test doğruluk oranı elde etmiştir. Araştırmada hesaplama karmaşıklığının olmaması göz önüne alındığında, çeşitli araçlara zahmetsizce dahil edilebilir, böylece hurma türlerinin tespiti kolaylaşır.

Anahtar Kelimeler: Otomatik tespit, sınıflandırma, hurma meyveleri, makine öğrenimi algoritmaları, sinir ağları

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Introduction

The yearly global production of date fruit is estimated at 8.46 million tons (Albarrak et al., 2022). The date fruit is prized for its use in sweets and as a fruit crop. Dates are mostly grown in the hot, dry regions

of Southwest Asia, North Africa, and the Middle East (Albarrak et al., 2022). From 1961 to 1985, date output went from 1.8 million tons to 2.8 million tons. Production of dates has increased from 5.4 million tons in 2001 to 8.46 million tons in recent years (Albarrak et al., 2022). There exist more than 40 distinct types of dates, along with over 400 variations, encompassing a vast spectrum of tastes, shapes, and hues, as well as varying in terms of cost and significance (Haidar et al., 2012). The classification of date fruits is a crucial process, especially considering that a significant portion of consumers lack the ability to distinguish between various types (Haidar et al., 2012). The lack of a fully automated system for classifying date fruit is a persistent issue in the market, forcing workers to rely instead on their own knowledge and judgment, which can be time-consuming, costly, and subject to bias (Albarrak et al., 2022). Therefore, it is of utmost significance to possess the capability to visually categorize date fruits for the purpose of automated factory classification.

Machine learning is a rapidly expanding field within the realm of computer science, characterized by its extensive range of practical applications (Osisanwo et al., 2017). In recent times, the field of image processing has gained significant popularity (Garcia et al., 2021; Koklu et al., 2021a; Ozaltin et al., 2022; Ozaltin & Yeniay, 2023a, 2023b; Wróbel et al., 2022). The acquisition of diverse information from images is a prevalent technological practice. The study utilized images of date fruits belonging to seven distinct classes, namely, Berhi, Deglet, Dokol, Iraqi, Rotana, Safavi, and Sogay, for the purpose of detecting the different varieties. The features of these images were extracted using the Otsu approach as described by Koklu et al. (2021b), resulting in the creation of the dataset. Thirty-four different features and 898 samples of date fruits were analyzed using machine learning algorithms. Machine learning algorithms make data processing easy, especially for features. If just image data is available, deep learning-derived convolutional neural networks (CNN) may be chosen. However, the construction of CNN would be laborious and complex computationally. Convolutional neural networks can extract several features that may not be obvious to the user. One notable advantage of the study described herein lies in its ability to properly explain the many sorts of features and afterward achieve the desired outcome without extra time spent.

Many researchers aimed to detect types of date fruit based on artificial intelligent as follows: Albarrak et al. (2022) developed a dataset of eight date fruit images for the purpose of classification. They utilized MobileNetv2 for this task. Their experimental findings demonstrated that their proposed approach achieved an accuracy of 99%. Muhammad (2015) introduced an algorithmic framework for the automated categorization of date fruit images. Initially, the author employed the feature extraction technique to derive features from the images of dates. Next, a feature selection method is employed to decrease the dimensionality of these features. In conclusion, SVM algorithm was assigned the task of classifying reduced features with an accuracy rate exceeding 98%. Koklu et al. (2021b) utilized a dataset consisting of 898 images of date fruit. They extracted features from these images using the Otsu method. They developed a stacking model comprising logistic regression and artificial neural networks. The method proposed by them achieved a precision of 92.8%. Altaheri et al. (2019) applied CNN using transfer learning approach for classification of five types of date fruit images. In final, their proposed approach had an accuracy of 99.01%. Abi Sen et al. (2020) proposed an automatic system for classifying four types of date fruit using SVM with an accuracy of 73.8%. Alsirhani et al. (2023) implemented DenseNet based on transfer learning approach to detect types of date fruit and obtained a test accuracy rate of 95.21%. Alhadhrami et al. (2023) utilized pretrained CNN to class date fruit images and they obtained a testing accuracy of 98.33%. Nasiri et al. (2019) proposed a deep CNN for detection types of date fruit from images. According to their experimental findings, their proposed approach was able to class effectively with an accuracy of 96.98%. Faisal et al. (2020) suggested a decision system including computer vision and deep learning approach and obtained an accuracy of 99.4%. Adige et al. (2023) aimed to detect apple types from images by using SVM and ResNet-50 via different optimal hyperparameters. Their experimental results demonstrated that SVM with an accuracy of 96% was superior to ResNet-50 with an accuracy of 90%. Arshaghi et al. (2023) used deep learning algorithms (AlexNet, GoogleNet, VGG, R-CNN, and transfer learning) to diagnose potato diseases from 5000 images. They obtained successful outcomes in their study. Gencturk et al. (2023) classified three types hazelnut based on InceptionV3 + ResNet50 data fusion model. In their study, 1024 features were obtained via their suggested model and then, they achieved 100% accuracy rate.

The literature review shows that the studies included computational complexity. Therefore, this study aims to introduce a novel framework for the classification of date fruit, employing a machine learning methodology without computational complexity. The dataset experienced training and validation utilizing decision tree, K-nearest neighbor (KNN), neural networks (NN), and support vector machine (SVM) with varying hyperparameters. The optimal hyperparameter and algorithm selection are achieved through the utilization of a wide range of performance metrics. As a result, the NN (with a layer size of 25) approach is regarded as a successful algorithm in the realm of date fruit identification and classification. Moreover, contributions and advantages of this study as follows:

1. In order to automatically classify date fruit based on features extracted from images, machine learning algorithms are utilized.
2. The hyperparameter that yields the best results for each classifier is chosen.
3. The dataset is divided into a training set of 80% and a testing set of 20%. Validation of the training set is accomplished by the five-fold cross-validation.
4. The testing results are offered to demonstrate the reliability of this study.
5. According to the findings of the experiments, it is possible to use machine learning algorithms to determine the species of an agricultural product. Therefore, these algorithms can be applied to devices and there will be an improvement in the quality of agricultural products. Figure 1 shows a framework of this study.

The following section of this study is outlined as follows: Section 2 clarifies the material and methodology that includes the overview of the dataset, machine learning algorithms along with their hyperparameters, cross-validation, and performance evaluation. In the next, experimental findings are presented, and discussed in Section 3. Finally, this study is concluded and the following investigations are explained briefly in Section 4.

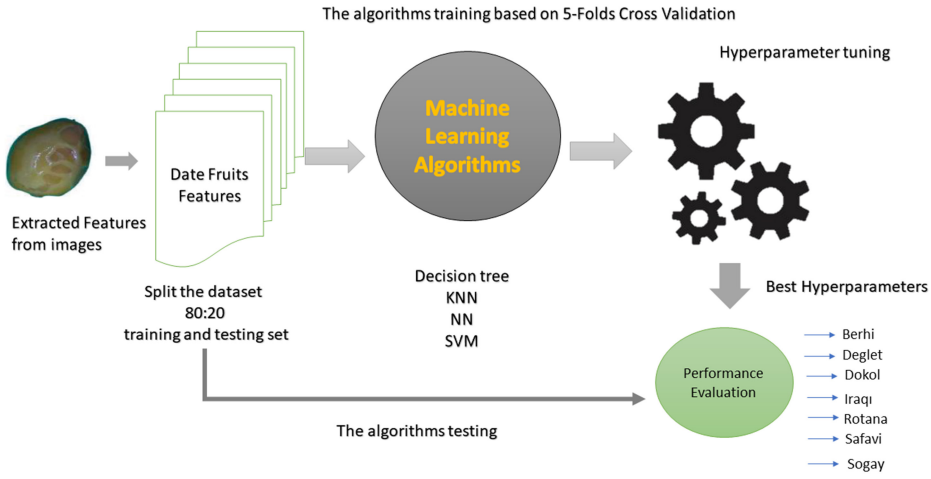

Figure 1.
Flowchart of the presented study.

Methods

In the presented study, features of date fruit images were classified using decision tree, KNN, NN, and SVM based on various hyperparameters to find the type of date fruit. Moreover, the dataset was split as 80:20 training–testing set and then the training set was validated by using five-fold cross-validation. All experiments were evaluated with diverse metrics. More details are given in this section.

Date Fruit Dataset

The date fruit dataset is downloadable in .xlsx format from the website https://www.muratkoklu.com/datasets/. This dataset comprises a collection of seven distinct varieties of date fruit which are obtained through the computer vision system (Koklu et al., 2021b). Based on the image processing approach, 34 features were achieved from date fruit images by Koklu et al. (2021b). They extracted morphological features from images and applied the image processing method. First, they converted color images to grayscale and binary for feature extraction. Then, they used threshold and pixel information methods. After image processing, date fruit were analyzed individually and features were retrieved by them. They employed the Otsu method, a common image thresholding approach and explained the Otsu method as follows: it uses a variable to distinguish between nature's groupings. The method operates on gray-level images, checking how many times each color is present on the image. The image color distributions are calculated first, and then other procedures are done on this distribution sequence.

These 34 features include genetic varieties such as morphological features, shape, and color. The main feature details are as follows: morphological features: area, perimeter, major axis, minor axis, eccentricity, roundness, equivalent diameter, solidity, convex area, extent, aspect ratio, and compactness. The other main feature is shape features: shapefactor_1, shapefactor_2, shapefactor_3, and shapefactor_4. The last main feature is shape features: shapefactor_1, shapefactor_2, shapefactor_3, and shapefactor_4, and the last main feature is color features: mean RR, std. dev RR, skew RR, kurtosis RR, entropy RR, all daub4 RR, mean RG, std. dev RG, skew RG, kurtosis RG, entropy RG, all daub4 RG, mean RB, std. dev RB, skew RB, kurtosis RB, entropy RB, all daub4 RB. (R: red, G: green, B: blue). More details about the dataset are given in Table 1. Further information can be found in reference (Koklu et al., 2021b).

In total, in the dataset, there are 898 date fruit classes and 34 different features obtained from images. Hence, the dataset possesses an 898 × 35 size.

Machine Learning Algorithms

Decision Tree

Decision tree are widely utilized in the field of machine learning as a prominent category of methods (Zhou, 2021). A decision tree often comprises a single root node, several internal nodes, and multiple leaf nodes. The terminal nodes represent the decision outcomes, while all other nodes represent feature tests. The samples contained within each node are partitioned into child nodes based on the outcomes of feature splitting. Every trajectory from the primary node to the terminal node can be considered as a succession of decisions. The objective is to generate a tree structure that possesses the ability to make accurate predictions on samples that have not been previously encountered (Zhou, 2021). The essence of the decision tree learning algorithm is in the process of identifying and selecting the most advantageous splitting criteria (Zhou, 2021). In this study, some splitting criteria, Gini's diversity index, maximum deviance reduction, and towing role, were examined to determine the best one. In addition, the maximum number of splits was determined as 100.

K-Nearest Neighbor

The nearest neighbor classifiers do not necessitate any preprocessing of the labeled sample set before their utilization. The crisp nearest-neighbor classification rule allocates an input sample vector y, whose classification is unknown, to the class of its nearest neighbor (Cover & Hart, 1967; Keller et al., 1985). The concept described can be generalized to the K-nearest neighbor algorithm, where the vector y is assigned to the class that is most frequently represented among its K-nearest neighbor (Keller et al., 1985). In the context of K-nearest neighbor, it is important to acknowledge the potential occurrence of ties among classes when multiple neighbors are taken into account. One straightforward approach to addressing this issue is to impose limitations on the feasible values of K. Given a binary classification problem, if we impose a constraint on the value of K such that it can only be odd, it ensures that there will be

Table 1.
The characteristics contained within the dataset (Koklu et al., 2021b)

Classes	Images	Number of Instances	Features
Barhee origin is Basra, Iraq.		65	Morphological features: 12 Shape features: 4 Color features: 18 Details: When it is ready to be picked, it is a golden-brown color. It has a hard shell and is small to medium in size.
Deglet Nour origin is not specified.		98	Morphological features: 12 Shape features: 4 Color features: 18 Details: It is a type of date fruit that ranges in size from medium to large and turns from yellow to dark brown after being picked.
Sukkary origin is Al Qassim region, Saudi Arabia.		204	Morphological features: 12 Shape features: 4 Color features: 18 Details: It is a medium-sized, golden-colored date fruit variety.
Rotap Mozafati origin is Kerman, Iran.		72	Morphological features: 12 Shape features: 4 Color features: 18 Details: It possesses a dense, dark brown look. It is a variety of medium-sized, succulent dates.
Ruthana origin is Madinah, Saudi Arabia.		166	Morphological features: 12 Shape features: 4 Color features: 18 Details: It possesses brown and gold hues. It is a species of medium-sized date fruit.
Safawi origin is Madinah, Saudi Arabia.		199	Morphological features: 12 Shape features: 4 Color features: 18 Details: It is a dark black cherry color with brown ends. It possesses medium-sized.
Sagai origin is Arabian Peninsula, particularly Saudi Arabia.		94	Morphological features: 12 Shape features: 4 Color features: 18 Details: The ends are dry and golden in hue, while the undersides are soft and brown in color. It is a date variety of medium-sized.

no possibility of a tie. When the number of classes exceeds two, this technique becomes ineffective. One possible approach for managing the situation of a tie is as follows. The sample vector is assigned to the class that has the minimum sum of distances from the sample to each neighbor in the class, among the classes that are tied. In the event that a tie occurs, the assignment will be given to the last class encountered among those that are tied. This assignment is considered arbitrary. It is evident that there will exist instances in which the categorization of a vector is subject to an arbitrary assignment, irrespective of the inclusion of supplementary procedures within the algorithm (Keller et al., 1985).

There exists a predetermined value for K, which is utilized in the process of determining the K-nearest neighbor through distance computation (Chomboon et al., 2015). In this study, K is identified as 10, and distance metrics: cosine, Euclidean, and Minkowski (cubic) were respectively analyzed to measure the performance of date fruit classification. Moreover, distance weights were equal for each process of classification.

Neural Networks

Neural networks (McCulloch & Pitts, 1943) are computational algorithms that aim to emulate certain aspects of the biological brain, such as the ability to learn, generalize, and abstract from past experiences. These computational systems possess the capability to perceive and analyze patterns in order to establish connections when presented with factual information. They are essentially comprised of fundamental computing units that are linked together in various manners to construct a network (Bourquin et al., 1997; Hecht-Nielsen, 1988; Kohonen, 1988). The capability to extract unconscious information from data renders NN intriguing tools for the purpose of modeling. NN can also be perceived from a mathematical perspective as an extensive category of versatile, nonlinear regression and discriminant algorithms (Bourquin et al., 1997). In this study, NN are employed for the purpose of image classification by leveraging their extracted features.

When designing a functional model of the biological neuron, there are three fundamental components that hold significance.

Initially, the synapses of the neuron are represented as weights. The weight value denotes the magnitude of the connection strength between an input and a neuron. In the realm of neural networks, it is widely acknowledged that weight values that are negative in nature represent inhibitory connections, whereas weight values that are positive in nature are indicative of excitatory connections (Dongare et al., 2012). The subsequent pair of components simulate the intrinsic dynamics occurring within the neuronal cell. A computational unit known as an adder operates by summing up all the inputs, which are subject to modification by their corresponding weights. This particular operation is commonly denoted as a linear combination. In conclusion, an activation function governs the magnitude of the output of the neuron. Typically, the acceptable range of output is bounded by the values of 0 and 1, inclusively, or by the values of –1 and 1, inclusively (Dongare et al., 2012). In the presented study, rectified linear activation function (ReLU), which is frequently used in this study, was chosen. Moreover, different size of hidden layers was determined and renamed NN. When the hidden layer size was 10, 25, and 100, the algorithm was named Narrow NN, Medium NN, and Wide NN, respectively. Meanwhile, Medium NN are proposed algorithm in terms of obtaining the highest success for classifying date fruit types. Additionally, maximum iteration was limited to 1000 in the presented study.

Support Vector Machine

Support vector machine is a type of machine learning algorithms that were initially developed to address classification problems and have now been extended to handle a range of additional scenarios. These algorithms are grounded in the ideas of statistical learning theory and convex optimization. They are presently employed in diverse fields such as bioinformatics, text categorization, and computer vision (Mammone et al., 2009). Support vector machine was first introduced by Vapnik and colleagues (Boser et al., 1992) in the 1990s (Mammone et al., 2009). They belong to a group of algorithms designed to learn two-class discriminant functions based on a given collection of training instances (Mammone et al., 2009). The initial introduction of the simplest model of SVM was referred to as the maximal margin classifier or hard margin SVM. While its practical application is limited due to its reliance on linearly separable data, this method serves as a foundational component for complex SVM. Furthermore, it is comprehensible and easy (Mammone et al., 2009). Due to the presence of noise in many real-world datasets, the maximal margin approach was not applicable as it generates a hypothesis that exactly aligns with the training data, making it unable to identify a linear separation between classes. This issue provided the basis for the advancement of a more robust version of the algorithm initially proposed by Cortes and Vapnik (Cortes & Vapnik, 1995). This enhanced version was designed to withstand the presence of noise and outliers in the dataset while minimizing significant changes to the answer. A higher-dimensional space, known as feature space, can be used to remap the data points for a more accurate representation of the data (Mammone et al., 2009). The explicit functional form of the mapping is not required to be known, as it is implicitly defined by the selection of a kernel function. In the presented study, three different kernel functions: linear, cubic, and quadratic were investigated to find the best classifying function. Further, other hyperparameters were as follows: Box constraint level = 1, multiclass method = one vs. one.

Cross-Validation

Cross-validation is a technique that has been devised to enhance the robustness of classification by minimizing potential security vulnerabilities (Koklu & Ozkan, 2020). Cross-validation is a technique that involves randomly partitioning the dataset into a predetermined number of sets, each of which has an equal size. The system is trained using the remaining sets, wherein one of the subsets is selected as the test set. The above process is iterated until all sets of numbers have been tested within the system. The outcomes derived from these procedures are generalized (Koklu et al., 2021b; Koklu & Ozkan, 2020). In the presented study, the dataset was first divided into 80:20 training and testing sets, randomly. Then the training set was validated based on cross validation approach where the number of folds was determined as 5. Therefore, overfitting is overcome.

Performance Evaluation

In this study, to identify which machine learning algorithm is the best, the performance metrics which are accuracy (acc), sensitivity (sens), specificity (spe), precision (pre), F1-score (F1), geometric mean (G-Mean), Matthews correlation coefficient (MCC) (Matthews, 1975), and the kappa value (κ) (Cohen, 1960) are used. The metrics are displayed in Equations (1)–(9) (Chicco et al., 2021; Ozaltin et al., 2023a, 2023b; Rajinikanth et al., 2020; Sharifrazi et al., 2021; Singh et al., 2022; Wang et al., 2019):

$$Acc = p_A = \frac{(TP + TN)}{(TP + TN + FP + FN)} \quad (1)$$

$$Sens = \frac{TP}{(TP + FN)} \quad (2)$$

$$Specificity = \frac{TN}{(TN + FP)} \quad (3)$$

$$\text{Precision} = \frac{TP}{(TP + FP)} \quad (4)$$

$$F1 - Score = \frac{(2 \times TP)}{(2 \times TP + FP + FN)} \quad (5)$$

$$G - Mean = \sqrt{Sensitivity \times Specificity} \quad (6)$$

$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP) \times (TP + FN) \times (TN + FP) \times (TN + FN)}} \quad (7)$$

$$Expected\ acc = p_E = \frac{(TP + FP) \times (TP + FN) + (FP + TN) \times (TN + FN)}{(TP + TN + FP + FN)^2} \quad (8)$$

$$\kappa = \frac{p_A - p_E}{1 - p_E} \quad (9)$$

where TP, FP, TN, and FN are true positive, false positive, true negative, and false negative, respectively.

Results

In this section, the findings of the generated models are shown. The models were constructed in order to recognize different types of date fruit based on features that were extracted from images. The suggested model has been built in the MATLAB (2022b) environment, which was run on a personal computer. The dataset has dimensions of 898 × 35, and it was first split into training and testing sets with a ratio of 80:20. As a result, the dimensions of the training set were 719 × 35, whereas the dimensions of the testing set were 179 × 35. Four different machine learning methods were then used to analyze the training set based on five-fold cross-validation. All of the features in the study were used, and none were ever dropped from the dataset. In fact, a few feature selection techniques were tested, however, the performance in this study did not improve with identified hyperparameters. The findings of the performance evaluations obtained by cross-validation and through tests are presented in Table 2 and 3, respectively.

While Table 2 is reviewed, the performance of four distinct algorithms, each of which is based on a different combination of three hyperparameters, is measured using various metrics. When a decision tree using Gini's diversity index, maximum deviance reduction, and towing role were chosen as the classifier, successful performance was attained using maximum deviance reduction splitting criteria with a validation accuracy of 84.42%. Based on the KNN classifier, the maximum validation accuracy with 86.65% and other metrics were obtained by using the Euclidean distance. The performance outcomes of neural networks employing various layer sizes, specifically 10, 25, and 100, exhibited striking similarities, with validation accuracies above 89%. Therefore, the evaluation of this method will be based on the outcomes obtained from the tests. In the case of SVM, a comparable scenario to that of NN was seen, wherein the performance outcomes exhibited a high degree of similarity, with validation accuracies above 89.8%.

In this research, a subset of the dataset consisting of 179 instances was tested. Testing results are shown in Table 3. According to this table, based on decision tree' results, Gini's diversity index and maximum deviance reduction achieved almost the same testing

Table 2.
The performance values of machine learning algorithms using five-fold cross-validation.

Model	Hyperparameter	Acc	Sens	Spe	Pre	F1	G-Mean	MCC	Kappa
Decision Tree	Gini's Diversity Index	0.8317	0.7740	0.9723	0.7763	0.7744	0.8675	0.7473	0.3128
	Max.Deviance Reduction	0.8442	0.7833	0.9745	0.7893	0.7849	0.8736	0.7605	0.3639
	Towing Role	0.8081	0.7364	0.9685	0.7425	0.7385	0.8445	0.7077	0.2163
KNN	Cosine	0.8401	0.7819	0.9724	0.8178	0.7864	0.8720	0.7685	0.3469
	Euclidean	0.8665	0.8195	0.9777	0.8345	0.8247	0.8951	0.8042	0.4548
	Minkowski	0.8595	0.8098	0.9765	0.8297	0.8150	0.8892	0.7949	0.4264
NN	Narrow	0.8901	0.8611	0.9819	0.8656	0.8632	0.9195	0.8452	0.5513
	Medium	0.8901	0.8634	0.9818	0.8691	0.8654	0.9207	0.8478	0.5513
	Wide	0.8971	0.8734	0.9831	0.8763	0.8746	0.9266	0.8577	0.5797
SVM	Linear*	**0.9096**	**0.8859**	**0.9851**	**0.8894**	**0.8864**	**0.9342**	**0.8723**	**0.6309**
	Cubic	0.8983	0.8677	0.9833	0.8710	0.8693	0.9237	0.8527	0.5848
	Quadratic	0.9082	0.8849	0.9849	0.8865	0.8853	0.9336	0.8704	0.6252

Note: *Bold metrics indicate the highest performance in this part of the study.

Table 3.
The performance values of machine learning algorithms testing results.

Model	Hyperparameter	Acc	Sens	Spe	Pre	F1	G-Mean	MCC	Kappa
Decision Tree	Gini's Diversity Index	0.8659	0.8303	0.9783	0.8329	0.8243	0.9012	0.8070	0.4525
	Max.Deviance Reduction	0.8603	0.8216	0.9773	0.8263	0.8212	0.8961	0.8001	0.4297
	Towing Role	0.8380	0.7950	0.9737	0.7987	0.7930	0.8798	0.7689	0.3385
KNN	Cosine	0.8715	0.8280	0.9779	0.8685	0.8351	0.8999	0.8216	0.4753
	Euclidean	0.9218	0.9087	0.9869	0.9124	0.9095	0.9470	0.8970	0.6806
	Minkowski	0.9106	0.8971	0.9850	0.8971	0.8967	0.9400	0.8819	0.6350
NN	Narrow	0.9050	0.8875	0.9847	0.8775	0.8811	0.9348	0.8664	0.6122
	Medium*	**0.9385**	**0.9290**	**0.9897**	**0.9292**	**0.9278**	**0.9589**	**0.9183**	**0.7491**
	Wide	0.9330	0.9241	0.9890	0.9189	0.9195	0.9560	0.9095	0.7263
SVM	Linear	0.9106	0.8963	0.9853	0.8982	0.8948	0.9398	0.8815	0.6350
	Cubic	0.9218	0.9041	0.9872	0.9073	0.9034	0.9447	0.8919	0.6806
	Quadratic	0.9274	0.9188	0.9882	0.9132	0.9138	0.9528	0.9031	0.7034

Note: *Bold metrics indicate the highest performance in this part of the study.

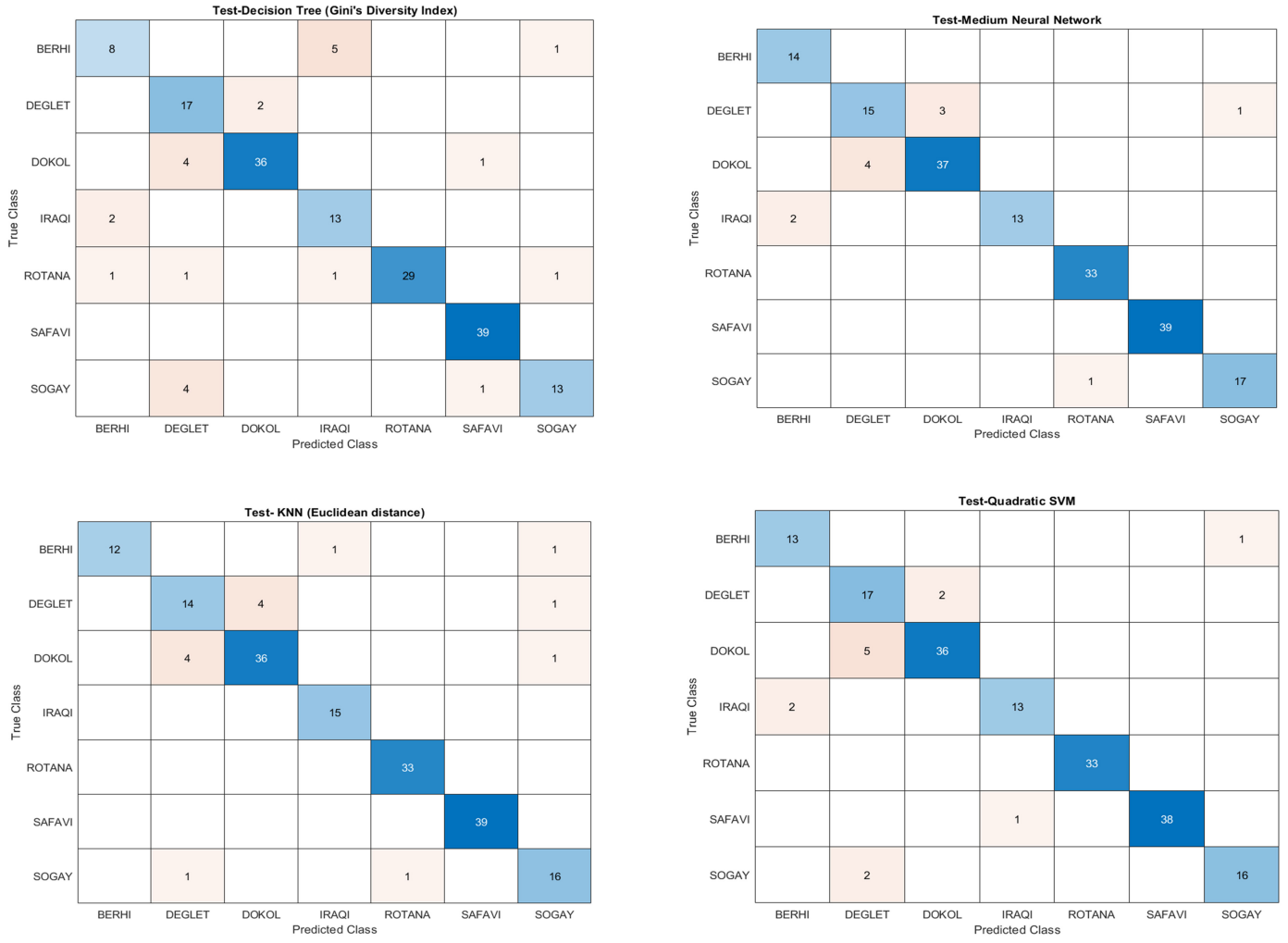

Figure 2.
Confusion matrices of machine learning algorithms.

results. The algorithm achieved the highest possible rate of testing accuracy, which was 86.59%; this is considered to be satisfactory. However, when the kappa values were analyzed, the results showed that values below 0.50 indicated that the method in question should not be used (Wang et al., 2019).

Based on the results of KNN, the maximum testing accuracy rate that was 92.18% was obtained using Euclidean distance. Moreover, the kappa value was 0.68, and also it can be said that the result was acceptable to detect the type of date fruit.

In the presented study, it was observed that the Medium NN with a layer size of 25 achieved the highest testing accuracy of 93.85%. Additionally, the technique also yielded a maximum kappa value of 0.75.

Based on the findings of SVM, it was observed that the Quadratic kernel function achieved a testing accuracy of 92.74%. Additionally, the corresponding kappa value was determined to be 0.70, which falls within an acceptable range. Nevertheless, the findings of this study indicate that Medium NN yielded the highest performance metrics. Hence, this study introduces the concept of Medium NN as a means to achieve optimal performance in classifying different species of date fruit. Figure 2 and Figure 3 display different scenarios of confusion matrix and ROC (receiver operating characteristic) curves. Additionally, these curves show AUC (area under curve) for each class.

Figure 2 displays four confusion matrices based on the most effective hyperparameters for detecting date fruit types. The first matrix is produced by a decision tree algorithm that uses Gini's diversity index. This scenario incurs 24 costs. The second matrix is generated by using the KNN algorithm, which utilizes the Euclidean distance. This scenario has a total cost of 14. The Medium NN method yields these findings, and there are 11 costs in total. The ultimate confusion matrix is obtained using the SVM algorithm via a quadratic kernel function and there are 13 costs in this scenario. As a result, confusion matrix of Medium NN has minimum cost, and it is the best algorithm to detect the types of date fruit.

The ROC curve demonstrates the relationship between sensitivity (true positive rate) and specificity (one minus the false positive rate). Classifiers with curves positioned closer to the top-left corner of the graph typically indicate better performance. In the presented study, Figure 3 indicates ROC curves and AUC values for each class using four classifiers (decision tree, KNN, Medium NN, and SVM) with the most optimal hyperparameters. Each AUC value falls within the range of 0.75 to 1.00, and the decision tree, KNN, Medium NN, and SVM have average AUC values of 0.9388,

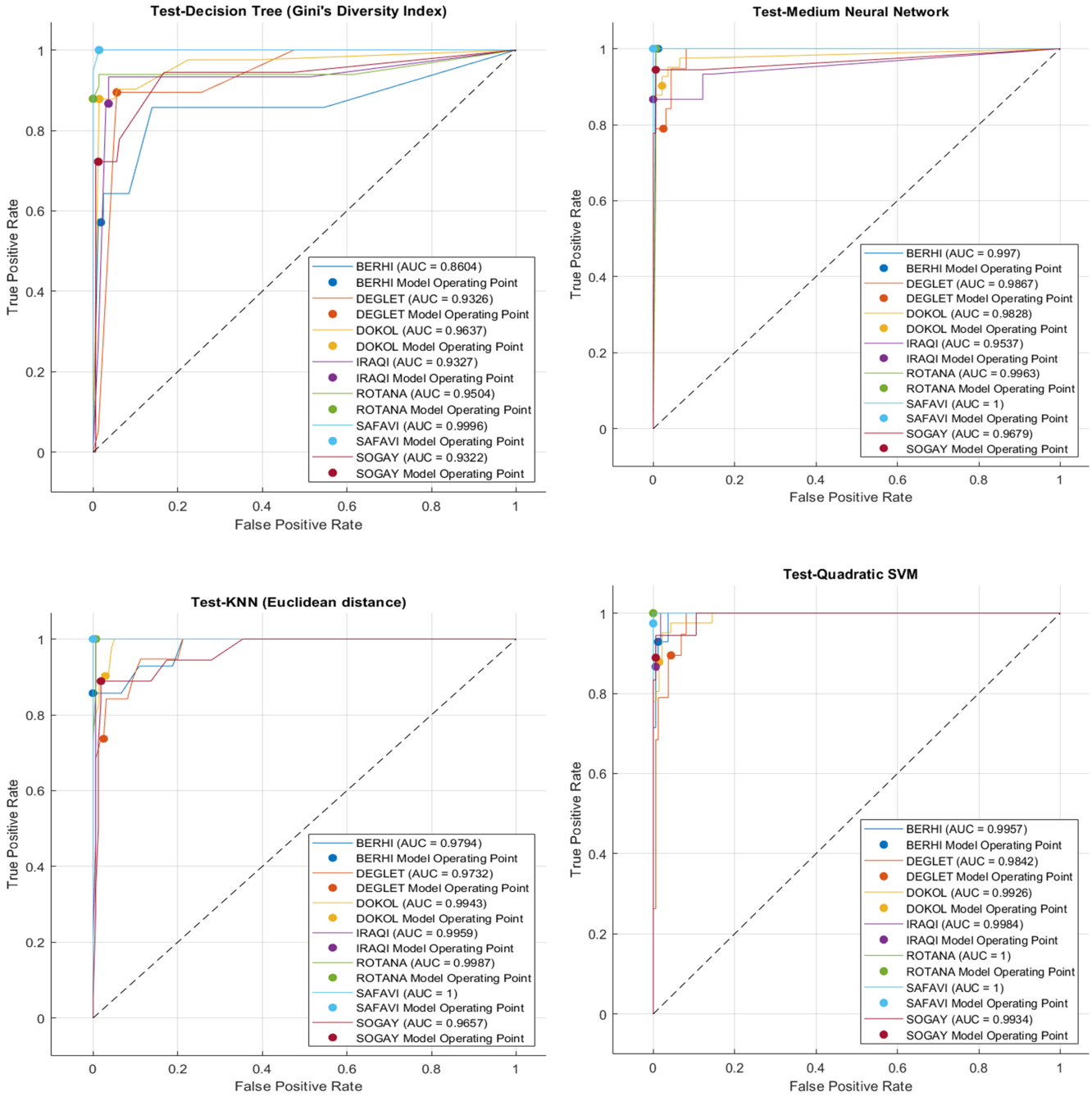

Figure 3.
Roc Curves of machine learning algorithms.

0.9867, 0.9835, and 0.9949 respectively. Classifiers have a remarkable ability to accurately identify different species of date fruit.

As a consequently, this investigation should have an emphasis on both of these different scenarios. The first recommendation is that research be conducted on the hyperparameters of machine learning algorithms. The second recommendation is that while presenting the data set, not only the result of the validation technique but also the results of the test should be included. In final, the presented study has the maximum testing accuracy of 93.9 % via Medium NN.

Machine learning algorithms offer a user-friendly approach to handling data, particularly in relation to incorporating various features. Convolutional neural networks derived from deep learning methods may be selected if solely the image data were accessible. Nevertheless, the process of constructing CNN would entail significant labor and computational complexity. Furthermore, CNN are capable of extracting a multitude of features, the significance of which may not be discernible to the observer. One notable benefit of this study is its significant departure from computational complexity. Other benefits of this study are: the dataset was evaluated for training–validation–testing and fine-tuning hyperparameters were effectively determined to class date fruit. One limitation of this study is the unavailability of the dataset images, which restricts the ability to perform comparisons with CNN.

Discussion, Conclusion, and Recommendations

Agricultural goods are easily categorized by machines, which benefits customers as well as vendors. This study proposes a method for automatically detecting and classifying various date fruit varieties. When features are extracted from images, machine learning algorithms can effectively identify seven types of date fruit using various hyperparameters.

In the presented study, various machine learning algorithms such as decision tree, KNN, artificial NN, and SVM are used to classify date fruit based on their different hyperparameters. The dataset was split into proportions of 80% for training and 20% for testing. To prevent overfitting, the training process utilized the 5-fold cross-validation technique. The dataset includes 34 features from images of date fruit. These features involve genetic variations like morphological features, shape, and color. Here are the main features in detail: These are some of the morphological features that can be examined: area, perimeter, major axis, minor axis, eccentricity, roundness, equivalent diameter, solidity, convex area, extent, aspect ratio, and compactness. Another main aspect is the shape features. Experimental results show some important findings as follows: (i) While the decision tree is selected as a classifier; it shows Gini's diversity index is the best hyperparameter and the algorithm obtains 86.59% testing accuracy. (ii) KNN achieves the highest performance via Euclidean distance with 92.18% testing accuracy. (iii) Artificial NN consisting of 25 layers (called Medium NN) achieved the best test accuracy rate, reaching an impressive value of 93.9%. Therefore, the presented study suggests Medium NN to detect types of date fruit (iv) SVM gets the successful performance based on quadratic kernel function. Additionally, this study also involved the calculation of the Kappa value and other relevant criteria. A kappa value exceeding 0.70 signifies that the proposed approach demonstrates strong classification performance. The proposed algorithm used the ReLU activation function and 1000 maximum iteration limits.

This study has some limitations. Owing to the unavailability of images of the dataset, a comparison with deep learning algorithms could not be presented. Furthermore, due to the inability to evaluate various image features or extraction methods, the effectiveness of machine learning algorithms in these circumstances remains uncertain.

The objective of future research is to conduct comparative analyses on agricultural products and to devise tools that utilize deep learning and machine learning algorithms to class images and features of the same images.

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Determination of Predators and Parasitoids of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Different Tomato Varieties Cultivated in Open Fields in Diyarbakır Province

Diyarbakır İlinde Açık Alanda Yetiştiriciliği Yapılan Farklı Domates Çeşitlerinde *Tuta absoluta* (Lepidoptera: Gelecehiidae)'nın Predatör ve Parazitoitlerinin Belirlenmesi

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ABSTRACT

This study was conducted to determine predators and parasitoids of the tomato leafminer [*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)] in open field tomato cultivation areas in Diyarbakir province during 2021–2022. Threeparasitoids and 10 predator insects were detected in survey areas. The determined parasitoid species were *Bracon hebetor* (Say, 1836), *Bracon didemie* Beyarslan, *Bracon (Habrobracon) viktorovi* Fischer, and the predatory insects *Nysius graminicola* (Kolenati, 1845), *Geocoris megacephalus* (Rossi, 1790), *Macrolophus costalis*, *Macrolophus pygmaeus* (Rambur) *Campylomma diversicornis* Reut., *Chrysoperla carnea* (Stephens), *Orius* spp., *Orius niger* (Wolff), *Coccinella septempunctata* (L.), and *Hippodamia variegata* (G.). The results of this study are important for biological and integrated pest management in tomato fields. Additionally, it is believed that the maintaining and increasing of the effectiveness of existing natural enemies is crucial in pest control.

Keywords: Tomato leaf miner, natural enemy, biological control, integrated control

ÖZ

Bu çalışma; Diyarbakır ili açık alan domates üretim alanlarında zarar yapan domates güvesi [*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)]'nin predatör ve parazitoitlerini belirlemek amacıyla 2021–2022 yıllarında yürütülmüştür. Sürvey alanlarından üçü parazitoit, 10'u predatör olmak üzere toplam 13 böcek türü tespit edilmiştir. Belirlenen parazitoit türler; *Bracon hebetor* (Say, 1836), *Bracon didemie Beyarslan*, *Bracon (Habrobracon) viktorovi* Fischer, predatör türler de *Nysius graminicola* (Kolenati, 1845), *Geocoris megacephalus* (Rossi, 1790), *Macrolophus costalis*, *Macrolophus pygmaeus* (Rambur) *Campylomma diversicornis* Reut., *Chrysoperla carnea* (Stephens), *Orius* spp., *Orius niger (Wolff)*, *Coccinella septempunctata* (L.), *Hippodamia variegata* (G.) olmuştur. Zararlıyla mücadelede doğal düşmanların korunması ve etkinliklerinin artırılması önemli olduğundan bu çalışmanın sonuçları domates üretim alanlarında biyolojik ve entegre mücadele çalışmaları için önem taşımaktadır.

Anahtar Kelimeler: Domates güvesi, doğal düşman, biyolojik mücadele, entegre mücadele

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Introduction

Vegetables have a significant role in human nutrition. The necessity of consuming vegetables for human health is increasingly understood every day, as they have many health benefits such as containing no fat, being rich in water and fiber, being easy to digest, and not causing weight gain. Tomato, which is

the most widely utilized vegetable in Turkish cuisine nowadays, is used directly in meals and as ketchup in many dishes during the summer months and it has become a vegetable that we can hardly think of without.

This pest, which was initially detected in tomato fields in the Urla district of Izmir Province in Turkey in 2009 (Kılıç, 2010), was found in the Kumluca district of Antalya, where covered cultivation is widespread, in January 2010 (Erler et al., 2010). Since with a high damage potential, it has quickly become the main pest in open fields and covered tomato cultivation. If not controlled in infested areas, it can lead to product losses reaching 80–100% in tomatoes and threatens all covered and open field tomato production (López, 1991).

In Türkiye 13.2 million tons of tomatoes were produced in 2020 and 13.095 million tons in 2021. The provinces of Antalya, Bursa, and Manisa were among the top producers in 2021. Türkiye ranked fifth with a 7% share of exports in 2020. Syria, Romania, and Russia accounted for the countries with the largest share of Türkiye's tomato exports. In the first four months of 2022, Turkey's tomato exports were around 205 thousand tons. According to TURKSTAT (Turkish Statistical Institute) data, Turkey's tomato production decreased to 12.8 million tons in 2022 (Anonymous, 2022a; Anonymous, 2022b).

In Türkiye, tomato is one of the most consumed vegetables throughout the year, but there are many diseases and pests that significantly limit its productivity (Anonymous, 2008). Tomato leaf miner [*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)] is one of the most important pests that threaten tomato cultivation.

As it is understood, combating pests in agricultural production is an important issue, and using only chemical pesticides is not sufficient for this fight. Therefore, it is necessary to have detailed knowledge about pests and to identify their natural enemies. By identifying natural enemies, it is possible to control pests naturally and reduce the use of chemical pesticides. These methods are part of sustainable agriculture criteria.

This study focuses on the identification and recognition of predators and parasitoids of pests. It is aimed to lead the studies to be carried out in the region on pest control, to reveal new information, to make production more economical and efficient. In this way, farmers will be supported to use more sustainable and environmentally friendly methods in pest control.

Another important point is that this study is just a starting point. The process of identifying and recognizing the predators and parasitoids of pests requires a long-term study, and the applicability of the knowledge gained form this study is also important. Nevertheless, this study can encourage farmers in the region to try new methods in the fight against pests and to produce according to the criteria of sustainable agriculture

In conclusion, combating pests in agricultural production is an important issue, and using only chemical pesticides is not sufficient for this fight. The identification and detection of predators and parasitoids helps in the development of new methods to combat pests and is part of criteria for sustainable agriculture. This study can help farmers in the region to use more sustainable and environmentally friendly methods in the fight against pests.

Methods

The number of tomato areas examined was determined according to Bora and Karaca (1970) taking into account the labor force, time, distance between areas, evaluation of collected samples, and the size/number of production areas. Field sampling was conducted at a rate of 2% for districts with a production area of 50–100 ha, 1% for districts with a production area of 101–1000 ha, and 0.1% for districts with a production area of 1001–10,000 ha. In the samplings, 20 plants per decare were randomly selected by entering the corners of the field diagonally, and all parts of the plants were examined with the help of a magnifying glass and a microscope.

Provincial Directorate of Agriculture and Forestry data

Studies were conducted in a production area of 15,950 hain 10 districts in order to represent the areas of tomato growing in open fields in the province of Diyarbakır (Table 1).

FDR 8565, H-2274, Falcon, Elibol, Karacadağ, and Lice tomato varieties are grown in the survey areas.

Sampling of Predators and Parasitoids

Visual Inspection Method

Sampling of predators: The whole parts of the plants designated for the purpose of determining the natural enemies were examined, and the known predators identified during the observation were recorded. The adults of the unidentifiable species were

Table 1.
Districts of Diyarbakır Province Where Tomato Is Grown in Open Fields and Examined Production Areas

District Name	Tomato Planting Area for Table (da)	Table Tomato Planting Area (da)	Tomato Planting Area for Drying (da)	Total Area (da)	The Area Needing Examination (da)
Bağlar	200	300	0	500	5
Bismil	1000	1400	200	1600	2
Ergani	1500	2500	1000	5000	5
Kayapınar	100	400	2500	3000	3
Lice	0	3000	0	3000	3
Yenişehir	0	1100	150	1250	1
Sur	50	250	100	400	4
Silvan	200	400	0	600	6
Çınar	0	1450	0	1450	1
Kulp	240	360	0	600	6
Total	3290	9710	3950	15,950	36

collected using aspirators, while their larvae and pupae were transferred to culture vessels to obtain adults and were transported to the laboratory to be made ready for diagnosis.

Sampling of parasitoids: Pest-infested plant samples were collected from tomato fields and were cultured under climate chamber conditions (25 ± 1°C temperature and 60 ± 5% humidity, 16:8 light–darkness). The larvae were cultured in jars and the emergence of parasitoids was monitored daily by routine examinations.

D-Vac Sampling Method

The D-Vac sampling method is a sampling technique used to detect pests in plant materials. In this method, plant samples are collected using a special vacuum device. The D-Vac device has a feature that allows pests on the plants to be collected by airflow (Vincent et al., 2003).

The sampling process is usually done to detect pests on the leaves and stems of the plant. During the sampling process, all parts of the plant are scanned with the device, and the pests collected in the device's filter are later counted and their species are identified.

In open tomato cultivation areas in the Diyarbakır province, samplings were conducted by walking along the rows for two minutes, taking samples from three different points along the diagonals. For each sampling, a 1-type mesh bag with a rubber-tipped end, 30 cm wide and 45 cm long, was used. The samples were kept in these bags, labeled, and brought to the laboratory. The species in the samples collected in a plastic container with a mouth aspirator and frozen to death, and possible natural enemies present in the samples were identified by subsequent examination.

The predators and parasitoids obtained at the end of the sampling were prepared for diagnosis and sent to subject experts. The diagnosis of species belonging to the family Braconidae was made by Prof. Dr. Ahmet BEYARSLAN (Retired Faculty Member, Department of Biology, Trakya University), the diagnosis of species belonging to the family Coccinellidae was made by Dr. Derya ŞENAL (Department of Plant Protection, Faculty of Agriculture and Natural Sciences, Bilecik Şeyh Edebali University), and the diagnosis of species belonging to the order Hemiptera was made by Dr. Gülten YAZICI (Ankara Plant Protection Research Institute).

Results

This study conducted in open tomato cultivation areas in Diyarbakır province revealed the presence of many predator and parasitoid species in 2021 and 2022 (Table 2).

The predatory insect species found in this study generally prey on a variety of harmful insect, and *Coccinella septempunctata* L., *Hippodamia variegata* G., *Macrolophus pygmaeus* R., *Nysius graminicola* K., *Chrysoperla carnea*, *Orius* spp., and *Geocoris megacephalus* in Table1 have also been reported as predators of T. absoluta (Altun-Aksu & Çıkman 2019, Türkmen 2019, Ferracini et al. 2019; Bayram et al. 2014; Güven et al. 2017; Keçeci & Öztop 2017; Polat 2014; Urbaneja et al. 2009; Öztemiz 2012). The other predatory insects *Campylomma diversicornis*, Macrolophus costalis, *Orius niger*, and *Nysius graminicola* are general predators and can consume eggs or larvae of *Aphis* spp., *Tetranychus urticae, Myzus persicae, Bemisia tabacci,* etc., but their effects on pest species cannot be determined.

Table 2.
Predators and Parasitoids Identified in the Study

Order	Family	Organism
Hemiptera	Miridae	*Campylomma diversicornis Reuter*
		Macrolophus pygmaeus (Rambur) *Macrolophus costalis Fieber*
	Anthocoridae	*Orius* spp.
		Orius niger (Wolff)
	Lygaeidae	*Geocoris megacephalus* (Rossi) *Nysius graminicola* (Kolenati)
Coleoptera	Coccinellidae	*Coccinella septempunctata* (Linnaeus)
		Hippodamia variegata (Goeze)
Neuroptera	Chrysopidae	*Chrysoperla carnea* (Stephens)
Hymenoptera	Braconidae	*Bracon hebetor* (Say)
		Bracon (Habrobracon) didemie Beyarslan
		Bracon (Habrobracon) viktorovi Fischer

Macrolophus pygmaeus Rambur is commercially used. According to a study, it consumes 2 larvae and 30 eggs daily while feeding on the eggs and larvae of *T. absoluta* (Urbaneja et al., 2009).

In addition, two larval parasitoids, *Bracon hebetor* (Say, 1836) and *Bracon didemie* Beyarslan, have been determined. These two species have been reported as parasitoids of *Tuta absoluta* in many studies (Altun-Aksu &Çıkman 2019, Türkmen 2019, Ferracini et al. 2019; Bayram et al. 2014; Güven et al. 2017; Polat 2014; Urbaneja et al. 2009; Öztemiz 2012).

Among predator species, *M. pygmaeus* was the most common and had the highest population. *C. diversicornis* was the second species. Among parasitoid species, *B. hebetor* was the most common species. *B. didemie* was the most common species with the second highest population.

In addition, *Bracon* (*Habrobracon*) *viktorovi* Fischer has not been previously reported as a *T. absoluta* parasitoid in previous studies. However, it has been reported to be present in vegetable gardens in Ordu and Malatya provinces (Beyarslan et al. 2008, Beyarslan & Çetin Erdoğan, 2012). Further studies are needed to determine whether this species is a parasitoid of *T. absoluta*

The species *Bracon didemie* Beyarslan and *Bracon* (*Habrobracon*) *viktorovi* Fischer have been detected for the first time in tomato cultivation areas within the borders of Diyarbakır province.

Discussion and Conclusions

In this study, three parasitoids and ten predator insects were detected. Some of these predator insects are effective on the tomato leaf miner while the others are general predators whose effect on the pest cannot be determined. Since the presence of parasitoids and predators as an alternative to chemical control, biological and biotechnical control methods should be considered together and integrated with other control methods, and the possibility of natural enemies being affected more during chemical control should not be overlooked.

In a study conducted in Antakya province of Turkey, nine parasitoid species belonging to four families of the Hymenoptera order (Eulophidae, Chalcididae, Pteromalidae, Braconidae) were found among the natural enemies of *T. absoluta*, including *Closterocerus clarus* (Szelenyi), *Ratzeburgiola christatus* (Ratzeburg), *Ratzeburgiola incompleta* Boucek, *Baryscapus bruchophagi* (Gahan), *Brachymeria secundaria* (Ruschka), *Hockeria unicolor* Walker, *Pteromalus intermedius* (Walker), *Bracon hebetor* Say, and *Bracon didemie* Beyarslan. The parasitism rates of these species were reported to vary between 0.7% and 37% (Doğanlar et al., 2011). Furthermore, in a study conducted in Şanlıurfa, which is a region in Turkey, *Bracon hebetor* (Say, 1836) was reported as a parasitoid of *T. absoluta* (Altun-Aksu & Çıkman, 2019).

Furthermore, the pest has many hosts so the possibility of turning to these host plants in the winter and spring when the first adult females cannot find tomato plants should be taken into account, weed control should be performed, and plant debris should not be left in and around tomato fields.

Natural enemies are biological control agents used to control pests in agricultural production. Biological pest control is preferred as an alternative to the use of chemical pesticides and is environmentally friendly.

Detecting natural enemies is crucial in agricultural production as it helps to identify the presence and effectiveness of them that can be used for controlling harmful organisms. Biological control agents are often highly specific to their target pests. This specificity reduces the risk of harming nontarget organisms, including beneficial insects, humans, and pets. This reduces the dependence on chemical inputs, minimizing environmental impact and promoting long-term ecological balance. Some biological control agents act both preventatively and curatively. They can prevent pest populations from reaching harmful levels and also help control existing infestations. Biological pest control is often a key component of integrated pest management, where different methods of pest control are combined into a comprehensive and sustainable approach.
Due to the use of broad-spectrum pesticides as part of intensive chemical control, the numerical values of predator and parasitoid species were found to be at a very low population level.

Specifically, the determination of natural enemies can help in the development of integrated pest management strategies in agricultural production. Integrated pest management strategies are methods of pest control that minimize the use of chemical pesticides by incorporating natural enemies. This allows farmers to control pests in a more cost-effective and environmentally friendly manner.

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Impact of Combined Rural Initiatives for Participatory Agricultural Transformation and Farmer Market School Approaches on Income and Food Security

Katılımcı Tarımsal Dönüşüm ve Çiftçi Piyasası Okulu Yaklaşımlarına Yönelik Kombine Kırsal Girişimlerin Gelir ve Gıda Güvenliğine Etkisi

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ABSTRACT

Interventions to increase agricultural production have always been biased toward production without much consideration of market strategies. It is against this background, several development agents initiated a project that combines rural initiatives for participatory agricultural transformation and farmer market school approaches with the aim of transforming smallholder farmers' agricultural production and marketing, respectively. The objective of this study is to examine the impact of combined rural initiatives for participatory agricultural transformation and farmer market school approaches on income and food security. The present study applied a cross-sectional research design, and the data used were gathered from a sample of 321 farming households, selected using a multi-stage random sampling procedure. Of the 321 respondents, 93 were farmers who participated in rural initiatives for participatory agricultural transformation and farmer market school, and 100 and 128 were farmers who participated in rural initiatives for participatory agricultural transformation interventions and non-participants, respectively. Data were analyzed using descriptive statistics and propensity score matching for quantitative data, while content analysis was applied for analyzing qualitative information. The results indicate that, across farmers enrolled in rural initiatives for participatory agricultural transformation and farmer market school and rural initiatives for participatory agricultural transformation only, and non-participants, there was no significant difference in levels of income and food diversity, although there was a positive difference. The results of rural initiatives for participatory agricultural transformation and farmer market school and rural initiatives for participatory agricultural transformation-only interventions were Tanzania Shilling (TZS) 73,947 and TZS 51,796, respectively, with food diversity scores of 7.454 and 7.418. The drought faced by farmers during piloting was found to be the main challenge for the insignificance impact of the approaches. The results of our study suggest that the adoption of combined rural initiatives for participatory agricultural transformation and farmer market school in agricultural interventions is likely to improve smallholder farmers' income and food security. The two approaches should be promoted to produce additional benefits in terms of productivity and land use efficiency.

Keywords: Rural initiatives for participatory agricultural transformation, farmer market school, propensity score matching, income, food security

ÖZ

Tarımsal üretimi artırmaya yönelik müdahaleler her zaman piyasa stratejilerini fazla dikkate almadan üretime yönelik olmuştur. Bu arka plana karşı, çeşitli kalkınma kuruluşları, sırasıyla küçük çiftçilerin tarımsal üretim ve pazarlamasını dönüştürmek amacıyla katılımcı tarımsal dönüşüme yönelik kırsal girişimleri ve çiftçi pazarı okulu yaklaşımlarını birleştiren bir proje başlattı. Bu çalışmanın amacı, katılımcı tarımsal dönüşüme yönelik birleşik kırsal girişimler ile çiftçi

pazarı okulu yaklaşımlarının gelir ve gıda güvenliği üzerindeki etkisini incelemektir. Bu çalışmada kesitsel bir araştırma tasarımı uygulanmış ve kullanılan veriler, çok aşamalı rastgele örnekleme prosedürü kullanılarak seçilen 321 çiftçi hanesinden oluşan bir örneklemden toplanmıştır. 321 katılımcının 93'ü katılımcı tarımsal dönüşüm ve çiftçi pazarı okulu için kırsal girişimlere katılan çiftçilerdi ve sırasıyla 100 ve 128'i katılımcı tarımsal dönüşüm müdahaleleri için kırsal girişimlere katılan ve katılımcı olmayan çiftçilerdi. Veriler, niceliksel veriler için tanımlayıcı istatistikler ve eğilim puanı eşleştirme kullanılarak analiz edilirken, nitel bilgilerin analizinde içerik analizi uygulandı. Sonuçlar, katılımcı tarımsal dönüşüm için kırsal girişimlere çiftçi pazarı okulu ve yalnızca katılımcı tarımsal dönüşüm için kırsal girişimlere kayıtlı çiftçiler ile katılmayanlar arasında, gelir ve gıda çeşitliliği düzeylerinde anlamlı bir fark olmadığını, ancak olumlu bir fark olduğunu göstermektedir. fark. Katılımcı tarımsal dönüşüme yönelik kırsal girişimler ve çiftçi pazarı okulu ve yalnızca katılımcı tarımsal dönüşüme yönelik kırsal girişimler müdahalelerinin sonuçları sırasıyla Tanzanya Şilini (TZS) 73.947 ve TZS 51.796 oldu ve gıda çeşitliliği puanları 7.454 ve 7.418 oldu. Çiftçilerin pilot uygulama sırasında karşılaştığı kuraklığın, yaklaşımların etkisinin önemsiz olmasındaki temel zorluk olduğu görüldü. Çalışmamızın sonuçları, katılımcı tarımsal dönüşüm için birleşik kırsal girişimlerin ve tarımsal müdahalelerde çiftçi pazarı okulunun benimsenmesinin, küçük çiftçilerin gelirini ve gıda güvenliğini iyileştirebileceğini göstermektedir. Verimlilik ve arazi kullanım verimliliği açısından ek faydalar üretmek için iki yaklaşımın desteklenmesi gerekmektedir.

Anahtar Kelimeler: Katılımcı tarımsal dönüşüm için kırsal girişimler, çiftçi pazarı okulu, eğilim puanı uyumu, gelir, gıda güvenliği

Introduction

Agriculture has remained the main source of livelihoods in Africa, and is characterized by smallholder farm households. Smallholder farmers are main actors on income and food systems in developing countries (IFAD, 2022). According to NEPAD (2013), more so than in other continents, Africa is dominated by smallholder farmers, who rely mainly on family labor, characterized by less than 2 ha and accounting for 80 percent of all farms globally. The importance of agriculture cannot be over-emphasized in Africa, including Tanzania; however, its productivity is low and lags behind other developing regions (African Development Bank Group, 2016) Hence, the continent has the highest incidence of undernourishment, estimated at almost one in four persons (African Development Bank Group, 2016; Christiaensen, 2017; FAO, 2017).

Agriculture is an important sector for Tanzanian inclusive economic growth and poverty reduction. The sector employs over 65% of Tanzanian workforce and contributes 100% of food in the country to make Tanzania a food-sufficient economy. Agriculture in Tanzania contributes 27.7% of GDP and 24.1% of export earnings as well as 60% of industrial raw materials (URT, 2021). As it is in Africa, about 80% of agricultural produces in Tanzania come from smallholder farmers who depend on local and manual cultivation and rainfed, and they are prone to weather shocks (IFAD, 2022). The growth rate of agriculture for the past several years (4–5%/year) has failed to achieve the national target (6–10% /year), and poverty reduction is also lagging behind (IFAD, 2022). Failure to achieve the growth target is rooted in several challenges facing the sector which require an integrated approach to reduce them for improved production and productivity. Addressing challenges facing agriculture, adoption of farming techniques, input use and the application of available technologies, and policy actions have been instrumental for alleviating poverty in rural Africa.

There are numerous interventions that have been implemented for improving production, productivity, and hence reducing both food insecurity and income poverty. Stewart et al. (2015) pinpoint that these interventions are meant to reduce income poverty and food insecurity among smallholders. Accordingly, skills development and adoption of available technologies are main approaches to achieve the objectives of these interventions. For improving income and food security from agriculture resulting from productivity, scholars (e.g., Bravo-Ureta et al., 2012; Nakano et al., 2017; Triebs & Kumbhakar, 2013) consider managerial skills to use the best existing technologies, and marketing-oriented production as major aspects to be promoted by intervention aimed at supporting farmers.

In practice, we see more interventions that are biased to either production or marketing than those focusing on both. While such efforts are useful, it is noteworthy that some of the interventions on farming are liable to failure due to lack of business orientation among the target group. According to Ferris et al. (2014), lack of market-based agricultural production has consistently locked millions of smallholder farmers in poverty. It is against this background that Sokoine University of Agriculture (SUA), Adventist Development and Relief Agency (ADRA) Tanzania, Research, Community and Organizational Development Associates (RECODA), and ADRA Denmark initiated a project that combines rural initiatives for participatory agricultural transformation (RIPAT) and farmer market school (FMS) approaches with the aim of transforming smallholder farmers' agricultural production and marketing, respectively. The project, which is known as '*Kilimo na Masoko*-Farming for the Market, was implemented as a pilot project for 2 years (October 2020–September 2022) with the aim of assessing the complementarity and synergy of the RIPAT approach with the FMS approach (RIPAT-SUA ", 2020).

The RIPAT approach is among agricultural interventions for which donors have invested substantial amounts of resources with the aim to support the efforts to bridge agricultural technology gaps for increased productivity. On the other hand, the FMS approach focuses on enabling smallholder farmers to explore and analyze the market to better understand the dynamics that determine the market and the value chains (ADRA Denmark, 2021). While the merits of combining the production and marketing aspects are well acknowledged, there is paucity of information regarding the effect of this combination on smallholder farmers' livelihood. Therefore, the study examined the impact of the RIPAT-FMS combination on the farming households' income and food security measured in terms of food diversity.

Methods

Data Collection

Data used in this study were collected in Mvomero district and Morogoro district in Morogoro region, Tanzania. Mvomero

Table 1.
Number of Respondents by Group/Category

District	Village	Group Name	FMS and RIPAT Group Members	RIPAT Group Members	Non-Group Members
Morogoro	Mgambazi	Faraja	12	-	5
	Magadu	Maendeleo	12	-	12
	Kauzeni	Mshikamano	12	-	10
Mvomero	Tangeni	Tupendane	12	-	12
	Mkuyuni	Uchumi	12	-	12
		Tukaleghoya	13	-	
	Changarawe	Nuru	-	19	18
		Amani	-	18	
	Peko	Tukalehamwe	-	22	20
	Kipera	Mashujaa	15	-	16
	Mlali	Umoja	12	-	10
	Mnyanza	Twikindem	-	15	13
		Chikena	-	19	
Total			100	93	128

Note: FMS = farmer market school; RIPAT = rural initiatives for participatory agricultural transformation.

District is located at latitude 06°26" south and longitude 37°32" east. Morogoro Municipal is located in North-East of Morogoro Region between 6°00" and 8°00" Latitudes South of Equator, also between Longitudes 36°00" and 38°00" East of Greenwich. Accordingly, Population and Housing Census, Morogoro Municipal had 56,723 households and Mvomero 58,314 households with a total population of 286,248 and 312,109 respectively (URT, 2022). The study employed a cross-sectional research design. Data were collected using a multi-method research approach, which comprised of quantitative and qualitative research methods namely household survey, focus group discussion, in-depth interviews with farmers and key informant interviews with village leaders and extension officers as well as FMS facilitators. For the quantitative data, selection of respondents was done randomly from 8 farmer groups that participated in RIPAT and FMS interventions, 5 farmer groups that participated in RIPAT only interventions[1] and farmers who did not benefit from any of the interventions but are in the villages/streets in which the interventions were introduced. As for the qualitative data, participants were selected purposively, criteria being participation in combined RIPAT and FMS interventions, participation in RIPAT intervention only, participation as FMS trainer, and village/street leadership or extension officer position in the project area.

Both purposive and random sampling were applied to select wards, villages, and participants. Purposive sampling was applied to select wards and villages based on the criterion of being RIPAT program intervention. The second stage involved random selection of farmers to participate in the programs. A total of 193 farmers were selected from 13 farmer groups (8 under both Farming for the Market and RIPAT-SUA projects, and 5 under RIPAT-SUA project only) whereas 128 non-group members were randomly selected from the list of farmers who were not members of any farmer group (Table 1). Both categories had respondents from each project village/ward for participating in the household survey. For the groups, at least 12 farmers (about 50% of the group members) were randomly selected from each group. A questionnaire was administered to the respondents with the aim to solicit their socio-demographic information, physical characteristics of the study area, income and food security statuses, and information regarding crop and livestock production and marketing.

In-depth interviews and focus group discussions were chosen as qualitative methods. During in-depth interviews, two farmers were selected from each of the 13 farmer groups under the FMS project not on the basis of representation but rather on the assumption that all the group participants possessed the investigated characteristics. However, an attempt was made to make sure that one of the participants was male and the other was female. The aim was to examine the determinants of an effective combination of RIPAT and FMS approaches. Farmers were interviewed at their households or at convenient places where they were found. From each group, seven to eight members were purposively selected for participation in focus group discussions (FGDs). The selection process ensured the inclusion of male and female members and group leaders. Thus, a total of 13 FGDs were conducted. Among other things, the FGDs were meant to obtain farmers' views regarding the combination of RIPAT and FMS approaches in terms of factors seen as enhancing and those seen as constraining the effective integration and the modalities with which the approaches were introduced.

Construction of Important Variables

Participation in the RIPAT training, RIPAT-FMS, and/or non-participating program is a dichotomous variable taking the value 1 if the farming household participated in the project, 0 otherwise. As explained earlier, farmers were grouped into three subgroups: non-participants, farmers participating in RIPAT, and the third

[1] RIPAT-SUA project, which used the RIPAT approach, was implemented in the area with 16 initial groups between February 2018 and June 2021, whereas *Kilimo na Masoko* project, which used the FMS approach, was implemented with 8 of the RIPAT-SUA project"s initial groups from October 2020 to September 2022. Five (5) of the groups which were not involved in the *Kilimo na Masoko* project have been selected randomly and treated as RIPAT only groups (RIPAT-SUA project"s final report, 2021; *Kilimo na Masoko* project proposal, 2020).

group was farmers participating in RIPAT-FMS. To achieve analysis of the combination, first analysis involved non-participants (0) and those participated in RIPAT only (1) and then non-participants (0) and RIPAT-FMS participants (1). The non-group members served as a non-participants group—for comparison purposes as indicated in Table 1 below.

Household income is the sum of all sources of income accrued from all sources. The present paper identified about nine potential sources of income in the questionnaire: retail business, farming, livestock, remittances, and other income. Income from farming was computed using information on the price and quantity of the harvest for each agricultural produce and then was aggregated. Agricultural products include maize, vegetables, fruits, beans, peas, cassava, sweet potatoes, and bananas. On the other hand, animals included chickens, pigs, goats, and rabbits. Income was computed by multiplying the total quantity of the crops/animals sold and the respective unit price.

The present research applied dietary diversity in measuring food security. Dietary diversity scores index is developed by counting food groups consumed over a given period, usually a 24-hour period or a week (Bizimana & Richardson, 2017; Carletto et al., 2013). A questionnaire with specific questions based on identified sixteen food groups, whereby each group scores one regardless of the number of food items consumed (Kennedy et al., 2011). Literature review revealed the following dietary diversity indicators developed, namely household dietary diversity score (HDDS), the Infant and Young Child Dietary Diversity Score, the Women Dietary Diversity Score (WDDS), and the Food Variety Score (Leroy et al., 2015; FAO, 2013; Rathnayake, 2012). Household dietary diversity score is used frequently and has been proposed over the years as an alternative means of capturing food access (Bizimana & Richardson, 2017; FANTA, 2006, Leroy et al., 2015). The present paper is enlightened and hence applies the HDDS in measuring food security.

Data Analysis

The study applied Propensity Score Matching (PSM) in analyzing the impact of training initiatives on income and food security. Like any other observational studies, the present one is plagued by lack of randomization to apply Randomized Control Trials (RCT). Relating to the present study, key issues that made randomization hardly applicable include (i) RCT requires a stable process and must not be in its early stages, (ii) the enrollment demand is minimal, (iii) it requires an extensive management process, and (iv) results from RCT for this study cannot be generalized to the population (Ozminkowski, 1998; Rossi & Freeman, 1993). Based on the conditions stated, the PSM technique was found relevant for data analysis. Propensity-score matching uses the probability of being a member in the group of interest or not (e.g., participants vs. non-participants group) based on homogeneity in covariates such as demographic and socio-economic to then be used in logistic regression to create a counterfactual group (Johnson et al., 2018; Smith, 1997). Propensity score matching does not require randomization nor a baseline for impact analysis and requires a large sample to make precise outcomes (Adeyanju et al., 2019; Benedetto, 2018; Olounlade et al., 2020). The main advantage of the PSM is its reduction in dimensions, which solves the problem of an insufficient number of sample cases (Guo et al., 2020).

The average treatment effect on the treated (ATT) generated using PSM is equal to the expected difference in the outcomes between participants and non-participants after being matched based on socio economic characteristics (Frölich & Sperlich, 2019). The uniqueness of this technique over other approaches (correlated random effects—CRE), Tobit, local average treatment effect parameter (LATE) is that PSM builds with common supports. It needs good quality data, otherwise common support can be a problem if two groups are very different. Accordingly, PSM is a powerful analytical tool for adjusting confounding variables and reducing selection bias since it accounts for the outcomes of the participant and non-participant groups, which provides an unbiased estimate by non-participants of observable factors and reduces matching problems (Hotmaida & Purba, 2018; Olounlade et al., 2020). The main basis of the PSM is its common support that identifies subgroups with similar socio-economic characteristics and these groups differ because of intervention/treatment only (Hotmaida & Purba, 2018). Accordingly, the model assumes unconfoundedness; all variables that influence treatment assignment and potential outcomes to be observed by the researcher, and the second is common support or overlap implying that all covariates have a positive probability of being assigned to treatment or not (Caliendo & Kopeinig, 2005; Lin, 2015; Morgan, 2018; Smith, 2000). According to Imbens and Wooldridge (2009), propensity score sub-classification, propensity score weighting, and matching estimators are robust in most data situations. Thus, using the PSM model follows two stages. Firstly, a logit model and the second stage entails estimating the ATT.

The RIPAT participants were matched and compared with non-participants and RIPAT-FMS versus non-participants on all similar observable characteristics except the treatment (Schulte & Mascha, 2018; Taylor, 2018). The estimation of propensity scores used for the matching exercise was analyzed as follows**.**

Participation in the program (participants = 1, non-participants = 0) at first was between participants in RIPAT and non-participants and the second was between participants in RIPAT and FMS and non-participants.

$$Y = {}^{2}_{0} + {}^{2}_{1}X_1 + \varepsilon_i \quad (1)$$

such that

$$Y = {}^{2}_{0} + {}^{2}_{1}X_1 + \varepsilon_{Cov} + \varepsilon_i \quad (2)$$

The outcome model is specified in the following equation

$$Y = {}^{2}_{0} + {}^{2}_{1}X_1 + {}^{2}_{2}X_2 + {}^{2}_{3}X_3 + {}^{2}_{4}X_4 + {}^{2}_{5}X_5 + {}^{2}_{6}X_6 + {}^{2}_{7}X_7 + {}^{2}_{8}X_8 + {}^{2}_{9}X_9 + {}^{2}_{10}X_{10} + {}^{2}_{11}X_{11} + {}^{2}_{12}X_{12} + \varepsilon_i \quad (3)$$

Whereby

Y = outcome variable (Income in Tanzanian shillings)

β_0 = Regression constant

β_i = Regression coefficient

X_1 = participation in the program (participants = 1, non-participants = 0) at first was between participants in RIPAT and non-participants and the second was between participants in RIPAT and FMS and non-participants. Other variables X_2 to X_{12} are covariates that can also affect the outcome variable but are not of interest for this paper.

X_2 = marital status

X_3 = age of the respondent

X_4 = education level of the respondent

X_5 = farming experience

X_6 = land ownership

X_7 = off-firm income

X_8 = source of finance for farming

X_9 = wealth in ownership of assets

X_{10} = distance to market

X_{11} = household size

X_{12} = capital used/farming investment

ε_i = error term.

Stage two involves participants and non-participants to be matched by using propensity score values from stage one. PSM fits into the data to evaluate the effect of participating in the RIPAT-FMS program on improving income and food security. The model is explained as follows.

Let Y_i^T and Y_i^C be the outcome variable for the participants and non-participants, respectively. The difference in outcome of the two groups is expressed in Equation (4) below:

$$\Delta_I = Y_i^T - Y_i^C \quad (4)$$

Whereby,

Y_i^T outcome of participants (i.e., youth female seaweed farmers' income, when she participates in the program)

Y_i^C outcome of the non-participating seaweed farmers

Δ_I difference between the outcomes of the two groups.

whereby, the causal effect notational form of this model, assigning by (D_i =1) as the experimental variable which takes the value of 1 for participants and 0 for non-participants, then the average treatment effect of youth females, can be written as follows:

$$\text{ATE}=\text{E}(Y_i^T \mid D_i = 1) - \text{E}(Y_i^C \mid D_i = 1) \quad (5)$$

whereby,

$\text{E}(Y_i^T \mid D_i = 1)$ = average outcome for participants (D_i =1)

$\text{E}(Y_i^C \mid D_i = 0)$ Average outcome for non-participants (D_i = 0).

The ATT for the sample is as follows:

$$\text{ATT}=\text{E}(Y_i^T - Y_i^C \mid D_i = 1) - \text{E}\left(Y_i^T \mid D_i = 1\right) - \text{E}(Y_i^C \mid D_i = 1) \quad (6)$$

The equations (1)–(6) are repeated and modeled for food security to determine the impact of RIPAT and FMS on food security.

Results, Discussion, and Conclusion and Recommendations

Technology Uptake Among Farmers

In supporting farmers to increase their income and food security, the projects (RIPAT-SUA and Kilimo na Masoko), which applied RIPAT and/or RIPAT and FMS approaches, introduced/promoted about nine technologies (Table 2). These were village savings and loan associations (VSLA), agricultural produces value addition, new crops, vaccination in poultry, improved feed, improved seeds, irrigation practices, and collective marketing and soil conservation practices. While 67% of the farmers reported full participation in VSLA, 13% only had adopted value addition practices. About 19%, 20%, and 56% of farmers adopted new crops as a result of market search under FMS, vaccination of chickens based on proper dosage and directives, and use of improved feeds respectively. About 62% of the participants were found using improved seeds, 24% consistently irrigated their crops, while about 14% were conducting collective marketing in their groups. The program put emphasis on soil conservation practices to reduce land degradation and improve production and productivity. Nearly a quarter (23%) of the trained farmers applied the promoted soil conservation practices (Table 2).

Table 2.
Uptake of Technologies Promoted Through RIPAT and FMS Approaches Among Farmers

Technologies Promoted Through RIPAT and FMS Approaches	Percent
Village Savings and Loan Association (VSLA)	67
Value addition and microprocessing	13
New crops	19
Poultry vaccination	20
Use of improved feed	56
Use of improved seeds	52
Irrigation practices	24
Collective marketing	14
Soil conservation practices	23

Note: FMS = farmer market school; RIPAT = rural initiatives for participatory agricultural transformation.

Income distribution

The results (Table 3) reveal that the overall average household income pooled from all sources was TZS 993,813. Specific to non-program participants, the household incomes from all sources were found to be Tanzania Shilling (TZS) 918,171, TZS 993,813, and TZS 1,026,381 for non-participants, RIPAT-only participants, and RIPAT and FMS participants, respectively. On the other hand, maximum incomes from all sources in the program areas were TZS 3,375,000, TZS 3,682,750, and TZS 3,910,443 for non-participants, farmers participating in RIPAT only, and farmers participating in both RIPAT and FMS, respectively (Table 3).

It should be noted that income level (Table 3) did not include the value of crops and animals consumed by a household member throughout the year and some sales which were made by the

Table 3.
Income Distribution

Statistics	Non-Participants	RIPAT Participants	RIPAT and FMS Participants
Mean	918,171	993,813	1,026,381
Minimum	100,000	158,000	254,838
Maximum	3,375,000	3,682,750	3,910,443
n	129	95	99

Note: FMS = farmer market school; RIPAT = rural initiatives for participatory agricultural transformation.

Table 4.
Descriptive Statistics of Covariates

Variables	Coef.	Std. Error	*Z*	*p*>z	95%CI	
(a) RIPAT- FMS farmers and non-participants						
Sex	−0.184	0.179	−1.030	0.303	−0.534	0.166
Age	0.014	0.007	1.890	0.059	−0.001	0.028
Marital status	0.049	0.142	0.350	0.729	−0.229	0.327
Education level	0.503	0.180	2.790	0.005	0.150	0.856
Household size	0.058	0.050	1.160	0.245	−0.039	0.155
Total plot size	0.081	0.047	1.710	0.087	−0.012	0.174
Constant	−2.369	0.679	−3.490	0.000	−3.699	−1.039
(a) RIPAT-only farmers and non-participants						
Sex	−0.211	0.183	−1.150	0.248	−0.571	0.148
Age	0.016	0.007	2.170	0.030	0.002	0.031
Marital status	0.093	0.146	0.630	0.526	−0.194	0.379
Education	0.398	0.189	2.110	0.035	0.028	0.768
Household size	0.048	0.048	1.020	0.310	−0.045	0.142
Total plot size	0.076	0.045	1.690	0.091	−0.012	0.165
Constant	−2.306	0.680	−3.390	0.001	−3.639	−0.973

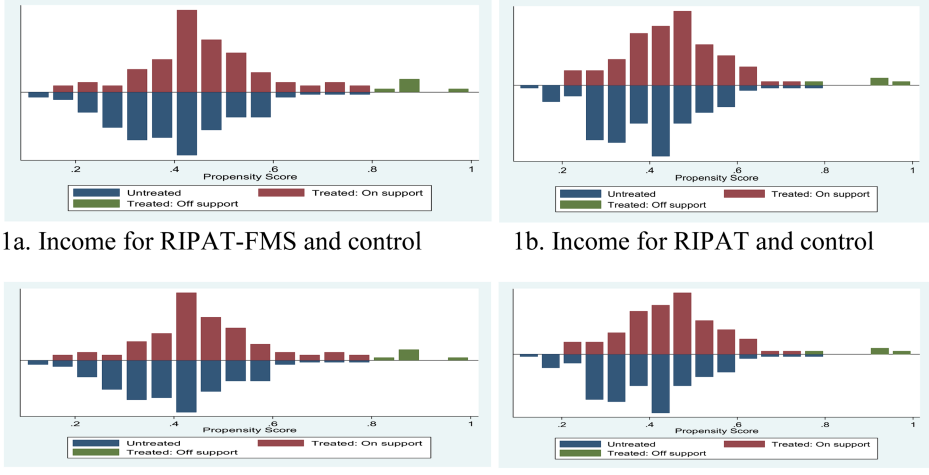
Note: RIPAT-FMS = rural initiatives for participatory agricultural transformation and farmer market school.

household purposely for buying other foodstuffs. For example, in most cases, surveyed households produced largely for consumption. During in-depth interviews with farmers and focus group discussions, it was revealed that farmers in the program areas spent about 70% of their produce for household consumption.

Propensity Score Matching Analysis Results

The nearest neighbor matching technique was applied to balance the covariates between the trainees and non-trainees. Table 4 reports the descriptive statistics of explanatory variables for: (a) farmers who participated in a project which applied both RIPAT and FMS approaches (RIPAT-FMS intervention); and (b) farmers who participated in a project which applied the RIPAT approach (RIPAT intervention), relative to non-participants. The main advantage of PSM is matching whereby group members whose characteristics cause statistical differences are dropped so that the remaining ones are those with comparable groups through common support method.

Propensity score distribution and common support (Figure 1) for propensity score estimation with a kernel matching technique: (a) income outcome variable between farmers participating in RIPAT-FMS intervention versus non-participants; (b) income outcome variable between farmers participating in RIPAT intervention versus non-participants; (c) food security outcome variable between farmers participating in RIPAT-FMS intervention versus non-participants; (d) food security outcome variable between farmers participating in RIPAT intervention versus non-participants.



1a. Income for RIPAT-FMS and control

1b. Income for RIPAT and control

1c. Food security for RIPAT -FMS and control

1d. Food security for RIPAT and control

Figure 1.
Propensity score distribution and common support for income and food security.

Table 5.
Impact of RIPAT Approach and Combined RIPAT and FMS Approaches on Household Income

Description	Treated	Non-participants	Difference	T-stat
RIPAT-FSM/non-participants				
Income unmatched	1,090,000	918,000	174,000	1.890
ATT	1,090,000	1,020,000	73,947	0.540
RIPAT/non-participants				
Income unmatched	1,070,000	918,000	152,000	1.660
ATT	1,070,000	1,020,000	51,796	0.380
RIPAT and FMS/RIPAT				
Income unmatched	1,210,000	1,090,000	122,000	1.110
ATT	1,090,000	1,060,000	33,664	0.220

Note: ATT = average treatment effect on the treated; FMS = farmer market school; RIPAT = rural initiatives for participatory agricultural transformation.

Impact of Participation in Combined Rural Initiatives for Participatory Agricultural Transformation and Farmer Market School on Income

Results in Table 5 indicate that across farmers enrolled in RIPAT, RIPAT and FMS and non-participants, there is no significant difference in levels of income between participants and non-participants, albeit there is a positive difference. Based on the matching process, the average income from all sources in the project areas is TZS 1,090,000, TZS 1,070,000, and TZS 1,020,000 for farmers participating in both RIPAT and FMS intervention, farmers participating in RIPAT intervention only, and non-participants, respectively. The results (Table 5) show that the farmers who participated in RIPAT-FMS intervention scored the ATT of TZS 73,947 relative to non-participants. On the other hand, the ATT for farmers who participated in RIPAT intervention only is TZS 51,796 relative to non-participants. In addition, a regression model based on the PSM approach was run to determine the relative impact of participating in RIPAT-FMS intervention relative to participating in RIPAT only. The results indicate an ATT of TZS 33,664. However, in both interventions, the coefficients for the income are not statistically significant at standard levels.

The results suggest that there was no statistically significant difference in income gaining between farmers who had been exposed to combined RIPAT and FMS approaches or RIPAT only and those that had not been exposed to the approaches. However, the positive income gained is an indicator that there is a positive direction with regard to the impact of the approaches toward increasing income among the farming households in the project area.

Table 6.
Consumption of Various Food Groups Among Households in Program Areas

Food Groups	Food Types Reported	Percent of Consumers (Pooled)
Cereals	Rice, maize-meals, millet, bananas, wheat products, porridge, or paste	100
White roots and tubers	Sweet potatoes, white cassava	95
Vitamin A rich vegetables and tubers	carrot,	58
Dark green leafy vegetables	Dark green leafy vegetables, including wild forms and locally available vitamin A-rich leaves such as amaranth, cassava leaves, and spinach	79
Other vegetables	Other vegetables (i.e. tomato, onion, eggplant) + other locally available vegetables	100
Vitamin A rich fruits	Ripe papaya and avocado	32
Other fruits	Other fruits: ripe bananas and watermelon	72
Organ meat	Liver, kidney, heart, or other organ meats, or blood-based foods	0
Flesh meats	Beef, pork, lamb, goat, rabbit, chicken, duck, other birds, insects	27
Eggs	Eggs from chicken, duck, guinea fowls, or any other egg	08
Fish and seafood	Fresh or dried fish or shellfish	13
Legumes, nuts and seeds	Dried beans, dried peas, lentils, nuts, seeds, or foods made from these (e.g., hummus, peanut butter)	100
Milk and milk products	Milk, cheese, yogurt, or other milk products	09
Oils and fats	Oil, fats or butter added to food or used for cooking	100
Sweets	Sugar, honey, sweetened soda or sweetened juice drinks, sugary foods such as chocolates, candies, cookies, and cakes	48
Spices, condiments, beverages	Spices (black pepper), condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages	29

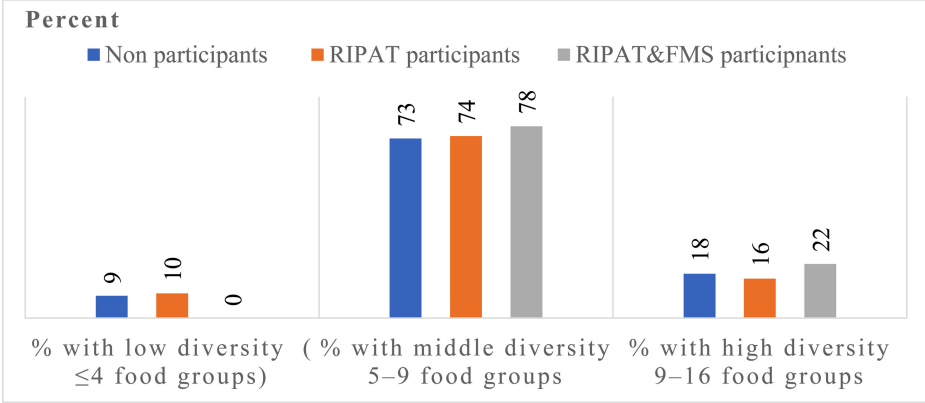


Figure 2.
Distribution of household dietary diversity score in the program area.

During the field work, it was revealed that farmers experienced drought in 2021–2022 cropping season, and hence the learned farming methods and marketing approaches would not work effectively. *"…I cannot say much because farmers are yet to practice the FMS training in full…"*—EO cum FMS facilitator. Further, it was observed that some farmers did not do well in transferring the practices and newly introduced crop varieties like bananas and maize, or livestock and poultry, namely goats, pigs, and chicken, to their own farms. They participated well at the demonstration plot and in group activities in general but did not do well in taking the practices home. Accordingly, adoption rate at farm level in Tanzania has remained low, and hence the impact of interventions is unlikely to be observed (Andrew et al., 2019).

Since it had been only about 1 year since the project applying the RIPAT approach phased out, it is logical to attribute the lack of statistical significance to it being too early to realize a significant contribution of the intervention to income. Studies conducted in areas where the RIPAT approach had been introduced 5 years past the data collection period showed no evidence of an increase in income as a result of the projects. For instance, Lilleør and Lund-Sørensen (2013) showed that there were no measurable effects of the projects on poverty, but there were indications of a shift in the sources and uses of agricultural income.

Dietary Diversity of Farming Households

Food security was measured in terms of households with low dietary diversity for recall for the past seven days. A household to be defined as food insecure had to have consumed less than 4 food groups, hereafter referred to as minimum dietary diversity (MDD) (WHO, 2008) that are required for a productive and healthy life. The sixteen food groups are recommended for healthy consumption according to food groups (FANTA, 2006; International Dietary Data, 2022). Table 6 indicates the proportion of 16 food groups households consumed in the study area. Figure 2 indicates that the majority of the farmers (73%, 74%, and 78% of non-participants, RIPAT-only participants, and RIPAT-FMS participants, respectively) scored mid-level of the food diversity.

In the context of dietary diversity, a household consumed about four groups or less is termed as the household with low dietary diversity. The study conforms to the study by Nithya and Bhavani (2018) who found that the majority of farming households with good climatic conditions had middle food diversity score. Accordingly, the results by Minja et al. (2021) found that a majority (80%) of the households in South-eastern Tanzania have medium dietary diversity, comprised of cereals, fats and oils, and proteins.

Impact of Participation in Combined Rural Initiatives for Participatory Agricultural Transformation and Farmer Market School Interventions on Food Diversity

Table 7 presents estimates of the average impact of participation in the combined RIPAT–FMS intervention and in RIPAT-only intervention. The results indicate that matched average food diversity per day in the program areas are 6.22, 7.418, and 7.454 for non-participant farming households, those involved in RIPAT-only

Table 7.
Impact of Combined RIPAT- FMS and RIPAT-Only Interventions on Food Diversity

Description	Treated	Non-participants	Difference	*T*-stat
RIPAT-FMS/non-participants				
Food diversity unmatched	7.455	6.557	0.898	0.400
ATT	7.454	6.134	1.316	0.960
RIPAT/non-participants				
Food diversity unmatched	7.495	6.899	0.596	0.249
ATT	7.418	6.220	1.198	0.640
RIPAT-FMS/RIPAT				
Food diversity unmatched	7.455	7.557	−0.102	0.259
ATT	7.454	7.134	0.320	0.960

Note: ATT = average treatment effect on the treated; FMS = farmer market school; RIPAT = rural initiatives for participatory agricultural transformation.

intervention, and farming households involved in combined RIPAT-FMS intervention, respectively. Overall, matching estimates show that both the combined RIPAT–FMS and RIPAT-only interventions have a positive but not robust effect on households' food security. The findings indicate that the combined RIPAT and FMS intervention improved households' food diversity by about 1.316 per day. This means that households that participated in combined RIPAT and FMS intervention ate one more food type compared to non-participants households. On the other hand, farming households that participated in RIPAT-only intervention had food diversity of about 1.19 more relative to non-participants households.

Comparing farming households that participated in combined RIPAT–FMS and RIPAT-only interventions, there is no sign of positive differences in food diversity score as both scored 7 out of 16 scale of food diversity score. This suggests that both programs have no causal influence on total food consumption when individuals are matched according to relevant socio-demographics, assets, and other covariates. Accordingly, in a population made up of low-income households and which is largely dependent on agriculture, if productivity is low, food intake based on both production and entitlement remains low too.

The respondents indicated that drought was the main cause of food insecurity in the households. Another possible reason for the lack of statistical significance in terms of the contribution of the interventions (combined RIPAT-FMS and RIPAT only) on food security is the fact that uptake of the introduced technologies and marketing techniques was not widespread among the participants. The low uptake of agricultural technologies has been reported by a number of scholars, including Teka and Lee (2020) and Andrew et al. (2019). Adoption of many seemingly beneficial technologies remains low (Ruzzante et al., 2021).

The results indicate that, across farmers enrolled in combined RIPAT–FMS intervention, those under RIPAT-only intervention, and non-participants, there is no statistically significant difference in levels of income and food diversity, albeit there is a positive difference which connotes a positive direction toward a significant impact. The depicted trend can be explained by the fact that an extended drought prevailed in the area during the 2021–2022 crop season. Also, adoption of the introduced agricultural technologies and marketing techniques was not widespread among the participants.

Although both single approach and combined approaches have not brought significant impact in terms of income and food security, the positive changes on the level of income and food diversity relative to non-participant farming households suggest that the introduced farming technologies and marketing techniques can cause significant impact in the long run. While this suggests the adoption of combined RIPAT and FMS in agricultural interventions aimed at improving smallholder farmers' income and food security, future efforts should have been beyond the demonstration plots/group training. This could include awareness of farmers to transfer knowledge and practices at their farms.

Study Limitations and Areas for Further Research

As this study used cross-sectional data, it is limited in terms of showing the time effect of participating in program on household income and food security. In addition, the extended drought that prevailed during the period 2021–2022 might have contributed to the impact of the interventions being insignificant. Future research is recommended for examining the impact using panel data.

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A Prototype Harvester For Chickpea Harvesting

Nohut İçin Bir Prototip Hasat Makinesi

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ABSTRACT

To meet the needs of Iranian farmers who grow rainfed chickpeas, a new harvester was developed and tested. The project began with a modified stripper harvester and continued with a new design. The main components of the machine, such as the platform, reel, chassis and power transmission system, were improved to enhance its work quality. The harvester, which is pulled by a tractor, uses a power take-off-powered reel with 6 bats and a diameter of 700 mm to hit the pods and detach them from the plants. The best results were achieved when the reel speed was 2.4 times the forward speed of 3 km/h. The harvester could cover 0.42 ha/h and collect 120 kg/h of pods with a working width of 1.4 m. The machine performed well in field trials, with low purchase and operation costs, acceptable efficiency and losses, and better outcomes than existing methods and machines for chickpea harvesting.

Keywords: Chickpea, design, harvester, harvesting losses, reliability, stripper header

ÖZ

İranlı çiftçilerin yağmurlama sistemlerinde nohut yetiştirmeleri ihtiyaçlarını karşılamak amacıyla yeni bir hasat makinesi geliştirilmiş ve test edilmiştir. Proje, modifiye edilmiş bir şerit hasat makinesi ile başlamış ve yeni bir tasarım ile devam etmiştir. Platform, makara, şasi ve güç iletim sistemi gibi makinenin ana bileşenleri, çalışma kalitesini artırmak için iyileştirilmiştir. Traktör tarafından çekilen hasat makinesi, nohudu bitkilerden ayırmak için 6 sopaya sahip, çapı 700 mm olan bir güç alımıyla çalışan makarayı kullanmaktadır. En iyi sonuçlar, makara hızının 3 km/s hızındaki ileri hareket hızının 2.4 katı olduğunda elde edilmiştir. Hasat makinesi, 1.4 m çalışma genişliği ile saatte 0.42 ha alanı kapsayabilir ve saatte 120 kg nohudu toplayabilir. Makine, düşük satın alma ve işletme maliyetleri, kabul edilebilir verimlilik ve kayıplar, nohut hasatı için mevcut yöntemler ve makinelerden daha iyi sonuçlar elde etmiştir.

Anahtar Kelimeler: Nohut, tasarım, hasat makinesi, hasat kayıpları, güvenilirlik, şerit hasat başlığı

Introduction

Rainfed chickpeas (Cicer arietinum L.) are grown in fallow fields of developing countries and harvested by hand. But in recent years, labor costs have risen due to smaller families and rural youth migration. This has led some farmers to abandon their fields or crops. Using conventional grain combine harvesters for chickpeas is not feasible (Bansal & Sakr, 1992; Haffar et al., 1991; Sidahmed & Jaber, 2004) because of high grain losses. According to farmers and unofficial statistics, up to 50% of the yield can be lost by using combine harvesters. To reduce harvesting losses in pulse crops, plant movement during harvesting should be minimized and headers that follow the ground and capture low pods should be used (Siemens, 2006).

Detaching pods from the anchored plant without harvesting the straw was applied for reducing losses. Behroozi-Lar & Huang (2002) applied the Shelbourne Reynolds stripper header, which was developed at the Silsoe Research Institute, UK and commercially produced by the British manufacturer Shelbourne Reynolds Engineering Ltd., for chickpea harvesting. It uses the transverse rotor principles in which stripping of the crop takes place along the whole length of the rotor (Tado et al., 1998). The main disadvantage of the stripper headers is that they have excessive losses in low harvest yield and/or immature crops. Therefore, the application of the stripper header for chickpea harvesting was an unsuccessful attempt in compliance with losses.

This study was developed as part of Kaywan Mahmoodi's master thesis titled "Design, Development, and Evaluation of a Chickpea Harvester Header" presented at the University of Kurdistan.

Bu çalışma, Kaywan Mahmoodi'nin Kurdistan Üniversitesi'nde sunduğu "Design, Development, and Evaluation of a Chickpea Harvester Header" başlıklı yüksek lisans tezinden üretilmiştir.

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To reduce losses, pods were detached from the plant without harvesting the straw. Behroozi-Lar & Huang (2002) used a Shelbourne Reynolds stripper header for chickpea harvesting. This header was developed at the Silsoe Research Institute, UK, and produced by Shelbourne Reynolds Engineering Ltd. It strips the crop along the length of the rotor (Tado et al., 1998). The main drawback of the stripper headers is that they lose too much crop in low yield or immature conditions. So, using a stripper header for chickpea harvesting did not work well in terms of losses.

In 2006, Golpira (2015a,b) surveyed and published the crop properties of Reynolds number, terminal velocity, sphericity, dimensions, densities, mass, volume hardness, impact velocity, coefficient of friction, and drag force. Golpira et al. (2013) developed a tractor-pulled harvester with a modified stripper header for chickpea harvesting. The header had a platform with forward-opening fingers that stripped the plants as they moved through the V-shaped slots. The platform also supported passive fingers and delivered the harvested material. A reel with three bats and a diameter of 60 cm pushed the pods and the top of the chickpeas over the header. A chain and a sprocket system controlled the reel speed from 30 to 110 rpm. A conveyor with an endless chain collected the harvested material and lifted it to a sacker unit 1 m above the ground. The modified stripper harvester had drawbacks such as high weight, high losses, poor maneuverability, and low reliability.

Golpira (2013) tried to reduce the losses of the modified stripper harvester and made a new machine. The goals were to improve the machine performance and reliability by 1) using a pneumatic conveyor for more flexibility, 2) optimizing the platform to lower losses, and 3) using a three hitch point chassis for better maneuverability. The stripper header for chickpea harvesting had a platform 1.4 m wide with 27 V-shape teeth, a reel with 6 bats, a diameter of 700 mm, and a kinematic index of 1.8. The floating header, which followed the ground level, reduced the pods left on the plant, but the platform losses were still high. To avoid the high time and cost of conventional design, a soft simulator was developed for optimizing the platform structure. Fuzzy modeling and genetic algorithm were combined with the experience-based data to create a virtual model. The result was an optimized platform that was used on the harvester presented in this research. This automatically generated harvester was later published by Golpira and Golpira (2017).

Both the modified stripper harvester and the redesigned chickpea harvester work based on stripping technology, where fingers of a platform detach pods from plants and a reel delivers harvested material. Six years of modification and trial have exhibited no acceptable working quality in regards to the mass of pods collected from the ground and those remaining on the plant after harvest. Furthermore, the reliability of the machines was not sufficient to support commercialization of the methodology and mechanism. The designer's knowledge reveals that the reel would harvest pods with fewer losses than the platform. Additionally, the design of a new concept with 1) an off-set and a semi-mounted chassis and 2) a power take off (p.t.o.)-powered reel is a feasible strategy for increasing reliability and reducing losses. These improvements enhance the methodology and mechanism applied in the chickpea harvesters for increasing harvesting performance.

This research developed and tested a tractor-pulled harvester for rainfed chickpea pods. The machine's reliability and losses were enhanced over 3 years of modification and field trials. Checking the purchase price and fixed costs of the concept can help to market the prototype.

Methods

Header Design

The harvesting works by a reel that hits the plants to take off the pods and toss them into a collection container (Figure 1). The platform with passive fingers and V-shaped slots holds and guides the plants for harvesting. Tire wheels make the platform move gently and lower shattering losses. The reel, with six bats and a diameter of 700 mm, removes pods from the plants. A key condition for reel performance is that the ratio of peripheral forward speed must be higher than the unit. The reel speed is calculated by:

$$v = \frac{\pi D n}{60} \quad (1)$$

where

v: tangential speed of reel (m/s)

n: reel speed (rpm)

D: reel diameter (m)

According to Eq. [1], the reel forward speed is 2.1 m/s (7.2 km/h) for the reel diameter of 0.7 m and a reel speed of 55 rpm.

Kinematic index of the reel can be calculated as follows:

$$\lambda = \frac{v}{V} \quad (2)$$

where

V: forward speed of harvester (m/s)

λ: kinematic index (dimensionless)

According to Eq. [2], the kinematic index of the reel is 2.4 for the forward speed of 3 km/h and the reel speed of 7.2 km/h

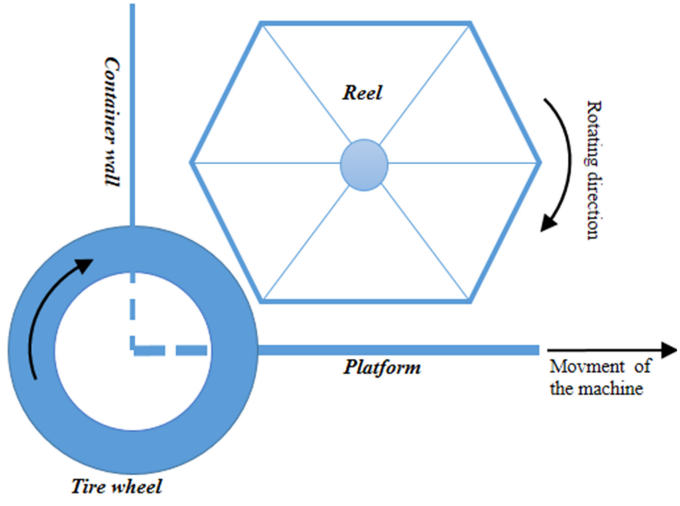

Figure 1.
Schematic drawing of the machine including main components and arrows indicating the movement of the machine and the reel.

Chickpea Harvester

The harvester for chickpea pods was tractor-pulled and had a semi-mounted and off-set chassis (Figure 2). It had a platform, a reel, a power transmission system, and tire wheels. A variable transmission system with a gearbox, a pulley, and a belt gave different reel speeds and kinematic indexes. The p.t.o.-power was transferred to the reel shaft. Two tire wheels with adjustable screws set the platform height from 0 to 150 mm. The platform angle was adjusted by semi-mounted linkage to avoid soil entry. The machine was 2500 mm wide and 1400 mm wide for working. It weighed 350 kg. The machine characteristics such as reel and platform sizes, gearbox and pulley system drive ratio were provided in Table 1. The laborer manually removed the harvested pods from the collection container. A pneumatic conveyor was made for material handling, but it was not on the machine in this design stage. This made the machine light and maneuverable to lower harvesting losses.

Machine Evaluation

The concept evaluation had two experiments. The first trial modified and adjusted the machine and tested its reliability. The final evaluation measured the harvesting losses with different reel kinematic indexes. The goal was to improve the machine's harvesting performance with modifications and adjustments. The first experiment was done in two sites of Dooshan farm of the University of Kurdistan in the summers of 2013 and 2014. Before the experiments, the working height was set at 5 cm (above the ground) to lower losses and soil entry (Table 2). Two adjustable screws fixed the vertical and horizontal distance between the reel bats and fingers at 1 cm so that the platform with passive fingers was not stuck by the stems and weeds. The platform angle was zero degrees. Also, the harvester ran at an average forward speed of 3 km/h for all the experiments.

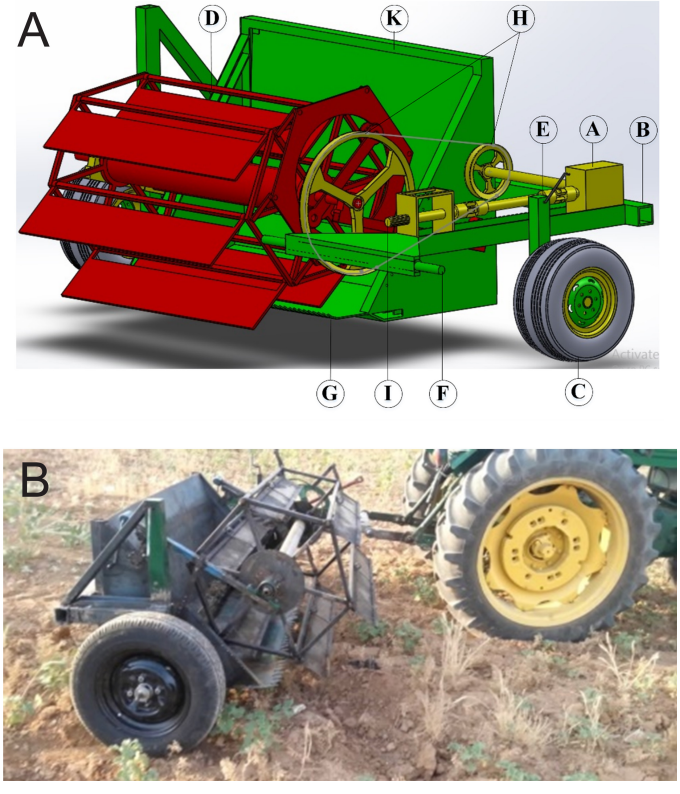

Figure 2.
A) Three-dimensional model of the prototype harvester: A, gearbox; B, chassis; C, ground-wheel; D, reel; E, adjustable screw; F, semi-mounted linkage; G, platform; H, driver and driven pulleys. B) Prototype harvester in the working position.

Table 1.
Key Variables of the Chickpea Harvester

Variable	Default Value
Reel	
Length (mm)	1400
Diameter (mm)	700
Number of bats on reel (dimensionless)	6
Gear box ratio	1 : 1
Pulleys ratio	1 : 3
Platform	
Length (mm)	600
Width (mm)	1400
Thickness (mm)	6
Chickpea harvester	
Weight (kg)	360
Working width (mm)	1300
Machine length (mm)	1300
Total width (mm)	2500

A designer wants to know how reliable a product is when it is new. This depends on its design and how it is made (Cruse, 1997). For a concept like the machine in this research, the concept of reliability was used for evaluation. Reliability is important for commercial or prototype machines. The concept of reliability evaluation is based on the designer's sense of hearing noises, seeing operation, and feeling vibration. The driver (designer) stopped the tractor when he felt he needed to check the machine. He checked, adjusted, and fixed the belts, the transmission shaft, and the pulleys during operation. These times were downtimes. The harvester ran for 50 m in the field and the time for crop harvesting was measured. The total time of operation was split into 1) theoretical time and 2) downtimes. The time for adjusting, repairing, attaching or detaching, and other downtimes in 50 m of rows were measured to find the concept reliability of the machine. The operational reliabilities were one minus the downtime probability in decimal form.

Harvesting Losses

The second experiment, field trial, tested the harvesting losses of the concept. Reel speeds of 45, 55, and 65 rpm, i.e., kinematic indexes of 2, 2.4, and 2.8 were used in the field. A fallow field of chickpea near Sanandaj was planted with a common chickpea variety, Kabuli. A hectare was plowed and disk-harrowed for

Table 2.
Operators of the Prototype Harvester

Value	Default Variables	Variable
3	3–6	Forward speed (km/h)
5	0–15	Working height (cm)
0	0–5	Platform attack angle (degree)
1	0–5	Horizontal distance (cm)
1	0–4	Vertical distance (cm)

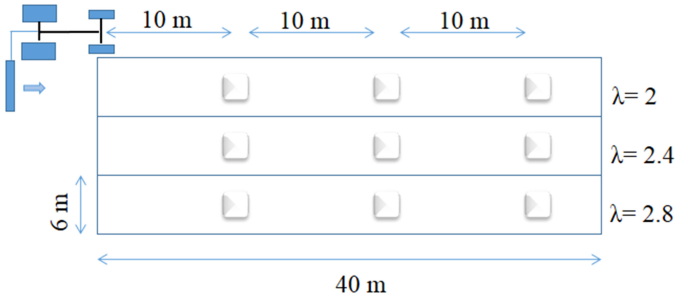

Figure 3.
Schematic drawing of experimental design and sample area for measuring harvesting losses.

chickpeas. An area of 40 m × 18 m was chosen for trials. The area was split into three blocks of 6 m width, with three plots in each block (Figure 3). Each plot was a square of 70 cm side for measuring losses. Before harvesting, sample frames were placed on the ground. Pre-harvest losses were measured and recorded by collecting the seeds and pods on the ground from the samples. Before harvesting, pods on the plants in the sample areas were measured to find total losses. Grains were separated from other material by a traditional threshing and cleaning method where tractor wheels pressed material on asphalt and then wind cleaned it manually.

The harvester ran, and total losses were measured after harvesting. Pods left on the plants and those scattered on the ground in the sample area were collected (Table 3). Losses include the pods that the header shattered (L_S) and those that stayed on the plant (L_P) calculated by this equation:

$$L = \frac{L_p + L_s}{L_p + L_s + H_p} \times 100 \quad (3)$$

where *Hp* is the number of harvested pods, L_s is the number of pods on the ground, and L_p is the number of pods on the plant after harvesting.

Cost and time limits and the dry year in the study area were the challenges for the evaluation. These factors limited the replication and losses data, but it was the only way to test. All the loss experiments were done as factorial based on a completely randomized design in three replications. The blocks had the same condition, so their effect was ignored. The data were analyzed with variance analysis to find the losses. The means of the treatments were compared with Duncan's multiple range tests at a 5% level for the losses.

Results

Operational reliability is the chance that a machine will work well under certain conditions at any time (ASAE, 2000). The simple structure of the chickpea harvester helps to achieve reliability. The reliability of many components is the product of the individual chances. Based on the theoretical and actual times calculated and measured, the machine reliability was 66% (Table 4). With a forward speed of 3 km/h, the machine travels 50 m in 60 seconds, which is the theoretical time. The reliability of the machine can affect field capacity in two ways: 1) raising the average forward speed of the tractor, 2) increasing field efficiency by reducing machine breakage and downtimes.

Table 3.
Data Showing Losses for Different Reel Kinematic Indexes

Reel Kinematic Index	Shattering Losses (%)	Remained Pods on Anchored Plant (%)	Total Losses (Remained +Shattered) (%)
2	13	8	23
	15	5	
	17	11	
2.4	14	3	20
	15	6	
	16	6	
2.8	25	4	35
	31	4	
	34	7	

Machine Performance

The analysis shows that pods left on the plant are not different for reel kinematic indexes of 2, 2.4, and 2.8. The bats' force is enough to take off pods from the plant and toss them to the container. But total and shattering losses are different for different reel kinematic indexes (Table 5).

The reel bats take off pods from the plants and also move pods and other material to lower pod-shattering on the ground. More kinematic indexes make the reel and pods move at a higher speed, which increase the chance of shooting harvested materials out of the container, leading to increased losses. Data show that the lowest losses were found when the reel index was 2 or 2.4. The lowest losses of 20% of the total yield were found for a kinematic index of 2.4, a forward speed of 3 km/h, and reel speed of 55 rpm. This loss shows the good performance of the concept

Table 5.
Data Showing Losses for Different Reel Indexes

SV	Df	Ss	Ms	Fs
Replication	2	450	225	25.95**
Error	6	52	8.67	
Total	8	502		

Table 4.
Comparing Reliability of the Fabricated Chickpea Harvesters

Factors / Machine	Theoretical Time (s)	Actual Time (s)	Downtime Probability (Decimal)	Reliability (Decimal)	Reliability (%)
Prototype harvester	60	90	$0.33 = \frac{90-60}{90}$	1–0.33 = 0.66	66

Table 6.
Physical Properties of Chickpea (Kabuli) During Harvesting

Crop Properties	Mean Values	Range	SD
Plant height (m)	22	15–30	0.5
Moisture content (% w.b.)	15	10.5–17	1.5
Number of pods (per plant)	7	2–16	2
Number of bushes (per m^2)	4	0–5	1

in terms of both the pods on plants and shattering losses. This reel speed is suitable for plants' distance of 15 cm in rows or more.

The plants in the study area are spaced more than 50 cm apart, which allows the forward speed to vary depending on the terrain and crop characteristics. The height of the anchored plant, which influences the losses, ranged from 12 to 28 mm in the field (see Table 6). The total yield was 300 kg/ha, which is normal for this region.

Economic Aspects

The design would focus on economic factors, such as field capacity, ownership cost, and purchase price, rather than technical ones. The work rate was 0.42 ha/h, calculated by: for a forward speed of 3 km/h and a working width of 1.4 m (Eq 4).

$$3\left(\frac{km}{h}\right)\times 1.4(m)\times 1000\left(\frac{m}{km}\right)\div 10000\left(\frac{m^2}{ha}\right)=0.42\left(\frac{ha}{h}\right) \quad (4)$$

The harvester has an actual field capacity of 0.25 ha/h, assuming a field efficiency of 60%. This is 16.6 times faster than manual harvesting by a worker. The machine can harvest 150 hectares in a year, working for 10 hours a day, 30 days a month, and 2 months a year, based on Eq. 5.

$$0.25\left(\frac{ha}{h}\right)\times 10\left(\frac{h}{day}\right)\times 30\left(\frac{day}{month}\right)\times 2\left(\frac{month}{year}\right)=150\left(\frac{ha}{year}\right) \quad (5)$$

The equipment costs $2000, which will be recovered over the harvester's economic life (10 years). The depreciation cost of the machine was calculated using a straight-line method and ignoring the salvage value, since the machine is simple and light. The depreciation cost of the machine is 1.33 $/ha, according to Eq. 6.

$$200\left(\frac{\$}{year}\right)\div 150\left(\frac{ha}{year}\right)=1.33\left(\frac{\$}{ha}\right) \quad (6)$$

The cost of shelter, insurance, and taxes is about 2.5% of the machine's original price (Hunt, 2001). This is 50 $/year or 0.3 $/ha. The real interest rate is 3.5%, based on a 14% inflation rate and an 18% investment rate. The interest cost of the machine is 70 $ per year or 0.46 $/ha, as shown in Eq. (7).

Table 7.
Total Costs of the Machine

Cost Type	Value ($/ha)
Repair and maintenance	1.6
Depreciation	1.33
Interest	0.3
Shelter, taxes, and insurance	0.46
Tractor cost	3.57
Total cost	7.26

$$2000\left(\frac{\$}{year}\right)\times 0.035=70\left(\frac{\$}{year}\right) \quad (7)$$

The R & M cost of the concept is 0.4 $/h or 1.6 $/ha, based on the average purchase price for harvesters 0.02% (Hunt, 2001). The total machine cost is 7.26 $/ha (see Table 7), which includes 15 $/day or 3.57 $/ha for a rented tractor (with operator and fuel costs). The cost of collecting the crop from the field by laborers is not included.

The concept has some important features, such as acceptable field capacity, losses, and reliability (Table 8). The equipment is affordable and cost-effective for the target area. The header can adapt to the ground unevenness and harvest low plants, which improves the mechanization of chickpea harvesting. The new method and machine for chickpea harvesting are efficient, with good maneuverability, low operating costs, a reasonable purchase price, and a work rate of 0.42 ha/h.

Discussion

Mennad et al. (2017) examined the effect of weather conditions, varieties, and harvesting modes on the yield of lentil in Algeria. It shows that the rainfall distribution was unfavorable for crop development, but the temperature was suitable. The varieties differed in their height, maturity, and adaptability to mechanical harvesting. The mechanical harvesting caused more loss than manual harvesting, especially for short and early varieties. The Metropole variety was the most suitable for mechanical harvesting, while the Syrie 229 variety had the highest yield in manual harvesting. The overall yield and production potential of lentil were low in both campaigns. They concluded that 1) the current varieties and harvesting methods are not encouraging for lentil cultivation, 2) there is a need to design a new mechanical harvesting method or to improve the varieties through genetic methods, and 3) the focus should be on creating rigid and uniform varieties that can resist pod shattering and adapt to mechanized harvesting. Therefore, there is a mutual interest between the findings of the recent paper and the results of the current research, where it emphasizes that the total harvesting loss is more than that for the manually harvested condition, and

Table 8.
Performance Factors of the Fabricated Chickpea Harvester Compared to Those in Manual and Mechanized Harvesting

Performance Harvesting System (Year)	Field Capacity (ha/h)	Reliability (%)	Losses (%)	Purchase Price ($)	Cost ($/ha)
Chickpea harvester	0.42	66	20–28	2000	7.26
Manually harvesting*	0.015	-	≤5	-	80

*Addressed by Golpira (2015).

shortfall and plant circumstances have affected the machine's ability.

Gharakhani et al. (2017) optimized a harvester for lentil plants where they tested three factors: forward speed, blades speed, and carousel speed. They found that forward speed was the most important factor and suggested the best settings for the harvester. They also compared the new cutter-bar of the harvester with a conventional one on different farms and found that the new one was more durable. However, they have not specified quantitative results regarding the actual harvesting losses. Tang et al. (2017) designed and tested a multi-functional rice combine harvester that can harvest grain and bale straw. This harvester could reduce environmental pollution, energy consumption, and labor cost. The study determined the optimal parameters and speeds for the threshing cylinder and the baler. The study also conducted field trials and measured the size, mass, and density of the straw bales. The harvester could be used for other stem crops as well. Modather et al. (2018) presented a paper that compares two types of combine harvesters for rice in Malaysia. It uses field and literature data to show that the mid-size harvester had better quality, less loss, and more suitability than the conventional harvester, which was imported and designed for wheat. It suggests that new harvesting methods or improved varieties are needed for rice cultivation in Malaysia, confirming the scope of this research, which is conducted to develop a specified harvester for chickpea based on the crop's requirements.

Another study tested the pod shattering resistance and the harvest delay limit in soybean where 16 soybean genotypes were planted and simulated the harvest delay on pots. They measured the pod shattering and seed dispersal on different nodes of the stem. The findings reveal that the lower nodes had more pods and more shattering than the upper nodes. They also classified the genotypes into five categories based on their resistance and suggested that resistant genotypes could be harvested 20 days after maturity, while susceptible genotypes should be harvested within three days (Krisnawati et al., 2022).

Wang et al. (2021) presented a review paper on the mechanized harvesting of rapeseed, which is very similar to chickpea in terms of its harvesting problems. They summarize the previous research on the structure, vibration, and control of the header, and suggest some future directions for improvement, such as 1) designing different types of vertical cutters to reduce vibration, cost, and weight, 2) improving the follow-up control of the vertical cutter to keep it perpendicular to the ground, 3) analyzing the overall vibration of the header and optimizing the configuration of its components, 4) studying the cutting characteristics of entwined branches of rapeseed and designing better cutters and reels, 5) combining agricultural machinery and agronomy to adjust the planting pattern of rapeseed and avoid pod burst loss. Their listed proposed key points and some other concerns, like economical concerns and average accessible power, encouraged the authors to conduct the current research.

Conclusion

This research presents a new concept of a harvester for chickpea pods. The paper describes the design and evaluation of the harvester, which is tractor-pulled and has a platform, a reel, a power transmission system, and tire wheels. The paper aims to improve the harvesting quality and efficiency of chickpea, which is a sensitive and important crop in developing countries. The paper reports the following findings: 1) the harvester has a reliability of 66%, which is acceptable for a concept machine and can be improved by reducing downtimes and increasing forward speed. 2) The harvester has a field capacity of 0.42 ha/h, which is 16.6 times faster than manual harvesting and can harvest 150 hectares in a year. 3) The harvester has a total loss of 20% of the yield, which is good for a concept machine and can be achieved by adjusting the reel kinematic index to 2.4, the forward speed to 3 km/h, and the reel speed to 55 rpm. 4) The harvester produces cleaner and healthier grain compared to the case where it is harvested by labor, which is important for the market and the consumers. 5) The harvester has a low operating cost of 7.26 $/ha, which includes the cost of depreciation, shelter, insurance, taxes, interest, repair and maintenance, and tractor rental. The paper concludes that the new concept of the chickpea harvester is efficient, cost-effective, and suitable for the target area. The paper suggests that the concept can be further improved by designing a pneumatic conveyor for material handling, modifying the reel to avoid pod shattering, and searching for new varieties that are better adapted to mechanical harvesting. The paper also acknowledges the limitations of the study, such as the low number of replications, the dry year in the study area, and the exclusion of labor costs for collecting the crop from the field.

The study concludes the following:

1) There is a need for more research and innovation on the mechanization of chickpea harvesting, as it can increase the yield and production potential of chickpeas.
2) The focus should be on creating harvesters that can adapt to the ground unevenness, harvest low plants, avoid pod shattering, and produce cleaner and healthier grain.
3) The harvesters should also be compatible with the crop characteristics, such as the height, maturity, and shattering resistance of chickpea varieties.

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