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Review

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SALICORNIA AS A SALT-TOLERANT CROP: POTENTIAL FOR ADDRESSING CLIMATE CHANGE CHALLENGES AND SUSTAINABLE AGRICULTURE DEVELOPMENT

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A B S T R A C T

Halophyte plant Salicornia has potential uses in farming and environmental management. Salicornia is one of the most important families of halophytes and known for its exceptional salt tolerance. It thrives well in saline habitats near coastal areas. A comprehensive review paper provides an overview of Salicornia, including details on the impact of temperature and salinity on the germination of different ecotypes, as well as the influence of day length and salinity on seedling establishment. *Salicornia* L. presents a promising opportunity for sustainable agriculture and economic development as it may improve the lives and livelihoods of underprivileged groups while also benefiting the environment through carbon sequestration, soil preservation, and biodiversity preservation.

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1. Introduction

Salicornia is a type of perennial herbaceous halophyte that belongs to amaranthaceae, that also comprises over 175 genera and 2000 species of herbs, shrubs, sub-shrubs, and small trees (Mroczek, 2015). Cárdenas-Pérez et al. (2021) have identified 64 species of *Salicornia*, with the most common being *S. brachiata, S. arabica, S. europaea, S. fruticosa L., S. ramosissima, S. herbacea*, and *S. bigelvolii*. The word "*Salicornia*" is inspired by the Latin words "sal" meaning "salt" and "cornu" meaning "a horn" due to being a saline vegetation with spiked tendrils (Ekanayake et al., 2023). Singh et al. (2014) state that *Salicornia* typically develops to a length of 25 to 35 cm and has moist, flexible scaly foliage and horn-like terminal plantlets. Salicornia reproduces naturally through seeds, but excessive saline conditions can impede seed germination since osmotic pressure has impacts on sprouting (Song et al., 2008). Rathore et al. (2019) divide the lifecycle of Salicornia into six phases: seed dissemination, root initiation, juvenile stage, exponential vegetative phase, blooming, and ripening stage, and aging phase. In autumn, the green plants become orange, pink, or crimson before decaying in the winter (Patel, 2016). Salicornia is predominantly reported in salt marshlands, ponds, or waterways that are favorable to its proliferation (Khan et al., 2014). As a halophyte, Salicornia could indeed endure a significant level of as high as 1000 mm NaCl or perhaps more (Volkov, 2015). Wang et al. (2009) suggest that Salicornia's saline adaptation technique has been reliant on restricting vesicles to ensure stable intracellular turgidity and diminishing the lethality of Sodium ions in the cytoskeleton. The above-mentioned trait assists the plants in colonizing down the tidal gradient, which is crucial to the preservation of genera zones in salt marshlands, indicating that Salicornia is suitable globally for the restoration of salinized ecosystems in dry and semi-arid regions (Ozturk et al., 2018). Mohammadi and Kardan (2015) explain that Salicornia has several adaptive responses which preserve it in higher salinity ecosystems, including constrained osmoregulation, ion compartmentalization, restricted photosynthesis, biosynthetic pathway of osmolytes and antioxidants, plant hormone induction and regulation, as well as antioxidant and enzyme production and activation.

Salicornia is a highly promising cultivar with ability as a substitute fodder for either livestock or human sustenance supply. It is often referred to as a "secondary vegetable," "famine sustenance," and "future plant." Salicornia species are valued as oil-seed commodities, as the oil retrieved from their seeds contains high quantities of beneficial polyunsaturated fats like linoleic and oleic acids (Loconsole et al., 2019). In addition, these plants can produce significant quantities of biomass rich in lignocelluloses that can be used to produce bioethanol (Ali et al., 2021). Salicornia plays a vital role in the environment by forming a buffer zone that protects coastal eroding caused by intense wave attack and helps to mitigate ecological pollutants (Gopi et al., 2019). Due to its exceptional salt tolerance, Salicornia has become a significant cash crop halophyte for seawater irrigation and can flourish in hypersaline conditions, making it a viable resource for cultivation in arid-desert locations with severe climatic conditions (Ozturk et al., 2018; Grattan et al., 2008). Researchers have additionally demonstrated that Salicornia is appropriate for re-greening coastal regions to enhance carbon storage and prevent soil loss (Gispert et al., 2021). *S. bigelovii*, a type of Salicornia, has been found to be effective in removing selenium from sediments and waterways, as well as inhibiting the development of the aquatic vegetation diatom *Skeletonema costatum*, which can help prevent eutrophication and hazardous algal blooms (Isca et al., 2014).

Salicornia species are renowned for being able to accrue and tolerate high concentrations of metals in their structures, making them suitable candidates for phytoremediation and for the establishment of novel crop species (Ventura et al., 2011a). World Bank established Climate-Smart Agriculture (CSA) as an integral model to resolve the intricate issues related to climatic crisis, nutrition reliability, as well as environmental sustainability (Group, 2016). CSA implementations seem to be perspective and focus on promoting the use of novel mechanized technology, including smart farming tools, automized assistance structure for water and soil monitoring, conservation and sustainably sourced agricultural strategies, comprehensive treatment of diseases and pests, and water stress, salt, and flood-tolerant crops (Campbell et al., 2014). Cultivating Salicornia species can, therefore, contribute to instilled global warming while also augmenting agricultural production and livelihood opportunities in salt-drought prone regions. However, the native saline ecosystems among those taxa are particularly vulnerable to temperature fluctuations, that is likely to result in longer, more severe, and more frequent drought periods, as well as increased soil salinity levels with high seasonal variability (Change, 2018).

This article provides a comprehensive overview of Salicornia, including its characteristics, adaptations, ecological significance, the investigation of its salt adaptation mechanisms, and the assessment of its potential as a climate-smart crop.

2. Role of Salicornia as a salt-tolerant crop against salinization

Salinization, or the rise in saline content throughout the environment, poses a major liability to industrial agriculture in many regions of the world, leading to the degradation of arable lands at an alarming rate (Ekanayake et al., 2023). Saline deposition caused by saltwater intrusion in coastline groundwater sources may worsen due to climate change, leading to limited soil fertility and agricultural output (Calone et al., 2022). Several factors, such as protracted droughts, elevated evaporation , inadequate drainage or waterlogging, extensive usage agrochemicals, as well as watering with saline water, have been contributing to the soil salinity of agricultural fields (Alfio et al., 2020). The current tempo of soil salinization is projected to salinize 50% of cultivated and irrigated fields by 2050, with present estimates of salinized agricultural areas being 20% and 33%, respectively (Machado and Serralheiro, 2017). When exposed to saline environments, plants experience eutrophication, osmotic instability, and peroxidation, resulting in reduced plant development and substantial reductions in agricultural production (Safdar et al., 2019).

The detrimental consequences of salt-induced soil degradation were estimated to cause global yearly crop losses of USD 27.3 billion, highlighting the magnitude of salinization's impact (Qadir et al., 2014). One solution to revive yield is to cultivate salt-tolerant plants on salinized soil. Identifying plants naturally adapted to high salinity and implementing mass cultivation will provide a pragmatic and effective solution (Debez et al., 2011). Halophytes, or inherently salt-tolerant species which can complete their developmental stages in salinity conditions, always had the highest potentiality to transform in to other crops in saline lands (Yuan et al., 2019; Gunning, 2016). Salicornia constitutes to the significant taxonomic groups of halophytes in existence today and therefore is regarded one of supreme halophiles crop, thriving in saline environments close to coastlines in numerous continents, traditionally acknowledged as a source of food (Patel, 2016; Mishra and Tanna, 2017). Halophytes have anatomical and morphological adaptations that enable their survival in saline environments, including the existence of salt ducts, salt bladders, and moist plant matter (Rozentsvet et al., 2017). Salicornia's adaptability to salt-affected lands enables it to convert unproductive soil into fertile land (Muscolo et al., 2014). Moreover, these species are alluring for the bioremediation of soil with high saline and metal toxicity, because of their significant vegetative generation and phytoextraction capacity (Caparrós et al., 2022). The Mediterranean basin is one of the regions most endangered by salinization due to climate change (Cuttelod et al., 2009). Therefore, a proactive approach, including crop diversification, crop rotation, soil conservation, improved irrigation practices, and the use of alternative water sources, is essential to prevent salinization and maintain food security.

3. Potential of Salicornia genus in addressing climate change challenges

Salicornia L. species, also widely recognized as samphire or sea asparagus, seems to be a group of halophytic plants that are well-suited to thrive in saline conditions including coastlines and mudflats (De Souza et al., 2018). These plants have attracted interest because of their prospective application as a staple food, biomass, and in bioremediation of soil salinity (Ventura and Sagi, 2013). Salicornia genus seems to be a group of succulents, halophytic plants that are commonly referred to as glassworts or samphires and belong to the Amaranthaceae family (Gouda and Elsebaie, 2016). They are extensively distributed in coastal areas, with approximately 30 species, which include *S. bigelovii, S. virginica*, and *S. europaea* being the most common (Cárdenas-Pérez et al., 2021). These plants have adapted to saline environments and have fleshy, cylindrical leaves and stems with reduced or absent leaves. Climate change, predominantly caused by human behaviors like clearing forests and consuming petroleum products, leads to a long-term shift in global weather patterns and the Earth's climate system (Fawzy et al., 2020). These activities contribute to increased levels of GHGs in the ecology, including the gases CO_2 and CH_4, that further absorb radiation and induce the warmth of the planet's surface causing directly to global warming (Turyasingura and Chavula, 2022). Climate change has far-reaching effects, along with more frequently occurring bushfires, desertification, but instead catastrophic

storms including flooding and storms (Turyasingura et al., 2022; Turyasingura, Ayiga, et al., 2022).

The melting of ice sheets and thermal expansion of seawater also cause rising sea levels, posing a hazard to low-lying areas and coastal cities globally. Global warming does indeed have substantial effects on ecosystems, agriculture, human health, and economies (Benzougagh et al., 2023). Reducing greenhouse gas emissions is crucial in mitigating climate change, which may be achieved through activities including switching to sources of clean energy, enhancing fuel consumption, and adopting sustainable practices for land use (Turyasingura and Chavula, 2022). Adapting toward the unavoidable consequences of global warming also involves actions such as strengthening infrastructure (Turyasingura et al., 2023), enhancing resilience, and implementing measures to safeguard vulnerable communities and ecosystems. The need to address climate change is urgent and requires global cooperation and concerted efforts from all sectors of society (Turyasingura, 2022). Salicornia species are an important source of food for many coastal animals, such as waterfowl, shorebirds, and certain fish species (Zedler, 1996). They are also used by humans as a food source and have a long history of culinary use in coastal regions around the world. In addition, Salicornia species have been used for medicinal purposes in traditional medicine, and there is growing interest in their potential as a source of biofuel and as a crop for cultivation in saline soils (Urbano et al., 2017). With the increasing concern over climate change and its impacts on agriculture and food security, Salicornia has been studied for its potential to grow in saline soils and seawater, which could expand the agricultural land base and reduce the pressure on freshwater resources. Additionally, Salicornia has been shown to have a high capacity for carbon sequestration, making it a potential tool for mitigating climate change (Benson and Ayiga, 2022). Salicornia has been found to be adaptable to a variety of environments, such as arid and semi-arid regions, and can be cultivated using minimal resources, including water, fertilizer, and pesticides, according to studies. It is also capable of producing substantial quantities of biomass, which could be employed to make biofuels and other goods. As a consequence, Salicornia may be beneficial in addressing the challenges presented by climate change, especially in areas under which natural ground water are minimal, and land degradation and desertification are prevalent. Nonetheless, further study is required to ascertain the ideal growing circumstances for such plant and the potential ecological consequences of its cultivation on coastal ecosystems.

4. Temperature and salinity effects on germination of Salicornia ecotypes

For many years, scientists have examined the impact of salinity and temperature on the development of various ecotypes of the Salicornia genus. Salicornia is recognized for its capability to withstand high levels of salinity, which is largely determined by differences in its genetics and the environment where it develops (Alfheeaid et al., 2022). Araus et al. (2021) notes that different ecotypes of Salicornia have varying degrees of tolerance to temperature and salinity stress. For instance, some ecotypes have been found to germinate more efficiently at high temperatures and salinity levels, while others perform better under cooler and less saline conditions. In general, Salicornia seeds require a minimum temperature of around 10-15°C to germinate, with optimal germination occurring at temperatures of 20-25°C. However, some ecotypes have been found to tolerate higher temperatures of up to 35°C or more. Salicornia seeds also require a certain level of salinity to germinate, with optimal germination occurring at salinity levels of 50-150 mM NaCl. Different ecotypes have been found to have varying degrees of salt tolerance, with some able to germinate and grow well in salinities of up to 600 mM NaCl or higher. However, excessively high salinity levels can be detrimental to seed germination and plant growth (Turyasingura et al., 2023), even for highly salt-tolerant ecotypes (Table 1). Overall, the response of various ecotypes of Salicornia to temperature and salinity stress is complicated and relies on a multitude of variables, such as genetic variation, environmental conditions, and the extent and duration of stress. Even farther study is required in order to properly comprehend the processes beneath such responses but also to devise strategies for improving the functioning of Salicornia under various ecological circumstances (Ventura et al., 2011b).

5. Influence of day length and salinity on seedling establishment

Day length and salinity seem to be two vital external variable that can reasonably influence the establishment and growth of seedlings.

Day length, also known as photoperiod, is the amount of time each day that a plant is exposed to light. It has a direct impact on the physiological processes of a plant, including the initiation of flowering, stem elongation, and leaf development. The optimal day length for seedling establishment can vary depending on the plant species. For example, some plants may require long days to initiate flowering, while others may require short days. However, for most plants, a day length of 12-16 hours is optimal for seedling establishment (Rajabi Dehnavi et al., 2020). Salinity is the measure of salt content of soil or water, which can negatively impact the development and growth of vegetation by producing osmotic stress and ion toxicity. While plant species exhibit differing degrees of tolerance to salinity, seedlings are typically more susceptible than fully matured plants. The impact that salinity has just on development of seedlings can depend on their stage of development and how long they are subjected to saltwater (Cao et al., 2018). The interaction between salinity and day length also has an important impact in germination and seedling. For example, some plants may be better adapted to seedling establishment in high salinity environments when day length is shorter, while other plants may require longer days and lower salinity levels for optimal growth. Understanding these interactions can help in the selection of appropriate plant species and management practices for successful seedling establishment in different environments.

Table 1. Growth rates of Salicornia under different salinity and temperature levels

S.N.	Growth conditions	Levels	Salicornia growth rate (cm/day)	Reference
1	Control	No salt	1.5	Amiri et al. (2010)
2	Moderate salinity	50 mM NaCl	0.9	Aghaleh et al. (2009)
3	High salinity	100 mM NaCl	0.5	Amiri et al. (2010)
4	High salinity	200 mM NaCl	0.2	Aghaleh et al. (2011)
5	Low temperature	10°C	0.7	Khan et al. (2000)
6	High temperature	40°C	0.8	Ayala et al. (1995)

Table 2. Nutrient content of Salicornia compared to other crops

S.N.	Crop	Protein (%)	Fat (%)	Fiber (%)	Minerals (mg/100 g)	Vitamins (mg/100 g)	References
1	Salicornia	22.3	3.7	32.4	1294	2.4	Castagna et al. (2022); Glenn et al. (1991); Choi et al. (2014)
2	Spinach	2.9	0.4	2.2	558	1.6	USDA, 2019
3	Broccoli	2.8	0.4	2.6	316	0.8	USDA, 2019
4	Kale	2.9	0.9	3.6	447	1.2	USDA, 2019
5	Carrots	0.9	0.2	2.8	33	0.7	USDA, 2019
6	Sweet potatoes	1.6	0.1	3.0	337	2.4	USDA, 2019

6. Opportunities and challenges of *Salicornia* L. for sustainable agriculture and development

A promising plant called *Salicornia* L. may be able to help with a number of sustainability issues in Sub-Saharan Africa and beyond. To combat food insecurity and malnutrition, it might offer a source of locally produced, nutrient-dense food (Table 2) (Martinez-Garcia, 2010; Cárdenas-Pérez et al., 2021), as well as a sustainable supply of biofuels and other renewable energy sources to help combat climate change and increase access to energy (Sharma et al., 2016; Makkawi et al., 2021).

Table 3. Production, economic status, and challenges of scaling up Salicornia farming

S.N.	Topic	Data					References
		USA	China	Spain	Iran	Australia	
1	Land use for Salicornia cultivation	1000 ha	500 ha	200 ha	5 ha	20 ha	Rey et al. (1990); Ventura and Sagi (2013); Holguin et al. (2021)
2	Yields of Salicornia farming	2-3 tons/ha	1.5-2 tons/ha	0.5-1 tons/ha	2.7 tons/ha	2.2 tons/ha	Rey et al. (1990); Holguin et al. (2021); Ventura and Sagi (2013)
3	Profit margins of Salicornia farming	2000-3000 $/ha	1500-2000 $/ha	500-1000 $/ha	2700 $/ha	2500 $/ha	Rey et al. (1990); Holguin et al. (2021); Ventura and Sagi (2013)
4	Challenges in scaling up Salicornia cultivation	Lack of infrastructure, Limited access to financing, Uncertain market demand, Drought stress, Salinity stress, High production costs					Ventura and Sagi (2013); Ganesan et al. (2019)
5	Potential benefits of Salicornia cultivation	High adaptability to salt-affected soils, Ability to sequester carbon, Potential as a food or feed crop					Cárdenas-Pérez et al. (2021); Negacz et al. (2021)

Salicornia L. might also be produced on marginal and degraded areas to support ecosystem services and land restoration (Wratten et al., 2013; Parida, 2005), as well as providing a new source of export income to diversify economies and lessen reliance on exports of conventional commodities (Glenn et al., 1999; Ansari et al., 2016). Salicornia L. may also present opportunities for value addition and agro-processing, which could result in new employment opportunities and sources of income for smallholder farmers and business owners (Nigam, 2011) as well as new understandings and advancements in plant genetics, biotechnology, and sustainable agriculture (Turcious et al., 2017). Although research on Salicornia L. might result in new approaches and best practices for sustainable agriculture and development, partnerships and collaborations among many stakeholders could serve to stimulate investment and scale up production and distribution of Salicornia L. products, while also addressing the unique challenges faced by farmers in different countries (Table 3) (Aronson, 1985). Salicornia L. might provide a variety of advantages for sustainable development, including community-based natural resource management, ecotourism, climate-smart agriculture, and inclusive economic growth (Herbert et al., 2015; Hamed et al., 2021; Ventura and Sagi, 2013; Blore, 2015; Arif et al., 2020; Aziz et al., 2022).

Salicornia L. presents significant potential for sustainable agriculture and economic development, but there are several challenges that need to be addressed to realize this potential. These challenges include a lack of research and knowledge on the nutritional value and health benefits of Salicornia L. products, which could limit consumer demand (Patel, 2016; Costa et al., 2018). Additionally, there is a lack of policy support and incentives for promoting Salicornia L. as a sustainable crop, which could limit investment and adoption (Bailis and Yu, 2012; Aluwani, 2023). Ethical and social challenges related to land use, labor rights, and gender equity could affect the sustainability and social impact of Salicornia L. production and marketing (Sani et al., 2012; Collinson et al., 2022). Furthermore, the lack of infrastructure and technology for efficient and sustainable Salicornia L. cultivation and processing, such as irrigation systems and drying facilities, presents a significant challenge (Chaturvedi et al., 2021; Joshi et al., 2020). Limited human capacity and technical expertise in Salicornia L. cultivation and value addition could also limit productivity and quality (Centofanti and Bañuelos, 2019; Cárdenas-Pérez et al., 2021). Other challenges include limited availability and accessibility of high-quality seeds, fertilizers, and other inputs (Gelfand et al., 2013), environmental factors such as soil salinity, water scarcity, and extreme temperatures that may affect crop productivity (Parida, 2005), competition with other crops and land-use practices that may be more based or profitable (Blanc, 2012),

limited access to credit, insurance, and other financial services for smallholder farmers and entrepreneurs involved in *Salicornia* L. cultivation and commercialization (Ahmadzai et al., 2021; Guerin and Guerin, 1994), lack of standardization and certification for *Salicornia* L. products, which could affect quality control and consumer confidence (Ventura and Sagi, 2013), limited market access and distribution networks for *Salicornia* L. products, especially in rural areas (Chaturvedi et al., 2021), potential negative environmental impacts of large-scale *Salicornia* L. cultivation, such as soil erosion, water depletion, and biodiversity loss (Hamed et al., 2021), and risk of market saturation and price volatility as *Salicornia* L. cultivation and commercialization expands (Ahmad et al., 2021). Addressing these challenges will require a collaborative, multi-stakeholder approach that engages different actors, including farmers, researchers, policymakers, and private sector players.

7. Conclusions and recommendations

Salicornia L. offers a bright prospect for sustainable agriculture and economic growth since it may support disadvantaged groups' lives and income while simultaneously providing advantages to the environment such carbon sequestration, soil preservation, and biodiversity preservation. Realizing this potential, however, would need resolving a number of issues, such as socioeconomic, institutional, and technological hurdles, as well as guaranteeing sustainability and fair benefit distribution. *Salicornia* L. cultivation and value addition need more study and development. Market access and distribution networks must also be supported, especially in rural regions, for *Salicornia* L. goods. For quality assurance and customer trust in *Salicornia* L. goods, standardization and certification are also crucial. To maintain the sustainability of *Salicornia* L. production and commercialization, it is also necessary to address possible adverse environmental effects such soil erosion and water depletion. In order to grow *Salicornia* L. as a sustainable crop, it is necessary to adopt a multi-stakeholder strategy that involves several parties, including farmers, researchers, legislators, and business representatives. Collaboration may result in the creation of novel approaches and industry-leading techniques for *Salicornia* L. cultivation and development that are sustainable for both people and the environment. Overall, *Salicornia* L. offers a great prospect for sustainable agriculture and economic growth; nevertheless, in order to fully realize this potential, it will be necessary to solve a number of issues and adopt a cooperative, multi-stakeholder approach. Thus, to maximize the benefits and minimize the risks of *Salicornia* L. cultivation and commercialization, the following recommendations are suggested:

1. For *Salicornia* L. goods, create and implement standards and certification programs to assure quality control and customer trust.

2. Improve distribution channels and market accessibility for Salicornia L. goods, especially in rural regions, to enable small-scale farmers to take use of the crop's potential.

3. Promote *Salicornia* L. cultivation and value addition research and development, notably in creating the infrastructure and technology for effective and sustainable production, as well as improving technical know-how and people ability.

4. Make sure that large-scale *Salicornia* L. initiatives are carried out in a way that respects the rights of local populations, prevents land grabbing and displacement, and is ethical and sustainable.

5. Help small-scale *Salicornia* L. growers by providing them with market access, financial backing, and technical support to help them compete with bigger players and reap the rewards of the crop's potential.

6. To optimize the crop's potential for sustainable development, encourage cross-sectoral collaboration and innovation that connect *Salicornia* L. farming with renewable energy, water management, and other areas.

By following these suggestions, *Salicornia* L. may evolve into a crucial crop for sustainable agriculture and development, assisting in, among other things, biodiversity preservation, poverty alleviation, and climate change mitigation.

Compliance with Ethical Standards

Conflict of Interest

As the author of article declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

Shambhu KATEL, **Shubh Pravat Singh YADAV**, **Benson TURYASINGURA** and **Aman MEHTA**: Each author made an equal contribution throughout all stages of manuscript preparation.

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We humbly give consent for this article to be published.

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UTILIZING LOCALLY ACCESSIBLE SUBSTRATE, TO MAXIMIZE OYSTER MUSHROOM (*Pleurotus ostreatus*) GROWTH AND BIOCONVERSION EFFICIENCY IN AMBO, CENTRAL ETHIOPIA

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A B S T R A C T

The effect of different locally available wastes as the substrates on oyster mushroom growth and bioconversion efficiency was investigated. *P. ostreatus* was grown on different substrates prepared from corn cob, sorghum stem, faba bean straw, pea straw, coffee husk, and sawdust alone (100%), and all with cottonseed waste in (1:1) ratio. Cottonseed waste alone was used as a control. Spawn run days, harvest days, average mushroom weight, fruiting body, cap diameter, stipe length, total yield, and biological efficiency were evaluated. All the quantitative data gathered were analyzed by SPSS statistical software for Windows version 25. Pea straw alone (T7) and pea straw:cotton seed waste (1:1) ratio (T8) with 15±2 and 15±3.1 days, had the shortest mycelia run, whereas sawdust alone (T11) took longer with 33±6.7 days for mycelia run. T7 had the shortest incubation to the first harvest 24±5.2 days, while T11 had the longest incubation to the first harvest 46±8.1 days. T11, 90±12 days, took the longest total production cycle, while T7, 63±6.6 days had the shortest total production cycle. T7 produced the greatest, number of fruiting bodies (254±48.5), whereas T11 produced the fewest fruiting bodies (20±5). The highest and lowest yield was obtained from the T7 substrate with 1614±17.1g and T11 substrate with 384±37.9g, respectively. The best substrate was found to be the T7; with mycelia run 15±2 days; incubation to 1st harvest 24±5.2 days, shortest production cycle 63±6.6 days, fruiting bodies 254±48.5, the highest total yield of 1614±17.1g and biological efficiency of 323±48.9%.

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1. Introduction

Mushrooms have a high protein, vitamin, and mineral content (Kimenju et al., 2009; Turfan et al., 2018). They are composed of 85-95% water, 3% protein, 4% carbohydrates, 0.1% lipids, and 1% minerals and vitamins (Palapala et al., 2006). It contains a high concentration of essential amino acids to near what the human body requires. Mushrooms are also easily digested and cholesterol-free (Oei, 2003). The bioactive substances extracted from medicinal mushrooms would help people's immune systems and improve their quality of life (Chang and Miles, 2004). The spent substrate left after mushroom harvesting, which is entangled with countless mushroom mycelia, can be used as animal feed (much more palatable), bio-fertilizer for soil fertility enrichment, and biogas (Alice and Kustudia, 2004). Besides, mushroom growing has been touted as a potential means of reducing poverty in underdeveloped nations due to its low production costs, large profit margins, and speedy returns (Masarirambi et al., 2011).

The oyster mushroom (*Pleurotus ostreatus*) is a tasty and flavorful edible mushroom. It has no starch, low sugar content, and a high amount of fiber, hence it serves as the least fattening food (Oei, 1996). It is the most widely cultivated mushroom species because it is easy to produce and grows well on a variety of agricultural by-products such as rice straw, sawdust, wheat straw, maize silk, sugarcane bagasse, and other cellulose-rich plant fibers (Pokhre et al., 2013); which shows *P. ostreatus* have good mycelial development with high saprophytic colonization potential (Nadir et al., 2016).

Ethiopia's economy is mostly based on agriculture, with crops accounting for a large portion of the country's output. Crop wastes are common as agricultural refuse after harvest. It is vital to dispose of agricultural waste in a green and environmentally friendly manner in this era of climate change. The utilization of organic material in mushroom production is an alternate way of using agricultural residues/wastes (Poppe, 1995). Despite Ethiopia's favorable climate, a relative abundance of land and manpower, and reasonably decent water resources, the cultivation, and use of mushrooms have been neglected in the past. As a result, the country has not reaped the benefits of mushrooms as the rest of the world has (Kiflemariam, 2008).

On the other hand, in Ethiopia, the most common substrate used for the production of *P. ostreatus* is cottonseed waste, which is both expensive and scarce (Abera et al., 2019). As a result, it's critical to develop a low-cost, high-quality mushroom fruiting body-stimulating substrate or substrate blend using locally available organic wastes. Agricultural by-products are plentiful in central Ethiopia, making mushroom cultivation a viable option. Furthermore, one of the biggest hurdles to mushroom farming in Ethiopia is a lack of understanding of the culinary and dietary relevance of mushrooms, as well as the monotonous traditional meals and conservative eating habits of Ethiopians. As a result, increasing mushroom cultivation technology transfer is an urgently needed intervention option. However, because there appears to be a wide range of agricultural crop leftovers on which the oyster mushroom can be grown, determining the best substrate for a high yield and high bioconversion efficiency can be difficult. With this rationalization, the current study was designed to look into the usability of various organic wastes, maize cobs, sorghum stems, bean straw, pea straw, coffee husk, and sawdust alone and cottonseed waste (1:1) ratios, on oyster mushroom production potential (growth performance and yield and biological efficiency) at Ambo, central Ethiopia.

2. Materials and methods

2.1. Source of culture and preparation of spawn

The study was conducted at Ambo University mushroom growing house, Western Ethiopia, Ambo. The *P. ostreatus* was received from Addis Ababa University, Department of Biology, Mycology laboratory and sub-cultured on freshly made potato dextrose agar (PDA). The *P. ostreatus* spawn was made using yellow sorghum grains as a major substrate, together with wheat bran and calcium sulfate ($CaSO_4$) in an 88:10:2 ratio (w/w) (Abera et al., 2019). Overnight, the sorghum grain was soaked in a sufficient amount of water. The excess water was then drained the next day, and the broken and floating grains were washed away with the water. The grain was then thoroughly mixed with the required amount of wheat bran and calcium sulfate.

The mixed spawn substrate was filled up to 75% into a capped bottle, leaving room for air exchange, and sterilized in the autoclave at 15 psi, 121°C for 1 hour. After sterilization, the spawn substrate was cooled in a safety cabinet before being inoculated with 20 pieces of 1 x 1cm block of *P. ostreatus* culture of 15-day-old and incubated at 28±2 °C for 21 days. Every five days, it was inspected for growth, and presence of contamination, and the bottle that showed signs of contamination was removed from the incubator.

2.2. Substrate collection and preparation

The corn cob, sorghum stem, faba bean straw, and pea straw were collected from farmers' fields around Ambo town in western Ethiopia. Coffee husk was collected from a dry coffee processing firm from Eastern Wollega, Ethiopia. Sawdust was collected from the wood processing shop of Ambo Town. Cottonseed waste was purchased from Addis Ababa, the capital city of Ethiopia. The wheat bran was purchased from the wheat processing factory. The calcium carbonate was obtained from the microbiology laboratory department of Biology, at Ambo University. All the substrates were transported to Ambo University, Department of Biology Microbiology Laboratory. For different treatments, the above-listed major substrates were prepared together with 10% of wheat bran 1% calcium carbonate otherwise mixed 50:50 (w/w) ratio with the cottonseed waste and as indicated in Table 1. The different substrates were soaked in water for 24 h and excess water was drained subsequently the wet substrate was filled into heat-resistant polyethylene bags in 0.5kg batches (yellow-coloredkurtupestal). The bags were sterilized in an autoclave at 121°C for 1 hour before being transferred into transparent production bags and allowed to cool to room temperature.

2.3. Spawning, incubation, and harvesting

After inoculating with 10% (w/w) spawn, the bagged substrates were placed in a disinfected dark room. To promote mycelia growth, the spawn was completely mixed with the substrate. Rubber bands were used to tie the bags. The inoculated bags were incubated at room temperature in the darkroom until the primordial phase began. Each treatment was replicated three times. For fruiting, the bags were relocated to the mushroom growing house. The bags were cut at the primordial formation site for the emergence of fruiting bodies once the primordial was commenced. The mushroom bags were watered in the morning and the evening until the harvest was completed. Temperature and humidity were regulated by wetting the concrete floor and spawning bags.

Table 1. The composition of the different substrates per treatment bag

Treatment	Composition per bag (w/w)
Treatment 1 (T1)	Corn cob (500g)
Treatment 2 (T2)	Corn cob (250g) + cotton seed waste(250g)
Treatment 3 (T3)	Sorghum stem (500g)
Treatment 4 (T4)	Sorghum stem (250g) + cotton seed waste (250g)
Treatment 5 (T5)	Faba bean straw (500g)
Treatment 6 (T6)	Faba bean straw (250g) + cotton seed waste (250g)
Treatment 7 (T7)	Pea straw (500g)
Treatment 8 (T8)	Pea straw (250g) + cotton seed waste (250g)
Treatment 9 (T9)	Coffee husk (500g)
Treatment 10 (T10)	Coffee husk (250g) + cotton seed waste (250g)
Treatment 11 (T11)	Sawdust (500g)
Treatment 12 (T12)	Sawdust (250g) + cotton seed waste (250g)
Treatment 13 (T13)	Cotton seed waste (500g)

NB. All the treatments received the recommended 10% wheat bran and 2% calcium carbonate added.

2.4. Data collection and analyses

The mycelia run in days, incubation to 1st harvest days, days between harvests, dates required for the total production cycle, number of bunches, number of fruiting bodies, number of aborts, cap diameter, stipe length, fresh weight, and biological efficiency were recorded for four consecutive harvests that took from 63-90 days. The biological efficiency (BE) of each treatment was calculated using the following formula.

$$BE = \frac{\text{Total fresh weight of mushroom (g) per substrate} \times 100}{\text{Dry weight of the substrate (g)}}$$

All quantitative data collected were analyzed by using SPSS version 25.0 by one-way analysis of variance (ANOVA). All of the statistics were performed at the 0.05 significance level and were presented as mean ± standard deviation (M±SD). The pairwise comparison was done and rearranged according to Tukey.

3. Results and discussion

3.1. Mycelia run and periods of different harvests

The effect of different substrates and their mixtures with cottonseed waste was investigated and found to influence the time taken to spawn run, incubation to the first harvest, and time taken between harvests, as well as the overall number of days taken for the complete production cycle. The time required for the spawn run showed a significant difference between treatments (P≤0.001). The shortest day was recorded for T7 and T8, 15±2 and 15±3.1 days, respectively, followed by T3 and T4, 16±4 and 16±3 days, respectively. T11 took the longest days for mycelia run 33±6.7 days (Table 2). The results of this study were at par with the results reported in the literature. Sitaula et al. (2018) reported the period required for the mycelia run was highest for the maize+paddy straw (20.50 days) and sugarcane bagasses+paddy straw (20.00 days), while it was lowest for the paddy straw (18.25 days) and sawdust+paddy straw (19.00 days). Chandra (2016) reported the fastest colonization period (34 days) of *P. ostreatus* from available substrates which was much more than the present study except for the sawdust substrate. The days taken for a spawn to colonize a specific substrate varies depending on the fungus strain, growth conditions, and substrate type (Chang and Miles, 2004). The slow colonization of sawdust may be due to the presence of more lignin than cellulose and hemicelluloses, which will be slowly degraded to release soluble sugars, whereas the rapid colonization of pluses straw (pea straw and faba bean straw) may be due to the high nitrogen content of these nitrogen-fixing crops. The factor affecting the overall low yield values from sugarcane bagasse and sawdust is the low breakdown of lignocellulosic compounds by *P. ostreatus* (Sharma et al., 2013). The time elapsed for the different major substrates and their mixture with cottonseed waste showed great variation from incubation to the first harvest together with the spawn run (P≤0.000). T7 had the shortest incubation to first harvest 24±5.2 days followed by T8, 26±1 days, and T9, 27±3.7 days. The lengthy incubation to 1st harvest was observed for T11; 46±8.3 days followed by T12, 44±4.5 days (Table 2). Chandra (2016) reported the period for the first harvest (40.20 days) for corn cob with rice bran supplement and the slowest was (48.70 days) for the vegetable residue (control). The time taken from 1st harvest to 2nd showed slight differences from 15 days for T7 and 24 days for T11. From 2nd to 3rd harvest was from 13 days for T7 and 20 days for T11 and T12. While that of the 3rd to fourth was 11 days for T7 and 16 days for T2 and T3 (Table 2). The longest days for the total production cycle were for T11, 90±12 days, while the shortest days for the total production cycle were for T7, 63±6.6 days (Table 2).

3.2. Effect of different substrate compositions on yield attributes of *P. ostreatus*

The average number of fruiting bodies 254±48.5 recorded on T7 differed remarkably (P≤0.000), followed by T8, 200±36. While, the average number of fruiting bodies from, T11 20±5, T1, 27±0.8; T2, 32±2, T12, 32±5.3 was very low (Table 3). This result was at par with the results reported by Sitaula et al. (2018). According to these authors, the substrate of T2 produced (108) fruiting bodies on average, followed by T1 (80) and T3 (20). The maximum number of effective fruiting bodies 74.25 was recorded on sawdust substrate and the minimum, was 12.75 on banana leaves (Mondal et al., 2010). In this study, more bunches were observed on T5, 7±0.99

followed by T8, 6±2.1, while fewer bunches were observed on T11 and T13, 3±1.5. The highest number of aborts was recorded from T7, 190±10 followed by T8, 150±25.5, and the fewer aborts were recorded from T10, 9±1, T11, 10±2, T13, 11±4.2 and T9, 12±1.5. The largest cap diameter was observed from T9, 14±2.5cm, followed by T5, 13±3cm, T10, 12±2cm, T13, 12±1cm, while the cap diameter from T1, T2, T3, T4, and T11, was smaller (Table 3). The results of the yield attributes of the different parameters observed in this study were comparable with the results reported in the literature. Mondal et al. (2010) reported the highest (7.79 cm) pileus diameter on sawdust substrate and the lowest (4.13cm) on banana leaves and rice straw (1:3) ratio. According to the study reported by Abera et al. (2019), different substrates had different effects on the yield-related parameters of oyster mushrooms. The largest cap diameters and stipe length of oyster mushrooms grown on these substrates were recorded on the bags received 30:30:40% wheat straw: waste paper and cotton seed waste and 40:40:20% the same substrate composition, while the smallest cap diameter of 6.23cm was measured from wheat straw 25%:waste paper 25% and cotton seed waste 50%. The smallest stipe length was measured from 20:20:60% wheat straw: waste paper: cotton seed waste. In this study, the stipe length of the oyster mushroom grown on different substrates showed slight variation from 3.5-2.00 cm. This observation was quite different from the stipe length reported by Patil et al. (2010), who indicated the average length of the stalk for *P. eryngii* (6.43cm) followed by *P. florida* (6.30 cm), *P. ostreatus* (5.94cm), *P. sajor-caju* (5.71cm) and a minimum length of stalk from *P. flabellatus* (5.05cm). The presence of glucose, fructose, and trehalose in the substrate may result in a higher number of functional fruiting bodies. *P. ostreatus* was able to better utilize favorable nutrients such as cellulose and hemicellulose from various agricultural residues, resulting in improved oyster mushroom output. The quality of the oyster mushroom *P. florida* is determined by the length of the stalk; the longer the stalk, the poorer the mushroom quality (Patil et al., 2010). In this study, the sporophores and quality of the oyster mushroom fruiting bodies were depicted in Figure 1.

Table 2. Days required for mycelia colonization, incubation to the first harvest, days required between harvests, and days for the total production time of oyster mushroom

Treatments	Period for colonization	Incubation 1st harvest	1st to 2nd harvest	2nd to 3rd harvest	3rd to 4th harvest	Total production time (days)
T1	25±3.0^{bc}	33±0.8^{cd}	20±2.0^{cd}	18±2.5^{bc}	15±1.0^{bc}	86±10.0^{ef}
T2	22±4.0^{ab}	30±1.0^{abcd}	19±3.0^{abc}	18±3.1^{bc}	16±2.0^{c}	83±5.0^{de}
T3	16±4.0^{ab}	30±1.5^{abcd}	18±1.8^{abcd}	18±2.0^{bc}	16±3.1^{c}	85±9.5^{jdef}
T4	16±3.0^{abc}	30±2.0^{abcd}	18±2.0^{abcd}	18±1.8^{bc}	15±2.9^{bc}	85±5.6^{def}
Ts	18±3.1^{abc}	30±3.5^{abcd}	18±4.1^{abcd}	18±1.9^{bc}	15±2.5^{bc}	82±6.2^{d}
T6	21±2.5^{abc}	34±4.1^{ab}	21±2.2^{de}	19±2.8^{bc}	16±1.5^{c}	90±11.6^{g}
T7	15±2.0^{a}	24±5.2^{a}	15±1.9^{a}	13±2.0^{a}	11±1.8^{a}	63±6.6^{a}
T8	15±3.1^{a}	26±1.0^{ab}	17±2.8^{abc}	15±3.2^{ab}	12±2.3^{ab}	70±6.8^{b}
T9	25±8.7^{bc}	27±3.7^{abc}	19±2.1^{b}	16±2.8^{abc}	13±3.3^{abc}	76±9.2^{c}
T10	23±1.0^{bc}	28±4.2^{abc}	16±1.9^{ab}	14±3.0^{a}	12±1.0^{a}	70±7.2^{a}
T11	33±6.7^{d}	46±8.3^{e}	24±5.2^{e}	20±5.2^{d}	-	90±12.0^{g}
T12	20±2.0^{abc}	44±4.5^{e}	22±3.8^{e}	20±2.2^{d}	-	88±13.0^{fg}
T13	18±3.0^{cd}	26±3.5^{ab}	19±1.8^{b}	16±2.9^{abc}	13±2.0^{abc}	76±8.0^{c}
Sign	0.001	0.003	0.000	0.000	0.002	0.005

NB. The figures followed by the same letter in the column are not significantly different from each other

Table 3. Number of mature aborts, number of bunches, cap diameter, and stipe length of the oyster mushroom grown on different substrates

Treatments	No. mature	No. of bunches	No. of aborts	Cap diameter (cm)	Stipe length (cm)
T1	27±0.8^{h}	4±0.5^{ab}	15±2.1^{e}	6±2.0^{c}	2±0.6^{a}
T2	32±2.0^{gh}	4±1.0^{ab}	13±2.7^{e}	6±0.5^{c}	3±0.1^{a}
T3	55±6.0^{ef}	4±2.0^{ab}	20±5.0^{de}	6±1.1^{c}	3±0.8^{a}
T4	85±10.0^{c}	4±1.5^{ab}	35±3.0^{c}	6±2.0^{c}	3±0.5^{a}
Ts	65±5.0^{de}	7±0.1^{a}	15±3.5^{e}	13±3^{a}	2±0.2^{a}
T6	70±8.0^{d}	5±2.0^{ab}	30±4.1^{cd}	10±1.5^{bc}	2.5±0.5^{a}
T7	254±48.5^{a}	5±1.1^{ab}	190±10.0^{a}	11±3.2^{ab}	3.5±0.9^{a}
T8	200±36.0^{b}	6±2.1^{ab}	150±25.5^{b}	11±2.0^{ab}	2.5±0.7^{a}
T9	42±3.0^{fg}	4±1.0^{ab}	12±1.5^{e}	14±2.5^{a}	3.5±0.8^{a}
T10	52±6.6^{ef}	5±1.6^{ab}	9±1.0^{e}	12±2.0^{ab}	3.5±0.6^{a}
T11	20±5.0^{h}	3±1.5^{c}	10±2.0^{e}	6±2.0^{c}	3.5±0.2^{a}
T12	32±5.3^{gh}	5±1.2^{ab}	21±2.1^{cde}	7±1.3^{bc}	3±0.7^{a}
T13	45±8.2^{fg}	3±1.5^{c}	11±4.2^{e}	12±1^{ab}	3.5±0.9^{a}
Sign	0.000	0.016	0.000	0.000	0.009

NB. The figures followed by the same letter in the column are not significantly different from each other

3.3. The yield per flush, total biomass, and biological efficiency of *P. ostreatus* grown on different substrates

In all of the flushes, the yield of oyster mushrooms varied greatly depending on the substrate (P≤0.000). In the first flush, the maximum yield (848±86.3g) was obtained on pea straw alone, followed by pea straw: cottonseed waste (1:1w/w) (680±6.2g), while the lowest yield (166±10g) was produced on sawdust. Pea straw (456±55.9g) yielded the most in the second flush, followed by a mixture of bean straw and cottonseed waste (350±5g), cottonseed alone (308±2g), and the mixture of pea straw and cottonseed (304±16.8g). Sorghum stems 100% gave the lowest yield (113±17.5g) in the same flush, followed by sawdust (140±14.7g) and corn cob alone (186±12g) (Table 4). Cottonseed waste (210±15g) produced the maximum yield in the third flush, followed by pea straw (204±28g). Sorghum stems produced the lowest yield of 62±12g in the same flush, followed by sawdust (80±5g) and corncob (90±14g) (Table 4). Cottonseed waste (180±10) produced the best yield in the fourth flush, followed by pea straw (106±15). The lowest yield of 32±5g was obtained on sorghum stem during the same flush, whereas sawdust and sawdust cotton seed waste mixture produced nil yield in the fourth flush (Table 4). The results of this study show similarities with the results reported in the literature. Maheswari et al. (2020) reported the total fresh weight of the first and second flush was highest for maize cob+paddy straw (718.7g) followed by sugarcane bagasses+paddy straw (527.8g), sawdust+paddy straw (459.0g), and lowest for paddy straw(408.3g). The highest total biomass of 1614±17.1g was recorded from pea straw followed by faba bean straw: cottonseed waste (1:1w/w), 1234±15.3g, and pea straw cotton seed waste (1:1w/w), 1165±26.0g, while the smallest total biomass was recorded from, sorghum stem 374±36g and sawdust 384±37.9g (Table 4). Mondal et al. (2010) reported the maximum biological yield (159.3 g) from rice straw and the minimum biological yield (36.35 g) was obtained from banana leaves and rice straw (1:1 w/w) in the first flush. Rice straw produced the highest biological yield (164.49g) in the case of the second flush.

The highest yield was obtained in T3 (761.5±7.5g) followed by 507±5 g and 317.7±3.1g in T1 and T2, respectively (Maheswari et al., 2020).

There was a significant variation in oyster mushroom biological efficiency under different treatments. Pea straw had a much higher biological efficiency (323±48.9%) followed by a mixture of faba bean straw (247±18.9%), cottonseed waste (245.2±33.4%), and pea straw + cottonseed waste (233±18.0%). The lowest biological efficiency of oyster mushrooms was found on sorghum stem at 76.8±18.8% and sawdust at 78.8±10.5% (Table 4) The result of biological efficiency of this study was much more than the results reported in the literature. Paddy straw showed significantly highest biological efficiency (96.29%) followed by maize cob+paddy straw (74.09%), sugarcane bagasses+paddy straw (71.90%), and lowest sawdust+paddy straw (71.05%) (Mondal et al., 2010). Sitaula et al. (2018) reported, that the maximum biological efficiency in T2 (92.08±0.89%) as compared to T3 (87.39±0.85%) and T1 (72.37±0.7%). Chandra (2016) reported the biological efficiencies of *P. ostreatus* which ranged from 91.99 to 109.50% in corn cob, 69.81 to 88.36 % in paper waste, and 52.26 to 65.22% in vegetable residue. The enhanced yield and biological efficiency observed in most of the treatments in this study could be due to the presence of favorable nutrients such as cellulose and hemicellulose from crop and pulse straw which were utilized better by *P. ostreatus*. The reduced amount of yield in sawdust and sorghum stem treatments could be attributed to rich lignin content and the deprived inability of *P. ostreatus* to degrade lignin. The highest yield on pea straw appeared to be due to the comparatively better availability of nitrogen, carbon, and minerals from this substrate. The low yield and biological efficiency of *P. ostreatus* on sawdust and sorghum stem could probably be due to the inability of the mushroom mycelia to produce appropriate enzymes that could hydrolyze and convert the substrates for its vegetative and reproductive growth.

Table 4. The yield of different harvests, total biomass, and biological efficiency of oyster mushrooms grown on different substrates

Treatments	1st flush (g/bag)	2nd flush (g/bag)	3rd flush (g/bag)	4th flush (g/bag)	Total biomass (g/bag)	BE (%)
T1	312±15.5^{i}	186±12.0^{i}	90±14.0^{fg}	52±5.0^{d}	640±55.0^{h}	128±22.0^{g}
T2	395±35.5^{f}	274±19.1^{e}	106±11.3^{de}	49±8.2^{d}	824±55.5^{f}	164.8±28.6^{e}
T3	167±44.0^{j}	113±17.5^{k}	62±12.0^{h}	32±5.0^{e}	374±36.0^{i}	78.8±10.5^{h}
T4	424±13.5^{e}	225±22.8^{f}	115±9.8^{d}	87±8.1^{c}	881±36.5^{d}	176.2±18.5^{d}
Ts	350±9.9^{h}	150±6.0^{j}	110±10.5^{de}	90±4.0^{c}	697±16.9^{g}	139±21.5^{f}
T6	600±10.0^{c}	350±5.0^{b}	180±9.0^{b}	100±4.0^{bc}	1234±15.3^{b}	247±18.9^{b}
T7	848±86.3^{a}	456±55.9^{a}	204±28.0^{a}	106±15.0^{b}	1614±17.1^{a}	323±48.9^{a}
T8	680±6.2^{b}	304±16.8^{c}	128±14.5^{c}	50±12.0^{d}	1165±26.0^{c}	233±18.0^{c}
T9	375±19.2^{g}	287±28.9^{d}	105±15.2^{de}	86±12.3^{c}	853±61.3^{e}	170.6±24.5^{d}
T10	393±22.9^{f}	204±13.3^{h}	117±13.6^{cd}	87±10.0^{c}	802±9.2^{f}	161±17.5^{e}
T11	166±8.6^{j}	140±14.7^{j}	80±5.0^{g}	-	384±37.9^{i}	76.8±18.8^{h}
T12	300±19.7^{i}	220±5.0^{g}	100±10.0^{df}	-	620±0.1^{h}	124±0.1^{g}
T13	530±5.0^{d}	308±2.0^{c}	210±15.0^{a}	180±10.0^{a}	1226±16.52^{b}	245.2±33.4^{b}
Sign	0.000	0.000	0.000	0.000	0.000	0.000

NB. The figures followed by the same letter in the column are not significantly different from each other

Figure 1. Sporophores of the oyster mushroom grown on different substrates: A) Primordial formation B) Sporophores on the cottonseed waste, C) Sporophores on pea straw, D) Sphorophores maize cob E) Sporophores on the coffee husk, F) Sporophores on faba bean straw

4. Conclusions

For countries like Ethiopia, where agriculture has historically been the main source of income, the promotion of mushroom production technology is most importance for enhancing community nutrition, health, and income. *P. ostreatus* is a type of specialty mushroom that can be grown on a variety of organic substrates, but it's important to choose a substrate or a combination of substrates that will produce the highest mushroom output and biological efficiency. One of the most important considerations when choosing a suitable substrate is the variety of substrates that are available in the area. According to the results of the current study, oyster mushrooms (*Pleurotus ostreatus*) can be grown on a variety of organic wastes, including sawdust, coffee husks, pea straw, bean straw, and cottonseed waste otherwise mixed in a 1:1 ratio. In terms of the number of days needed for a full spawn run, a combination of cotton seed waste, bean, and pea straw, performed better as compared to other substrates tested. The enormous amount of agricultural waste products that are currently available may be resolved by using bean and pea straws as substrates for oyster mushroom growing. However, more research must be done to determine the potential effects of diverse agricultural wastes on the growth of oyster mushrooms.

Compliance with Ethical Standards

Conflict of Interest

As the author of article declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

Asefa KENENI: Investigation, Conceptualization, Writing - original draft, Formal analysis, Data curation.

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We humbly give consent for this article to be published.

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CHANGES IN THE RELATIONSHIPS BETWEEN POMOLOGICAL CHARACTERISTICS IN HAZELNUTS ACCORDING TO THE PICKING MANUALLY FROM THE BRANCH AND THE GROUND

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A B S T R A C T

This research was carried out to determine the relationships between pomological characteristics of hazelnuts collected manually from the branch and the ground. The research was carried out in three different orchards belonging to a producer, which contains Tombul, Foşa and Çakıldak hazelnut varieties in Kocaali district of Sakarya province (Türkiye). The orchards, located at an altitude of 300 m, face north. Hazelnut samples of Tombul, Foşa and Çakıldak varieties were collected from the branch in the first (2009) and second year (2010), on 12-15 August, 15-18 August and 22-25 August, respectively, and from the ground on 24-27 August, 27-30 August and 4-7 September, respectively. Nut weight, nut size, shell thickness, kernel weight, kernel size, kernel cavity, kernel percent, shriveled kernel ratio, good kernel ratio, full and average blanching ratios were determined in dried fruits. Correlation analysis was performed between the properties examined separately in the two groups of samples. In the samples collected from the branch and the ground, the highest variation was seen in the shriveled kernel ratio and the lowest in the good kernel ratio. It was determined that all of the significant correlation coefficients in the samples collected from the branch were positive, and the highest correlation coefficients were between full blanching ratio-average blanching ratio, nut weight-kernel weight and nut size-kernel size, respectively. In the samples collected from the ground, more significant correlations, and also negative significant relationships were found between the investigated properties. It was determined that the highest positive correlations were found between nut size-kernel weight, nut weight-kernel weight, full blanching rate-average blanching rate, nut weight-kernel size and nut size-kernel size, respectively; the highest negative correlations were found between the shell thickness-good kernel ratio, the shell thickness-kernel size, and the shriveled kernel ratio-good kernel core ratio, respectively. It can be said that the samples collected manually from the ground in hazelnut were more homogeneous than those collected from the branch in terms of the quality characteristics examined; in the samples collected from the ground, the good kernel ratio and kernel size were negatively affected by the shell thickness, the shriveled kernel ratio was positively affected, and there were no differences between the samples in terms of other relations.

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1. Introduction

Harvesting hazelnuts is currently one of the most expensive processes in the production cycle, adding up to 40-60% of the production cost and is quite time-consuming when done manually. The degree of mechanization also depends significantly on the land topography (Bernardi et al., 2017). Since the 1980s, mechanical harvesting has almost completely replaced manual harvesting in developed countries, and mechanical harvesting machines have also continuously improved during this period. The transition to machine harvesting has caused some important changes in hazelnut production techniques (Monarca et al., 2013).

In Türkiye, which is the leader of the world hazelnut production and trade, harvesting is generally done by hand in the 1st standard region, and generally by machine in the 2nd standard region (İslam, 2018). Although shaking and picking from the ground is considered the best method for manual collection, this is not possible on sloping lands. On the other hand, shaking and picking from the ground seem to be more positive in terms of efficiency and quality than picking from the branch by hand (Çırak and Bostan, 2018). Due to topographic conditions, hand picking from the branch is the most common method in the region. In this method, care should be taken not to damage the buds that will produce crops the next year.

Correlation is one of the important biometric tools that measures the degree and magnitude of the relationship between various features (Sharma, 2003). Phenotypic correlation and heritability are important parameters that researchers should consider in breeding programs (Valentini et al., 2004). Estimates of correlation coefficients allow direct versus indirect selection to be compared and to obtain information about the second trait associated with the first trait (Falconer and Mackay, 1996).

It has been stated in studies on hazelnut yield, yield parameters and fruit quality characteristics that there are many simple or phenotypic correlations of the morphological features examined and that the correlations between the parameters generally vary according to species, varieties, genotypes and years (Bostan, 2022).

The formation of defective fruits in hazelnuts may be related to both pre-harvest, during and post-harvest processes. For this reason, it is important to first know these defects and their causes and then take precautions against them in a timely manner (Bostan, 2019).

Although many studies have been conducted on the relationships between pomological characteristics in hazelnuts, no study has been found that reveals the relationships between the quality characteristics of hazelnuts harvested according to different methods. This study was conducted to reveal the relationships between the important pomological properties of hazelnut samples collected manually from the branch and the ground. Thus, it was aimed to determine the homogeneity and interdependence of quality characteristics of hazelnut samples collected by hand from the branch and the ground.

2. Material and methods

2.1. Plant materials

The research was carried out in three different orchards belonging to one producer, in the 'Ocak' planting system, in the Kocaali district of Sakarya province of Türkiye, containing Tombul, Foşa and Çakıldak hazelnut varieties. The orchards, located at an altitude of 300 m, are oriented towards the north and are in complete yield age (40-55 years).

Cultural practices (suckers cutting, disease and pest control, fertilization) are carried out regularly in the orchards.

Standard soil analyzes performed on soil samples taken from the orchards at a depth of 0-30 cm revealed that all three orchard soils were very acidic in character (pH: 4.62-4.90), clayey loamy in structure (60-65%), unsalted (0.42-0.58 dSm^{-1}), low in lime (0.1%), moderate in organic matter 2.07-2.46%), good in nitrogen (0.10-0.12%) and insufficient in phosphorus (4-5 ppm).

2.2. Methods

Before harvest, the ocaks were determined for branch and ground collection practices, 3 varieties, 3 orchards, 3 repetitions and 3 in each repetition. Accordingly, all of the clusters were collected from a total of 27 ocaks from 3 orchards for 1 variety and 1 application in every two years.

First, in each orchard, the ocaks where the clusters would be collected from the ground were randomly determined. Then, the clusters in the ocaks around them were collected by hand, thus preventing the samples in the ocaks from mixing with each other. The fruits were harvested when the husks turned yellow and reddened, the nuts began to move inside the husk and ¾ of the hard shell turned red (Okay et al., 1986).

Hazelnut samples of Tombul, Foşa and Çakıldak varieties were collected from the branch in the first (2009) and second year (2010), on 12-15 August, 15-18 August and 22-25 August, respectively, and from the ground on 24-27 August, 27-30 August and 4-7 September, respectively. The samples from each orchard and variety were grouped separately on the basis of repetition, and all clusters in the ocaks were evaluated.

The clusters collected from the branch was kept in the sun for an average of 3 days in the grass threshing floor, then sorted manually, and the nuts dried in the sun again for 5 days. The fruit collected as nut from the ground were brought directly to the drying floor and left to dry in the sun.

In dried nuts, nut weight, nut size (the arithmetic average of the width, length and thickness), shell thickness, kernel weight, kernel size (the arithmetic average of the width, length and thickness), internal cavity, kernel percentage, shriveled kernel ratio, good kernel ratio, and full and average blanching rates (incubated at 175 °C for 15 min) (Bostan and İslam, 1999a) were determined.

2.3. Experimental design and statistical analysis

The experimental design was planned in random plots with 3 replications. Two years' data were evaluated in statistical analyses.

Correlation analysis was performed in the SAS JMP 13.2.0 (US, Canada) statistical program to determine the relationships between the pomological characteristics examined in hazelnuts.

3. Results

In the research, analyzes and evaluations of hazelnuts collected from the branch and the ground were made separately.

3.1. The samples collecting from branch

The mean, standard deviation (SD), minimum, maximum and coefficient of variation (CV) values of hazelnuts collected from the branch are presented in Table 1.

Table 1. Simple univariate statistics of the traits examined in hazelnuts collected from the branch

Traits	Abbreviation	Mean	SD	Min.	Max.	CV (%)
Nut weight (g)	NW	2.12	0.23	1.63	2.90	10.77
Nut size (mm)	NS	16.93	0.92	14.56	18.52	5.43
Shell thickness (mm)	ST	1.45	0.18	1.18	2.04	12.69
Kernel weight (g)	KW	1.14	0.13	0.89	1.52	11.22
Kernel size (mm)	KS	13.07	0.75	11.00	14.61	5.75
Kernel cavity (mm)	IC	3.78	1.17	0.54	5.96	30.99
Kernel percentage (%)	KP	53.57	2.96	47.80	59.81	5.52
Shriveled kernel (%)	SK	2.78	3.46	0.00	15.00	74.55
Good kernel (%)	GK	92.31	4.09	80.00	100.00	4.43
Full blanching (%)	FB	75.09	25.69	10.00	100.00	33.43
Average blanching (%)	AB	88.24	17.56	20.00	100.00	19.90

In the samples collected from the branch, the highest variation was seen in the shriveled kernel ratio (74.55%) and the lowest in the plump interior ratio (4.43%). The coefficients of variation of shriveled kernel, full blanching and kernel cavity were determined to be over 20%. The coefficient of variation remained below 10% in terms of good kernel ratio, nut and kernel sizes. The correlation analysis performed for the samples collected from the branch showed that all of the significant relationships among the examined features were positive, and the highest relationships (over 77%) were full blanching ratio-average blanching ratio (91.1%), nut weight-kernel weight (87.4%) and nut size-kernel size (%). 77.5) (Table 2).

Table 2. Simple correlation coefficients and significance levels between the traits examined in hazelnuts collected from the branch

	NW	NS	ST	KW	KS	IC	KP	SK	GK	FB
NS	0.497**									
ST	0.097	-0.206								
KW	0.874***	0.524***	0.017							
KS	0.354**	0.775***	-0.226	0.440**						
IC	0.538***	0.692***	0.019	0.524***	0.663***					
KP	-0.163	0.101	-0.155	0.336*	0.207	0.027				
SK	-0.141	0.029	0.023	-0.227	-0.042	0.086	-0.175			
GK	0.327*	0.311*	-0.044	0.387**	0.330*	0.313*	0.132	-0.230		
FB	0.226	0.098	0.182	0.158	-0.024	0.037	-0.125	-0.123	0.053	
AB	0.174	-0.020	0.193	0.100	-0.092	-0.007	-0.140	-0.185	0.057	0.911***

Sign.: *= 5%, **= 1%, ***= 1‰

On the other hand, nut size-kernel cavity (69.2%), kernel size-internal cavity (66.3%), nut weight-kernel cavity (53.8%), nut size-kernel weight and kernel weight-internal cavity (52.4%), nut weight-nut size (49.7%), kernel weight-kernel size (44%), kernel weight-good kernel ratio (38.7%), nut weight-kernel size (35.4%), kernel weight-kernel percentage (33.6%), kernel size-good kernel ratio (33.0%), nut weight-good kernel ratio (32.7%), good kernel ratio-kernel cavity (31.3%) and nut size-good kernel ratio (31.1%) relationships were also found to be significant, respectively.

3.2. The samples collecting from ground

The mean, standard deviation (SD), minimum, maximum and coefficient of variation (CV) values of hazelnuts collected from the ground are presented in Table 3.

Table 3. Simple univariate statistics of the traits examined in hazelnuts collected from the ground

Traits	Abbreviation	Mean	SD	Min.	Max.	CV (%)
Nut weight (g)	NW	2.19	0.17	1.87	2.61	7.60
Nut size (mm)	NS	17.28	0.83	15.36	18.78	4.79
Shell thickness (mm)	ST	1.29	0.15	0.93	1.62	11.92
Kernel weight (g)	KW	1.17	0.11	0.91	1.37	9.63
Kernel size (mm)	KS	13.25	0.69	11.83	14.76	5.20
Kernel cavity (mm)	IC	3.37	1.67	0.33	11.10	49.71
Kernel percentage (%)	KP	53.57	3.12	47.14	60.48	5.82
Shriveled kernel (%)	SK	1.20	2.56	0.00	10.00	83.55
Good kernel (%)	GK	96.67	4.00	85.00	100.00	4.14
Full blanching (%)	FB	87.30	15.84	20.00	100.00	18.14
Average blanching (%)	AB	95.37	7.41	68.00	100.00	7.77

In the samples collected from the ground, as in those collected from the branches, the highest variation was observed in the shriveled kernel ratio (83.55%) and the lowest in the good kernel ratio (4.14%). In addition to the shriveled kernel ratio, the variation in the kernel cavity was determined to be over 20%, and in addition to the good kernel ratio, the weight and size of the nut and kernel, the kernel percentage and the average blanching ratio were determined to be below 10%. Variation was generally lower in samples collected from the ground.

Correlation analysis in the samples collected from the ground revealed that there were more significant relationships and negative significant relationships among the examined features, unlike those collected from the branch (Table 4).

Table 4. Simple correlation coefficients and significance levels between the traits examined in hazelnuts collected from the ground

	NW	NS	ST	KW	KS	IC	KP	SK	GK	FB
NS	0.790***									
ST	0.066	-0.133								
KW	0.807***	0.835***	-0.050							
KS	0.520***	0.762***	-0.304*	0.655***						
IC	0.415**	0.441**	0.205	0.457**	0.347*					
KP	0.060	0.380**	-0.188	0.637***	0.433**	0.239				
SK	-0.098	-0.070	0.450**	-0.035	-0.151	-0.011	0.067			
GK	0.089	0.143	-0.351**	0.304*	0.262	0.147	0.407**	-0.292*		
FB	0.132	0.120	0.100	0.194	0.085	0.170	0.152	-0.011	0.108	
AB	0.081	-0.088	0.254	0.033	-0.090	0.099	-0.057	0.031	0.027	0.786***

Significance: *= 5%, **= 1%, ***= 1‰

Among the negative relationships, shell thickness-good kernel ratio (35.1%), shell thickness-kernel size (30.4%) and shriveled kernel ratio-good kernel ratio (29.2%) relationships were found to be significant.

The highest positive relationships were between nut size-kernel weight (83.5%), nut weight-kernel weight (80.7%), average blanching rate-full blanching rate (78.6%), nut weight-nut size (79.0%), nut size-kernel size (76.2%), kernel weight-kernel size (65.5%), kernel weight-kernel percentage (63.7%), nut weight-kernel size (52.0%), kernel weight-kernel cavity (45.7), shell thickeness-shriveled kernel ratio (45.0%), nut size-kernel cavity (44.1%), kernel weight-kernel percentage (43.3%), nut weight-kernel cavity (41.5%), good kernel ratio-kernel percentage (40.7%), nut size-kernel percentage (38.0%), kernel size-kernel cavity (34.7%) and kernel weight-good kernel ratio (30.4%), respectively.

4. Discussion

The results of this study could not be directly compared with the results of previous research, as no study revealing the relationships between the quality characteristics of hazelnuts harvested according to different methods could be found. For this reason, the correlation analysis results of previous studies on the examined features were included in the evaluation.

In our study, in two groups of samples, the relationships of nut size, kernel weight, kernel size and kernel cavity with nut weight were positively significant. The relationship between nut weight and shell thickness was found to be insignificant. In previous studies, nut weight-nut size, nut weight-shell thickness, nut weight-kernel weight and nut weight-kernel size relationships were positive and significant in Tombul and Kalınkara varieties (Bostan, 1995); the nut weight-shell thickness relationship was positive and significant in Tombul, Palaz, Sivri and Kalınkara varieties (Bostan, 1999a); in Palaz and Sivri varieties, nut weight-nut size, nut weight-kernel size and nut weight-shell thickness relationships were positive and significant (Bostan and İslam, 1999b); nut weight-nut size and nut weight-kernel weight relationships were positive in hazelnut genotypes (Yao and Mehlenbacher, 2000); in the Tombul variety, nut weight-kernel weight and nut weight-kernel cavity relationships were positive, significant, the others were insignificant (Bostan, 2003); nut weight-

nut size, nut weight-kernel size and nut weight-kernel weight relationships were positive in hazelnut genotypes (Sharma, 2003); in Tombul, only the nut weight-kernel weight relationship was positive and significant, the others were insignificant (Karadeniz and Bostan, 2004); in Tombul, Palaz, Çakıldak and Kalınkara varieties, nut weight-nut size, nut weight-shell thickness, nut weight-kernel weight and nut weight-kernel cavity relationships were positive and significant (İslam et al., 2005); in Tombul variety, nut weight-kernel weight, nut weight-nut size and nut weight-kernel size relationships were positive and nut weight-shell thickness relationship was negatively significant.

In Kalınkara variety, nut weight-kernel weight and nut weight-kernel size relationships were positive and nut weight-shell thickness relationship was negatively significant. In Sivri variety, nut weight-kernel weight relationship was positively significant (Akdemir, 2010); in Palaz and Tombul varieties, nut weight-kernel weight relationships were positively significant, nut weight-shell thickness and nut weight-kernel cavity relationships were negatively significant (Bak, 2010); in the Tombul variety, the nut weight-kernel weight relationship was positively significant and the nut weight-shell thickness relationship was negatively significant (Kırca, 2010); nut weight-nut size relationship was positively significant in 10 hazelnut varieties (Milošević and Milošević, 2012); nut weight-kernel weight relationship was positively significant in the hazelnut population (Mohammadzedeh et al., 2014); in the wild hazelnut population, nut weight-nut size, nut weight-kernel weight and nut weight-kernel size relationships were positively significant (Ershadi et al., 2020); in Tombul and Palaz varieties, nut weight-kernel weight and nut weight-kernel cavity relationships were positively significant, nut weight-nut size, nut weight-shell thickness and nut weight-kernel size relationships were insignificant (İşbakan and Bostan, 2020); in the Çakıldak variety, nut weight-nut size, nut weight-shell thickness, nut weight-kernel weight and nut weight-kernel size relationships were found to be positively significant (Top and Bostan, 2020); in Tombul and Palaz varieties, nut weight-kernel weight relationships were found to be positive, nut weight-kernel cavity and nut weight-shell thickness relationships were found to be negatively significant (Bak and Karadeniz, 2021). The study results were largely similar in terms of the positive relationships between nut weight-nut size, nut weight-kernel weight and nut weight-kernel size.

In this study, while the relationships between the kernel percentage and nut weight, shell thickness and kernel cavity were insignificant in both groups of samples, the kernel percentage-kernel weight relationship and also the kernel percentage and nut and kernel sizes in the samples collected from the ground were found to be positively significant. In previous studies, kernel percentage was highly and negatively related to nut weight (Mehlenbacher et al., 1993); kernel percentage-nut weight and kernel percentage-shell thickness relationships in Tombul variety and kernel percentage-shell thickness relationship in Kalınkara were negatively significant and kernel percentage-kernel weight relationship was insignificant in Tombul and positive significant in Kalınkara (Bostan, 1995); kernel percentage-nut size and kernel percentage-shell thickness relationships were negative in Palaz and Sivri varieties, kernel percentage-kernel weight relationship was insignificant in Palaz, positive in Sivri, kernel percentage-nut weight relationship was negative in Palaz and insignificant in Sivri (Bostan and İslam, 1999b); in hazelnut genotypes, kernel percentage-nut size and kernel percentage-nut weight relationships were negatively significant (Yao and Mehlenbacher, 2000); in the Tombul variety, kernel percentage-kernel weight and kernel percentage-kernel size relationships were positively significant, while kernel percentage-nut weight, kernel percentage-shell thickness and kernel percentage-kernel cavity relationships were insignificant (Bostan, 2003); in hazelnut genotypes, kernel percentage-nut size, kernel percentage-kernel size and kernel percentage-nut weight relationships were negatively related, while kernel percentage-kernel weight relationship is positively related (Sharma, 2003); in the Tombul variety, the kernel percentage-kernel weight relationship was positively significant and the kernel percentage-nut weight, kernel percentage-nut size, kernel percentage-shell thickness, kernel percentage-kernel size and kernel percentage-kernel cavity relationships were insignificant (Karadeniz and Bostan, 2004); in hazelnuts, kernel percentage-shell thickness and kernel percentage-nut weight relationships were negatively significant (Valentini et al., 2004). In Tombul, Palaz, Çakıldak and Kalınkara varieties, there were negative significance relationships between the kernel percentage and nut size, nut weight, shell thickness, kernel cavity, and there was an insignificant relationship between the kernel percentage-kernel weight (İslam et al., 2005). In Tombul variety, kernel percentage-kernel weight and kernel

percentage- kernel weight relationships were positive, in Kalınkara variety, kernel percentage-nut weight relationship was positive and kernel percentage-shell thickness relationship was negatively significant, in Sivri variety, kernel percentage-nut weight and kernel percentage-kernel weight relationships were positively significant (Akdemir, 2010); the kernel percentage-nut weight relationship was positive and significant in the Palaz variety, but insignificant in the Tombul variety (Bak, 2010); in the Tombul variety, kernel percentage-nut weight and kernel percentage-kernel weight relationships were positively significant, while kernel percentage-shell thickness relationship was negatively significant (Kırca, 2010); The kernel percentage-nut weight relationship was positive and significant in the hazelnut population (Mohammadzedeh et al., 2014); the kernel percentage-nut weight relationship was insignificant in Tombul and Palaz varieties (İşbakan and Bostan, 2020); in the Çakıldak variety, the kernel percentage-nut weight relationship was insignificant (Top and Bostan, 2020); In the Palaz variety, kernel percentage-nut weight and kernel percentage-kernel weight relationships were found to be positively significant (Bak and Karadeniz, 2021). The positive relationship between kernel percentage and kernel weight was similar in almost all previous studies.

Hazelnut varieties with large fruits have higher rates of abortive and shriveled kernels (Mehlenbacher, 1991; Thompson et al., 1996); it has also been stated that shriveling was a genetic feature and that this may be related to cell size or composition (Thompson et al., 1996). On the other hand, it has been stated that the heritability of good kernel ratio in hazelnuts was medium (42%), shriveled kernel ratio is low (22%), and there was a negative relationship between good kernel ratio and shriveled kernel ratio (Mehlenbacher et al., 1993). In our study, this relationship was negative in both sample groups, but significant only in samples collected from the ground, while İşbakan and Bostan (2020) also stated that the relationship between good kernel ratio and defective kernel ratio was negatively significant. On the other hand, the relationship between good kernel ratio and kernel percentage, which was insignificant in samples collected from the branch, was found to be positively significant in samples collected from the ground, and it was stated that this relationship was insignificant in the Tombul variety (Bostan, 2003). In the samples collected from the ground, the relationship between good kernel ratio and shriveled kernel ratio was found to be negatively significant. As in our study, Karadeniz and Bostan (2004) found the good kernel ratio-kernel percentage relationship to be positive and the good kernel ratio-shriveled kernel ratio relationship to be negatively significant. In our study, the good kernel ratio in samples collected from the branch was found to be positively related to nut-kernel weight and nut size, and the kernel weight and kernel percentage in samples collected from the ground. Ozturk et al. (2017) also found the relationships between the good kernel ratio and the kernel weight and kernel percentage to be positively significant, similar to our study. Bostan (2003) found the good kernel ratio-shell thickness relationship to be positively significant in the Tombul variety. In our study, this relationship was found to be negative but insignificant in samples collected from the ground, similar to the previous study, and in samples collected from branches.

It was stated that the heritability of the blanching rate in hazelnuts was moderately high (48%) (Mehlenbacher and Smith, 1988), and that it varies significantly depending on varieties, ecology, years, temperature and duration of the blanching process (Köksal and Okay, 1997; Richardson and Ebrahem, 1997; Bostan, 1999b; Bostan and İslam, 1999a; Bostan and Günay, 2009). In our study, a positive significant relationship was determined only between the full and average blanching ratio in both sample groups, and the relationships between the blanching ratio and other fruit characteristics were insignificant. In previous studies, the blanching ratio was found to be negative with shell thickness in Tombul and Kalınkara varieties, positive with nut and kernel weight in Palaz variety, and negative with nut thickness in Sivri variety (Bostan and İslam, 1999c); in hazelnut genotypes, the blanching ratio was negative with nut and kernel weight and positive with nut size (Yao and Mehlenbacher, 2000); it has been stated that there was a positive relationship with hazelnut cultivars and the kernel rate in wild and local species (Frary et al., 2019). From these results, it is understood that the blanching ratio varies significantly under the influence of many factors.

5. Conclusions

As a result, it can be said that the hazelnut samples collected by hand from the ground were more homogeneous in terms of the quality characteristics examined than those collected from the branch; in the samples collected from the branch, quality characteristics were only significantly correlated with each other in

a positive direction; quality characteristics interact more with each other in samples collected from the ground; in the samples collected from the ground, the shell thickness affects the good kernel ratio and the kernel size in the opposite direction, the shriveled kernel ratio was linearly affected, and in terms of other relations, there were generally no differences between the samples collected from the branch and the ground.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical approval

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Data availability

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THE EFFECTS OF HAZELNUT PULP ADDING ON SENSORIAL PROPERTIES OF TARHANA

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In this study, hazelnut pulp added to tarhana to increase its nutritional properties and create a new product. For this purpose, cold-pressed partially defatted hazelnut pulp obtained and added to the tarhana formulation at certain rates of 0%, 5%, 10%, 15%, 20%, 25% and 30%. Sensory tests carried out to measure the liking of tarhana with hazelnut pulp, a new product. In the sensory evaluation, all samples examined in terms of odor, color, taste-aroma, consistency, and general acceptability. Because of the sensory analysis carried out by cooking tarhana in the form of soup, it observed that there was no significant difference between the control group and the tarhana with hazelnut pulp in terms of color, smell, consistency, taste, aroma and general acceptability. However, when the sensory analysis results are examined, it is seen that tarhana with hazelnut pulp received higher scores than the control group.

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1. Introduction

Tarhana varies depending on its raw material, the materials used in its production and the variability of production methods. Tarhana, which is generally dried and powdered, preserved fresh in some regions without being dry, while in some regions, it dried as chips and consumed as a snack. Fermented foods are reliable products; taste and aroma constitute another factor to be consumed (Dağlıoğlu, 2000). Fermented foods produced in comparison with the ingredients in their compositions are nutrients that had a long shelf life with their nutritional and sensory properties (Gotcheva et al., 2001). Bilgiçli et al. (2014) examined the effects of yeast (*Saccharomyces cerevisiae*), malt flour and phytase enzyme preparation on some nutritional parameters and phytic acid amount of tarhana and stated that the mineral content and protein bioavailability of tarhana are very high and tarhana is natural. It seen that the fermentation process is sufficient in this regard and the effects of yeast, malt and phytase are limited. Gökmen (2009) investigated the effects of adding quince to tarhana and it found that the use of raw quince in making tarhana more accepted, it is also a product that has good mineral value and high protein value. Tarakçı et al. (2013) investigated the effect of blackberry substitution on some functional and physicochemical properties of tarhana and concluded that there was a decrease in acidity, dry matter, water retention capacity, foaming capacity and foam stability in tarhana with the addition of blackberry. In viscosity measurements, they determined that viscosity decreased with increasing temperature for all samples. In the study conducted by Çağlar et al. (2013), the possibilities of using carob in tarhana were investigated and it was determined that the addition of carob flour positively affected the amount of mineral substances in tarhana and gave better results in terms of functional properties. Even if a small amount of carob flour, such as 3%, added to tarhana, it was determined that consumers preferred the product in terms of taste, color and smell. Some of these include the formulation of tarhana was found to be a product suitable for enrichment with various foods. In this study, tarhana enriched for nutritional, sensory, and structural enrichment (Tarakçı et al., 2013). As fruit additions, cranberry (Koca et al., 2006), quince (Gokmen, 2009), and carob (Herken and Aydin, 2015) have been used. The goal of this study was to produce a new type of tarhana by hazelnut pulp and to adding tarhana with nutritional, sensory, functional, aroma, and structure properties. In addition, hazelnut is an undeniable fact that the benefits to human health in the food industry as a side component aimed to evaluated in a different field.

2. Material and methods

For the production of tarhana samples, wheat flour, yoghurt, tomato paste, fresh yeast, mint, red pepper, tomato, salt and hazelnut samples purchased from the market in Ordu city. Physical, chemical and sensory analyzes were carried out in the Food Engineering Laboratories of Ordu University Faculty of Agriculture. Tarhana varieties produced in three replicates. Preparation of hazelnut; natural hazelnuts from the Ordu province market were first broken down and divided into smaller pieces in a food processor. In the cold pressed oil extraction machine, the hazelnut oil rate reduced. The pulp hazelnut ground in a food processor, divided into smaller pieces, and made ready for additional use.

Tarhana samples production: In the study, 0% (FK), 5% (F5), 10% (F10), 15% (F15), 20% (F20), 25% (F25), and 30% (F30) hazelnut pulps added to tarhana samples. For each tarhana sample, 500 g wheat flour (50%), 250 g yoghurt (25%), 120 g onion (12%), 60 g tomato paste (6%), 40 g salt (4%), 10 g fresh yeast (1%), 10 g red pepper (1%), and 10 g dry mint (1%) were added. While the hazelnut ratio increased in the product formulations, the amount of the other inputs kept constant. Before chopping the onions in the food processor, tomato paste, dried mint, red pepper, salt added, and a mixture obtained. After the mixture was pre-baked, water added and then cooked for a while. When the temperature of the obtained mortar decreased to 20°C, flour, yoghurt, yeast, and hazelnuts added. Kneaded for 10 minutes to ensure homogeneous dough structure. The prepared tarhana doughs allowed fermenting for 30 hours at 30°C. Fermented tarhana doughs brought into hazelnut-sized pieces on the drying tray. The fermented tarhana doughs dried in a fan oven (Nucleon, NST-120, Ankara) at 52°C until the moisture content was 12%, ground, and pulverized.

Sensory analysis tarhana samples: Sensory analysis performed in accordance with the study, 100 g Tarhana sample, 1.5 L distilled water, 40 g oil, 10 g salt were mixed and the mixture is cooked in the steel pot at medium heat for 5 minutes after stirring.

The cooked samples kept in an oven at 60°C and presented to the panelists in porcelain bowls. Faculty members and students (5 males, 5 females) served Tarhana soups from the Faculty of Agriculture who were between the ages of 20-40 years old and had no obstacles to sensory testing; color, odor, consistency, taste-aroma, and general acceptability evaluated using the sensory (Şensoy and Tarakçı, 2023).

Statistical Analysis: One-way ANOVA method used with Minitab 18 package program for statistical analysis of the data of the analysis results of Tarhana samples with hazelnut addition. Tukey multiple comparison test used to compare the samples, which found to be significant because of variance analysis.

3. Results and Discussion

Sensory properties in tarhana samples

Substances added while enriching the nutritional value of foods should cause no or little change in their sensory properties, and should not contradict consumer habits (Eyidemir, 2006). Sensory tests carried out to determine the sensory properties of the soups prepared from tarhana samples and to measure the degree of appreciation of the panelists, especially the tarhana with the addition of hazelnut pulp, which is a new product. For sensory testing, tarhana soups, are cooked for 10 minutes and then served in porcelain bowls to a group of 10 panelists at 60°C. Tarhana, it was evaluated separately by a group of 10 panelists out of a total of 10 points (1, very bad, 10, excellent) in terms of five features: color, smell, consistency, taste-aroma and general acceptability.

Table 1. Comparison of the values of sensory properties in Tarhana soups (1-10 Scores)*

Hazelnut ratio (%)	Colour	Smell	Consistency	Taste-Aroma	General Acceptability
FK	6.90±2.08a	6.80±2.20a	7.10±2.33a	5.90±1.97a	6.50±1.72a
F5	7.40±1.27a	7.50±1.43a	7.40±1.65a	7.20±1.32a	8.10±0.99a
F10	7.70±1.06a	8.10±1.29a	7.50±1.51a	7.70±1.77a	7.00±1.83a
F15	7.70±1.42a	7.30±1.95a	7.80±1.69a	7.70±1.77a	7.20±1.62a
F20	6.60±1.90a	7.30±2.31a	7.40±2.22a	7.00±2.79a	6.80±2.49a
F25	7.30±1.57a	8.00±1.70a	7.80±1.03a	8.00±1.25a	7.60±1.78a
F30	7.00±1.70a	7.60±1.96a	7.50±1.18a	8.00±1.76a	7.90±1.85a

*There is a significant difference between the letters in the same column ($p<0.05$).

Color scores of tarhana soups

The substances to be added, during the enrichment of the nutritional value of the food should make no or very little change in the sensory properties of the food, and this change should not contradict the consumer habits. The panelists to assess the level of appreciation carried it out. Variance analysis conducted for color evaluation for Tarhana soups. The effect of hazelnut pulp ratio not found to be significant, according to the results. Given that the odor scores of all tarhana with other substitution rates are higher than the control group, it concluded that hazelnut pulp substitution increases odor admissibility. Table 1 shows the variance analysis results for color evaluation for tarhana soups. According to the results, the effect of hazelnut pulp ratio not found to be significant ($p>0.05$). When the color values, a feature analyzed during the panel test, examined, it was determined that there was no statistically significant difference between the tarhana ($p>0.05$). It observed that the lowest color score belonged to the tarhana with 20% hazelnut pulp, with an average of 6.60±1.90, and the highest scores, 7.70±1.06 and 7.70±1.42, belonged to the tarhana with 10% and 15% hazelnut pulp substitution, respectively (Table 1). While the panelists liked the red color formed with the addition of 10-15% hazelnut, the panelists did not like pulp, the red color intensity formed with increasing amounts (20-25-30%).

Smell scores of tarhana soups

Table 1 shows the variance analysis results for the odor evaluation of tarhana soups. According to the results, the effect of hazelnut pulp ratio was not statistically significant ($p>0.05$). However, the lowest odor value found in the control group tarhana produced without the addition of hazelnut pulp (0%), with an average of 6.80±2.20.

The highest odor value, 8.10±1.29, seen in tarhana prepared with the addition of 10% hazelnut pulp (Table). According to these data, it seen that the most popular tarhana in terms of smell are those with 10% hazelnut pulp replacement. Considering the fact that the odor scores of all tarhana using other substitution rates (5, 15, 20, 25, and 30%) are higher than the control group, it be said that the hazelnut pulp substitution increases the acceptability in terms of odor. Şensoy and Tarakçı (2023) found that almond pulp added to tarhana resulted in similar color, smell, consistency, taste and aroma. When the consistency scores of panelists tarhana soups examined. The effect of hazelnut pulp ratio was not statistically significant in the taste-aroma and general acceptability scores.

Consistency scores of tarhana soups

The variance analysis results of the consistency evaluation for tarhana soups given in Table 1. When the consistency scores of the panelists' tarhana soups were examined, it was seen that there was no statistical difference between the tarhana ($p>0.05$). One of the features evaluated in the sensory panel was determined as consistency. Multiple comparison test results for hazelnut pulp ratios shown in Table 1. The lowest score seen in control tarhana with 7.10±2.23, while the highest score seen in tarhana with 15% and 25% hazelnut pulp added, with 7.80±1.69 and 7.80±1.03, respectively. The consistency scores of all tarhana in which other substitution rates used are higher than the control group, it said that the hazelnut pulp substitution increases the acceptability in terms of consistency. Tarakçı et al. (2004) investigated the use of corn flour and whey in tarhana and found that it was compatible with sensory values in their study.

Taste-aroma scores of tarhana soups

Variance analysis results of taste-aroma evaluation for tarhana soups shown in Table 1. The effect of hazelnut pulp ratio in determining the taste-aroma sensation was not found to be statistically significant ($p>0.05$). Multiple comparison test results for taste-aroma evaluation for hazelnut pulp ratios given in Figure 1. Because of the test, the control group tarhana produced without the addition of hazelnut pulp (0%) had the lowest taste-aroma value of 5.90±1.97, while the tarhana prepared with the addition of 25% and 30% hazelnut pulp had the highest taste-aroma value of 8.00±1.25-8.00±1.76. Again, the scores of the tarhana with 5, 10, 15 and 20% hazelnut pulp substituted at the end of the sensory test were higher than the control tarhana, and it said that the hazelnut pulp substitution increased the acceptability in terms of taste and aroma. Since tarhana is a fermented food, an important element that determines its taste is the formation of lactic acid based on lactic acid fermentation. In fact, the tarhana sample with 30% hazelnut pulp, which received the highest score in terms of taste, is also the sample that showed the highest acidity development.

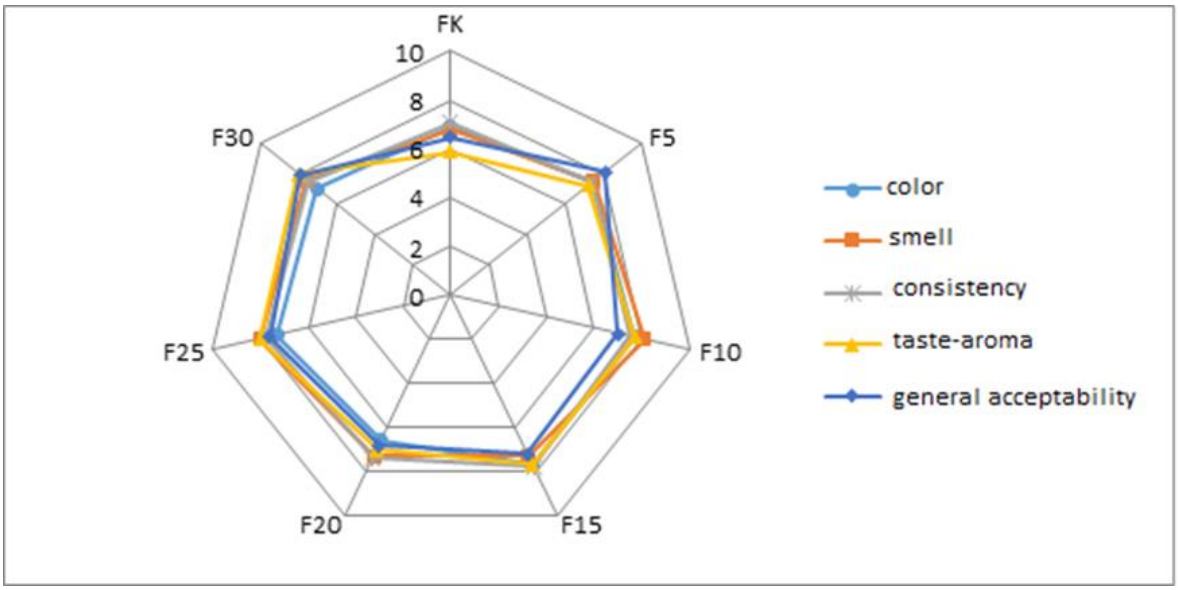

Figure 1. Sensory analysis results on tarhana samples

The sensory analysis carried out by cooking tarhana in the form of soup; it observed that there was no significant difference between the control group and the tarhana with hazelnut pulp in terms of color, smell, consistency and taste-aroma. However, when the sensory analysis results are examined, it is seen that tarhana with hazelnut pulp obtained higher scores than the control group.

General acceptability scores of tarhana soups

The variance analysis results for the general acceptability feature, which is included last in the sensory test form, given in Table 1. According to the results, the effect of hazelnut pulp was not found to be statistically significant ($p>0.05$). The multiple comparison test results of the general acceptance scores obtained in the sensory evaluation given in Table 1. While the lowest general acceptance score seen in the control group tarhana with 6.50±1.72, it observed that the tarhana prepared with 5% hazelnut pulp substitute had the highest general acceptability score with 8.10±0.99. It seen that the panelists with a rating of 7.90±1.85 liked the tarhana with 30% hazelnut pulp, after the tarhana with 5% hazelnut pulp. Considering the sensory analysis results in the light of these data, it is seen that tarhana with hazelnut pulp obtained higher scores than the control group. Actually, the scores obtained at the end of the sensory test are higher than the control tarhana, and it said that the hazelnut pulp substitution increases the acceptability of the tarhana. Tarhana is a fermented food; lactic acid formation based on lactic acid fermentation is an important factor in determining its flavor. When the sensory analysis results taken into consideration in the light of these data, it seen that hazelnut pulp added tarhana received higher scores than the control group. It said that hazelnut pulp substitution increases the acceptability of tarhana when the scores obtained at the end of the sensory test are higher than the control tarhana.

When some studies examined, various flours such as barley flour, quinoa flour, and corn flour, which substituted in certain proportions instead of wheat flour, used in tarhana production, and these products received low scores in terms of general acceptability (Erkan et al., 2006; Üçok et al., 2019; Anıl et al., 2020). However, wheat flour used in this study and no other flour substituted in the formulation. For this reason, it estimated that almonds have a positive effect on increasing general acceptability.

4. Conclusion

Hazelnut is the hard-shelled fruit with the most widespread cultivation area in the world after almonds, and Türkiye ranks first in the world in hazelnut production and export. For this reason, defatted hazelnut pulp was added to tarhana, our traditional product that has been produced in Türkiye and around the world from past to present, in certain proportions and its production was carried out in a laboratory environment. Because of the sensory analysis carried out by cooking tarhana in the form of soup, it observed that there was no significant difference between the control group and the tarhana with hazelnut pulp in terms of color, smell, consistency, taste, aroma and general acceptability. However, when the sensory analysis results are examined, it is seen that tarhana with hazelnut pulp received higher scores than the control group. In addition, new products created by adding a different flavor to tarhana soup, which is one of our traditional products. It has also been shown that products with high added value can be produced by using hazelnuts in tarhana, which we have more than half of the world's production.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Zekai TARAKÇI: Methodology, Investigation, Conceptualization, and Writing - original draft, Visualization; **Merve Nur OĞURLU**: Formal analysis, Data curation, Statistical analysis.

Ethical approval

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ASSESSMENT OF GROWTH CHARACTERISTICS AND YIELD OF DIFFERENT CUCUMBER CULTIVARS

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ABSTRACT

A field experiment was carried out to determine the performance of different cucumber varieties. The research was carried out in Randomized Complete Block Design (RCBD) with 4 treatments and 6 replications. The varieties used are Bhaktapur local, Kamini, Ragini, and Ranjha. Data were collected on the following parameters such as stem length, plant height, number of leaves, number of branches, number of male flowers, number of female flowers, days to first flowering, male to female flower ratio, days to first male flowering, days to first female flowering, fruit weight, fruit length, number of fruits per plant and yield. It is found that among the performance of different varieties, Kamini was the best high yielding variety for this locality with a yield of 58.93 ton ha^{-1} followed by Ranjha. Kamini exhibited a greater count of female flowers and fruits. In comparison, Bhaktapur local outperformed other varieties in various aspects such as plant height (193.37 cm), number of leaves (42.39), number of branches (7.13), and male to female ratio (2.63).

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1. Introduction

Cucumber (*Cucumis sativus* L.) is an edible fruit that comes under the family Cucurbitaceae. It comprises 117 genera and 825 species and is cultivated in warmer parts of the world (Nagamani et al., 2019). There are more than 30 species in the genus *Cucumis*, including the economically significant and widely cultivated cucumber (Huang et al., 2009). Cucumber is very popular among the Cucurbits and is now grown throughout the world (Shetty and Wehner, 2002). Cucumber is the fourth most important cultivated vegetable after cabbage, onion, and tomatoes in the world (Fareed et al., 2017). The fruits are edible and are used during summer as a cooling food (Akbar et al., 2015). Cucumber plants usually grow with very dense branches and leaves which lead to producing vegetative growth only, so the formed flowers and fruits tend to decrease (Mardhiana et al., 2017). It was reported that originated in India about 3,000 years ago domestication of cucumber occurred later throughout Europe (Bisognin, 2002; Shetty and Wehner, 2002). It was widely grown in China, Cameroon, Iran, the Russian Federation, and Türkiye (Amin et al., 2018). Dhading has been designated as a "pocket area": agriculture-based special economic zones that are directed towards promoting Nepalese agriculture, livestock products, and commodities that have a comparative advantage (Sedhain et al., 2018). In Dhading, Nepal cucumber is cultivated with a cultivation area of 440 ha with 6600 Mt production and productivity of 15.50 mt ha^{-1} (MOALD, 2020). The mostly cultivated variety of cucumber in Dhading is Bhaktapur Local.

Table 1. Status of Cucumber production in Dhading, Nepal (Source: MOALD 2012-2020)

S.N.	Year	Area (ha)	Production (Mt.)	Yield (Mt. ha^{-1})
1	2011/12	423	6134	15
2	2012/13	428	6206	15
3	2013/14	428	6206	15
4	2014/15	429	6221	15
5	2015/16	429	8220	19.2
6	2016/17	436	6344	15
7	2017/18	460	7598	14.5
8	2018/19	460	7586	16.49
9	2019/20	440	6600	15

Cucumbers are prostrate, branched, stiffly hairy vines possessing sharply five-cornered leaves and unbranched tendrils. Although most newer cultivars of cucumbers are gynoecious and several older cultivars are andromonoecious, cucumbers are monoecious. The flowers are formed in the leaf axils on extremely short axillary shoots with bright yellow color approximately 4 cm in diameter. In one axillary position, multiple staminate flowers often occur, whereas pistillate flowers usually appear singly (Tatlioglu, 1993).The calyx and corolla of all type of flower are provided with 5 lobed while staminate flower have three stamen and pistillate flower with five stigmas. The pistillate flower are provided with a long cylindrical shaped ovary that corresponding to the mature fruit (Tatlioglu, 1993). The intensity and type (e.g., gynoecious or monoecious) of sex expression are important in commercial cucumber production because differences in sex type and flowering can affect harvest date and relative yield (Staub et al., 2008). The cultivated species of cucumbers are predominantly monoecious but it consists of quantitative sex variations, ranging from almost male to completely female individuals (Shifriss, 1961). The first flowers to appear near the base of a cucumber plant are male. In about a weak after male flower initiation the female flowers appear with the small cucumber fruit at the base. Normally, fruits at the base of the plant are smaller than those borne on laterals or on the upper portion of the plant. It was revealed from the research done in Mid Hills of Nepal that the longest fruits (34 cm) were produced by the genotype Bhaktapur local at Hemja. At Lumle, the mohico green long produced the longest (28.37 cm) fruits followed by the Bhaktapur local (27.52 cm) and Kusule (26.83 cm) (Upadhyay et al., 2004). Experiment performed at Banepa-4, Kavre, Nepal in 2019 shows higher number of fruits, yield per plant and yield per hectare was observed on the variety Kamini (Shrestha et al., 2020). The research site was facing the problem of low productivity of cucumber due to the use of indigenous varieties and traditional cultivation practices. So, the research was conducted to know the best variety of cucumber.

2. Materials and methods

2.1. Site selection

The site of the study was selected at Dhading which was commanding area of PMAMP, Project Implementation Unit, Dhading. Nepal. The area is situated within the 27˚54'26.91''N latitude and 84˚53'11.74'' E longitude with an elevation of 487m above sea level. It is located in the sub-tropical climate of Nepal having average temperature of less than 10˚C in winter and more than 30˚C in summer season. Average annual rainfall of 3500 mm.

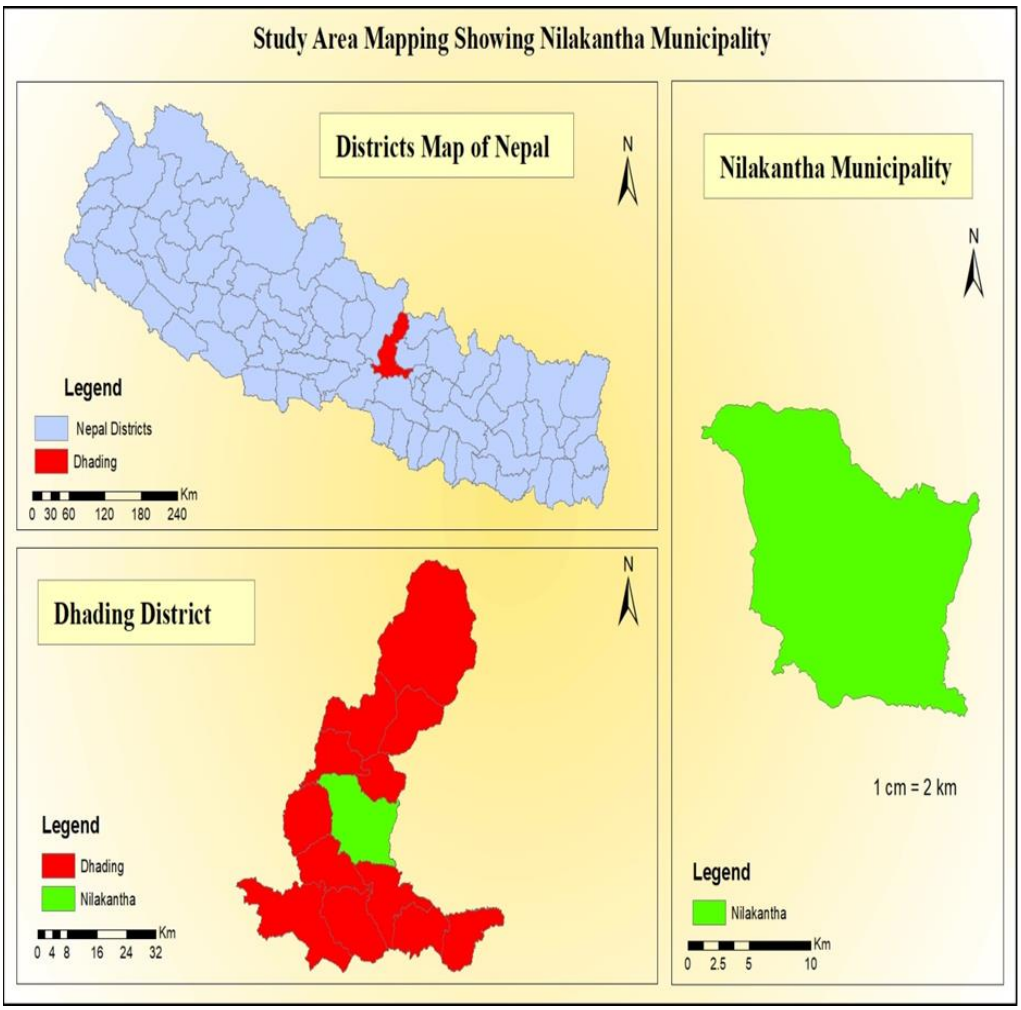

Figure 1. Research site, Nilakantha-7, Dhading

2.2. Climate of study area

The research site lies in the sub-tropical zone of Nepal. It is characterized by three distinct seasons namely, rainy monsoon (June – October), cool winter (November – February), and hot summer (March – May). Dhading has sub-tropical climate where average temperature becomes <10°C in winter and >30°C in summer. The minimum monthly average relative humidity was during month of April (51.09 %) and maximum during month of June (80.93 %) with average relative humidity of 61.27 during the crop period. The monthly average maximum temperature ranged from 18.49°C (February) to 27.98°C (May) and the monthly average minimum temperature ranged from 7.94°C (February) to 20.48°C (June).

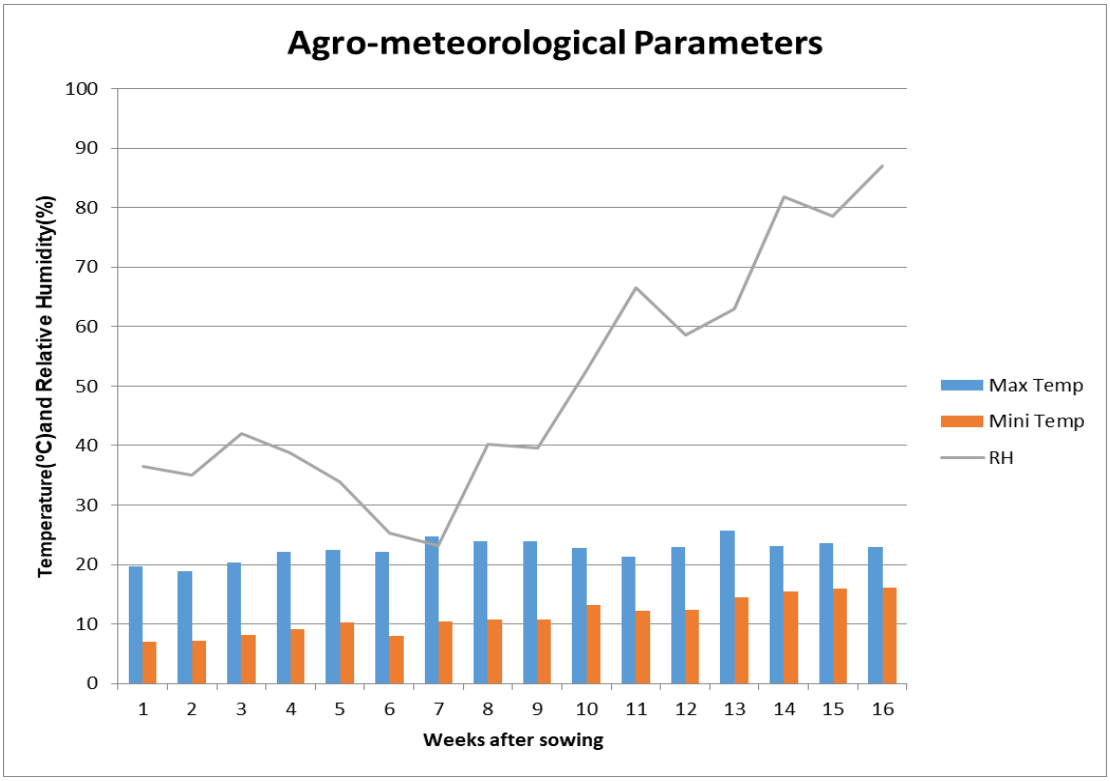

Figure 2. Graph of weekly average maximum and minimum temperature and relative humidity during the crop period in Dhading, Nepal (Source: Nepal Hydrological and Meteorological Department, 2021)

2.3. Physical and chemical

Before application of Farm Yard Manure (FYM) and chemical fertilizers, soil samples were taken from each replication by using shovel from 0 to 15 cm. The physical and chemical properties of soil sample taken from experimental field were tested. The texture of soil in experimental field was found to be sandy loam.

The pH of soil of experimental field was found to be 6.6. The nitrogen level was found to be medium, whereas the level of phosphorus and potassium was found to be low by Olsen method and Flame photometer respectively.

2.4. Experimental design

The experiment will be conducted on Randomized Complete Block Design with 4 treatments and 6 replications. The spacing between replication is 0.65 m×0.65 m and between plant is 0.75 m×0.75 m.

2.5. Details of treatment

For the research, the following 4 varieties (treatments) were selected.

Table 2. Details of treatments used in the study area

Symbols	Varieties
T1	Bhaktapur Local
T2	Kamini
T3	Ragini
T4	Ranjha

2.6. Field layout

Each variety (treatment) was replicated 6 times and each plot contained 25 plants, out of which 5 plants were taken as sample.

2.7. Field preparation

In order to get friable, well aerated and moist, and weed free soil, the field was firstly ploughed by power tiller on March 13, 2021. Individual pits of depth 30 cm were dug out to transplant the cucumber on March 15, 2021.

2.8. Plants under treatment

2.8.1. Seedling preparation

Soil, Farm Yard Manure (from the backyard farm) and sand in the ratio of 2:1:1 respectively was mixed, and poly-bags were filled with this mixture on February 22, 2021. Poly-bags were prepared, and one seed of each variety was sown in each polybags. They were regularly watered during seed raising period. Intensive care was taken for raising the seedling.

2.8.2. Transplanting

When seedlings were 22 days old and attain three leaves and hard enough, they were transplanted in the main field. 3 to 4 leaf stage healthy seedlings were transplanted after removing the polybag without disturbing the roots with spacing of 0.75 m * 0.75 m row-row and plant-plant distance on March 15, 2021.

2.8.3. Fertilizer

Recommended dose of NPK is 150:75:75 kg per hectare was applied in the form of Urea, Diammonium phosphate (DAP) and Muriate of Potash (MoP) respectively. Half amount of Nitrogen and full dose of Phosphorus and Potassium applied as basal dressing and remaining half dose of Nitrogen was split into two equal halves and top dressed after 4 weeks and 7 weeks of transplanting, respectively.

2.8.4. Intercultural operation

After transplanting of seedlings, various intercultural operations were done like weeding, irrigation and staking as per as the requirement. Two hand weeding were done at 20 Days after Transplanting and 45 Days after Transplanting. Stakings was done after 20 Days after Transplanting (DAT). Irrigation was done as per the requirements.

2.8.5. Harvesting

Manual harvesting was done when the cucumber gains desirable size of around 200-250 gram (Sharma and Bhattarai, 2006).

2.9. Data Collection

Each plot contained 25 plants which was the sampling frame. Out of these, 5 plants in each plot were selected by simple random sampling technique in each plot for data collection. Two types of parameters (growth and yield) were chosen for evaluation of five sample plants.

2.9.1. Growth Parameters

a) Plant height (cm)
The height of the five tagged plants was recorded in cm after 15 days, 30 days, 45 days and 60 days of transplanting with the help of meter scale.

b) Number of leaves
From five tagged plant, number of leaves per plants were counted and recorded after 30 days, 45 days and 60 days of transplanting.

c) Number of branches

The number of braches from each five tagged plants were counted and recorded after 30, 45 and 60 days of transplanting

2.9.2. Yield attributing characters

a) Number of male and female flower

The number of male and female flowers were recorded after first flowering from each tagged plants.

b) Days to appearance of first male flower

The number of days for the appearance of first male flower was recorded. If the variety takes lesser number of days to the appearance of first male flower, it was considered more ideal.

c) Days to appearance of first female flower

The number of days for the appearance of first female flower was recorded from each tagged plant. If the variety takes lesser number of days to the appearance of first female flower, it was considered ideal for cultivation.

d) Number of fruits

The total number of fruit from each plant and plot was counted and recorded while harvesting.

e) Fruit length (cm)

The length of the fruit was taken with the help of scale after each harvest.

f) Fruit yield (kg plant^{-1})

The fruit yield was calculated by weighing the fruits harvested at various pickings. The total weight of all picked fruits per plant during the season determined the fruit yield per plant.

g) Fruit yield per hectare

The fruit yield was determined by weighing the fruits harvested at various pickings. The total weight of all picked fruits during the season per plot was recorded, yielding the fruit yield per plot. The fruit yield per plot was then converted to yield per hectare.

2.10. Data analysis

The recorded data were then entered and organized in a Microsoft Excel 2013 (Microsoft Corporation, Redmond, Washington, United States). The obtained data was subjected to analysis of variance (ANOVA) using appropriate statistical software (R Studio, V-4.2.2, Boston Massachusetts, USA) (RCT, 2023). The mean was evaluated by Duncan's Multiple Range Test (DMRT) for interpretation level of Probability.

3. Results and discussion

3.1. Growth parameters

3.1.1. Plant height

Among four different varieties of cucumber, Bhaktapur local is the local variety and remaining are hybrid varieties. Plant height was measured with the help of meter scale. Table 3 shows that there was a non-significant difference among different varieties of cucumber in plant height during early stage of growth i.e., up to 15 DAT. However, there was significant difference in plant height among the different varieties of cucumber at 30, 45 and 60 DAT. Bhaktapur local recorded tallest plant height (77.73 cm) which was statistically at par with the variety Kamini (71.7 cm). Variety Ragini recorded shortest plant height (48.5 cm) which was statistically at par with the variety Ranjha (58.03 cm). Bhaktapur local recorded tallest plant height at 45 DAT (156.27 cm) and at 60 DAT (193.37 cm). At 45 DAT, variety Ranjha recorded shortest plant height (88.5 cm). At 60 DAT, variety Ranjha recorded shortest plant height (116.33 cm) and statistically at par with the variety Ragini (121.97 cm). At 60 DAT, the plant height of different varieties was in range of 116.33 cm to 193.37 cm. Bhaktapur local recorded highest plant height and number of branches among different varieties in " Varietal screening of Cucumber in Sundarharaicha Municipality, Morang, Nepal" (Sah et al., 2021).

Plant height was found to be highest in variety Chadani followed by Bhaktapur local and then Kamini in "Evaluation of Cucumber varieties for quality traits and yield" (Shrestha et al., 2020). It has been reported that the highest plant height was observed in Kathmandu local (203 cm) and the lowest plant height in Kasinda (148.70) with average plant height of 177.45 cm (Maharjan et al., 2015).

Table 3. Average plant height (cm) of different cucumber varieties at different growth stages

Varieties	Plant height (cm)			
	15 DAT	30 DAT	45 DAT	60 DAT
Bhaktapur local	20.70	77.73^{a}	156.27^{a}	193.37^{a}
Kamini	20.55	71.7^{a}	118.5^{b}	152.47^{b}
Ragini	20.43	48.5^{b}	102.47^{bc}	121.97^{c}
Ranjha	20.27	58.03^{b}	88.5^{c}	116.33^{c}
SEM (±)	0.15	3.08	5.79	6.53
F probability	Ns	***	***	***
$LSD_{0.05}$	0.72	11.33	16.45	11.43
CV %	2.85	14.38	11.48	6.36
Grand mean	20.49	63.99	116.43	146.03

Note: DAT: Days after Transplanting, Ns: Non significant, ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test.

3.1.2. Number of leaves

Green leaves were counted from each tagged plant in each plot. Table 4 shows among four different varieties, number of leaves per plant was found to be statistically non-significant at 30 DAT. Varieties differed significantly for number of leaves at 45 DAT and 60 DAT. Highest number of leaves were obtained from variety Kamini (21.12) and was statistically at par with Bhaktapur Local (21.01) and Ranjha (19.87). Poor result was obtained from variety Ragini (16.07). Highest number of leaves per plant was observed in Bhaktapur local (42.39) followed by Kamini (39.47) and then Ranjha (34.87). Likewise, the lowest number of leaves per plant was recorded in Ragini (29.70) during entire cropping duration.

Table 4. Average Number of leaves of different cucumber varieties at different growth stages

Varieties	Number of leaves		
	30 DAT	45 DAT	60 DAT
Bhaktapur local	13.97	21.01^{a}	42.39^{a}
Kamini	12.80	21.12^{a}	39.47^{ab}
Ragini	10.80	16.70^{b}	29.70^{c}
Ranjha	13.13	19.87^{a}	34.87^{b}
SEM (±)	0.84	0.75	1.23
F probability	Ns	*	***
$LSD_{0.05}$	2.78	2.89	4.70
CV %	17.84	11.93	10.43
Grand mean	12.68	19.67	36.61

Note: DAT: Days after Transplanting, Ns: Non significant, *, significant at 0.05 P value, ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test.

3.1.3. Number of branches

The number of branches per plant indicates the growth performance of the vine (Sharma et al., 2005). The result of statistical analysis showed that among different varieties, number of branches at 30 DAT, 45 DAT and 60 DAT was found significant. Significantly higher number of branches were recorded in Bhaktapur local followed by Kamini at 30 DAT, 45 DAT and 60 DAT. Likewise, poor results were obtained from Ragini during entire crop duration. At 45 DAT and 60 DAT, variety Kamini and Ranjha were found statistically at par as shown in Table 5.

Similarly, among different varieties of cucumber, the greater number of branches was found in Bhaktapur local (5.26 branch) and the smaller number of branches was found in Encounter-962 (1.20 branch) by (Sah et al., 2021). Likewise, number of primary branches was recorded highest on the variety Chadani which was statistically at par with the variety Shahini-2, Bhaktapur local and Kamini by (Shrestha et al., 2020). Also (Subedi and Sharma, 2005) reported Bhaktapur Local had significantly longer vine and the vine had significantly very high number of branches.

Table 5. Average plant height (cm) of different cucumber varieties at different growth stages

Varieties	Number of branches		
	30 DAT	45 DAT	60 DAT
Bhaktapur local	3.27[a]	5.37[a]	7.13[a]
Kamini	2.70[b]	3.87[b]	5.03[b]
Ragini	1.97[d]	3.37[c]	4.30[c]
Ranjha	2.35[c]	3.80[b]	5.23[b]
Sem (±)	0.11	0.16	0.22
F probability	***	***	***
$LSD_{0.05}$	0.27	0.38	0.39
CV %	8.52	7.56	5.88
Grand mean	2.57	4.10	5.43

Note: DAT: Days after Transplanting, ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test

3.2. Yield attributing characters

3.2.1. Number of flower per plant and days to first flower

The result of the statistical analysis shows the number of flowers among different varieties during total growth period were found significantly different at 0.1 % level of significance as shown in Table 6.

Male flowers: Significantly highest number of male flower was found in Bhaktapur local followed by Kamini. Likewise, among different variety lowest number of male flower per plant was found in Ranjha.

Female flowers: There was a significant difference among different varieties on number of female flowers per plant. Highest number of female per plant was recorded from Kamini which was statistically at par with Ranjha. Likewise, lowest number of female flower per plant was recorded in Bhaktapur local.

Days to first male flower: The statistical analysis for days to first male flowering showed significant result. Male flowers were significantly first observed in Ranjha which was statistically at par with Kamini and Ragini. Similarly, the numbers of days to first male flowers were significantly greater at Bhaktapur local (24.21 days).

Days to first female flower: Duration to first flower initiation is an important character for identifying early genotype (Upadhyay et al., 2004). Variety Ranjha produced the first female flower significantly in short duration (22.76 days) and was statistically at par with Kamini (22.86 days). Similarly, Bhaktapur Local produced female flowers significantly later at 31.83 days after transplanting.

Male to female ratio: Sex ratio was statistically found higher in Bhaktapur local (2.63). The significantly lower sex ratio was statistically found in variety Ranjha which was statistically at par with Kamini.

Similar results were found in following findings:

- In Bhaktapur local significantly higher number of male flowers (32 m^{-2}) was reported in "Single stem cultivation and performance of cucumber cultivars during winter-spring seasons" by (Subedi and Sharma, 2005).

- Bhaktapur local recorded maximum number of male flowers per plant in control (107 per plant) by (Dhakal et al., 2019).

• The lowest number of female flower (69.33 flowers plant^{-1}) was reported in Bhaktapur local in "Varietal screening of Cucumber in Sundarharaicha Municipality, Morang, Nepal" by (Sah et al., 2021).

• According to "Monitoring and varietal screening cucurbit of fruit fly, Bactrocera cucurbitae Coquillett (Diptera: tephritidae) on cucumber in Bhaktapur and Kathmandu, Nepal" by (Maharjan et al., 2015), Kamini had the highest number of female flowers (27.33 flowers plant^{-1}), while Kusle had the fewest (7.83 flowers plant^{-1}).

• (Shrestha et al., 2020) reported variety Bhaktapur local took longer days (21.3±0.1 days) to initiate male flower which was significantly different (P≤0.001) from all other varieties.

Table 6. Floral characters of different cucumber varieties

Treatments	Male Flowers	Female Flowers	Days to first male flower	Days to first female flower	Sex Ratio
Bhaktapur local	42.83^{a}	16.37^{b}	24.21^{a}	31.83^{a}	2.63^{a}
Kamini	37.78^{b}	24.70^{a}	20.57^{b}	22.86^{c}	1.54^{c}
Ragini	35.71^{c}	18.17^{b}	20.96^{b}	24.00^{b}	1.97^{b}
Ranjha	33.80^{d}	24.45^{a}	20.25^{b}	22.76^{c}	1.38^{c}
Sem (±)	0.75	0.82	0.37	0.78	0.10
F probability	***	***	***	***	***
$LSD_{0.05}$	1.89	2.08	1.26	1.01	0.19
CV %	4.05	8.07	4.75	3.23	8.36
Grand mean	37.55	20.92	21.49	25.37	1.88

Note: ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test

3.2.2. Number of fruits per plant and fruit length

Number of fruits per plant: Fruits from each randomly selected plants were counted at each harvest and total number of fruits per plant was recorded and average numbers of fruits were calculated. Table 7 shows there was a highly significant difference among the varieties on total number of fruits per plant. Significantly higher number of fruits per plant were harvested from variety Kamini (15.17) and was statistically at par with Ranjha (14.50). Similarly, lowest number of fruits per plant were harvest from Bhaktapur local (8.17). (Shrestha et al., 2020) reported highest numbers of fruits were harvested from variety Kamini (19.7±2.0) and the lowest numbers of fruits were harvested from the variety Bhaktapur local (12.8±1.4).

Fruit length (cm): The result of statistical analysis shows non-significant difference in the fruit length among the different varieties. Table 7 shows that the average fruit length was 20.45 cm. However (Shrestha et al., 2020) reported that longest fruit length on the variety Karma (26.8±1.2 cm) which was at par (P≤0.05) with the varieties Shalini (26.7±1.4 cm), Bhaktapur local (26.7±0.6 cm), Shahini-2 (26.3±0.1 cm) and Chadani (25.5±0.2 cm) followed by the variety Kamini (24.4±0.4 cm) and Manisha (20.3±0.3 cm).

Table 7. Number of fruits per plant and fruit length of different varieties of cucumber

Varieties	Number of fruits per plant	Fruit length (cm)
Bhaktapur Local	8.17^{c}	20.75
Kamini	15.17^{a}	20.19
Ragini	11.33^{b}	20.63
Ranjha	14.50^{a}	20.23
Sem (±)	0.65	0.14
F probability	***	Ns
$LSD_{0.05}$	2.13	0.85
CV %	14.06	3.36
Grand Mean	12.29	20.45

Note: Ns: Non significant, ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test

3.2.3. Average fruit weight and yield

Average fruit weight: Varieties differed significantly for average fruit weight. The highest result was obtained from Bhaktapur local (0.312 kg) and lowest result was obtained from Ragini (0.200 kg) as in Table 8. It has been shown that the Bhaktapur Local was found superior as compared to the other varieties in terms of average fruit weight (Sah et al., 2021). It has been also reported that weight of different varieties of cucumber depends on heredity and genetic variability (Kumar et al., 2013).

Yield: Varieties differed significantly for yield per plant. The highest result was obtained from Kamini (3.315 kg) and significantly higher yield (58.93 mt ha^{-1}). Poor yield per plant was obtained from Bhaktapur local (2.543 kg) and significantly lower yield (45.21 mt ha^{-1}) which was statistically at par with variety Ragini (2.847 kg). In this research, we found Kamini as the best yielding variety. However, NS-404 variety was found superior as compared to the other varieties in terms of yield by (Sah et al., 2021). Likewise, Bhaktapur local recorded minimum yield of 17.48 t ha^{-1} in control (Dhakal et al., 2019). Also, lowest yield was recorded in Bhaktapur local variety (3.53 mt ha^{-1}) by (Dahal and Adhikari, 2021).

Table 8. Average weight (kg), yield per plant (kg) and yield (mt ha^{-1}) of Cucumber

Variety	Average weight (kg)	Yield per plant (kg)	Yield (mt ha^{-1})
Bhaktapur local	0.312^{a}	2.543^{b}	45.21^{b}
Kamini	0.252^{b}	3.315^{a}	58.93^{a}
Ragini	0.200^{d}	2.847^{b}	50.60^{b}
Ranjha	0.219^{c}	2.897^{ab}	51.50^{ab}
Sem (±)	0.01	0.09	1.522415
F probability	***	*	*
$LSD_{0.05}$	0.02	0.44	7.74
CV %	5.39	12.20	12.20
Grand mean	0.245	2.90	51.56

Note: *, significant at 0.05 P value, ***, Significant at 0.001 P value. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan Multiple Range Test

4. Conclusion

Bhaktapur local was found to be superior in morphological characters such as stem length, number of leaves and number of branches whereas Kamini was found to have highest number of female flowers and fruits per plant. Kamini was most appropriate variety followed by Ranjha to obtain higher yield in short duration whereas Ragini and Bhaktapur local was least appropriate in terms of yield.

Compliance with Ethical Standards

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this manuscript.

Authors' Contributions

All authors contributed equally to all stages of the preparation of this manuscript. Similarly, the final version of the manuscript was approved by all authors.

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EFFECT OF PINCHING ON THE GROWTH AND YIELD OF CHILI (*Capsicum annuum*)

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A B S T R A C T

Pinching is known to invigorate the growth of multiple shoots, promote the growth of lateral, and increase fruit formation. An experiment was conducted in the field of the Gokuleshwor Agriculture and Animal Science College, Baitadi, Nepal to examine the effect of pinching on the growth and yield of the chili (Capsicum annuum). The experiment utilized the 'NS-1701 variety and was carried out in a Randomized Complete Block Design (RCBD) with five replications and four treatments; pinching at 20, 30, and 40 days after transplanting (DAT), and no pinching as control. Results revealed significant effects of pinching on various parameters, including plant height, leaf number, number of branches, number of fruits, and fruit yield. The maximum plant height was observed in the control group without pinching. The maximum number of branches, the highest leaf number, the number of fruits, and the yield were achieved when pinching was performed at 30 DAT compared to other treatments and control. Based on the observed result, it can be concluded that pinching the chili plants at 30 DAT was the most effective approach for achieving optimal growth and yield.

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1. Introduction

Chili (*Capsicum annuum*) is a highly valued and widely cultivated spice crop known for its heat, flavor, and vibrant colors. They play an essential role in various cuisines, adding richness and depth to dishes such as vegetables, pickles, salads, and appetizers (Kumara et al., 2016). Chili belongs to the *Capsicum* genus, which is indigenous to southern North America and northern South America. This genus comprises a diverse range of species, estimated to be between 25 and 200. Among these species, there are five commonly cultivated ones: *Capsicum annuum* L., *Capsicum frutescens* L., *Capsicum chinense* Jacq., *Capsicum baccatum* L., and *Capsicum pubescens* L. (Roy, 2016).

In Nepal, chili cultivation is a significant agricultural activity, throughout the year. The primary chili season spans from October to April, accounting for approximately 70% of the country's total production (Ashrafuzzaman et al., 2011). However, despite its importance, Nepal faces challenges in meeting the demand for chili peppers, resulting in substantial imports from neighboring India. About 80% of dry chilies and 24% of green chilies are sourced from India, indicating the low domestic production and no self-sufficiency in this spice crop. Several factors affect the limited chili production in Nepal. Farmers encounter constraints such as a lack of necessary inputs, insufficient knowledge about appropriate farming practices, and limited technology development and transfer. Additionally, farmers in rural and hilly areas often lack awareness of effective pest and disease management techniques, further impeding chili cultivation.

To address these challenges and enhance chili production, it is crucial to explore innovative techniques and practices that can improve yields and farmers' livelihoods. One such technique is pinching, which involves removing the apical buds and some leaves, allowing side branches to develop (Rajput et al., 2020). Pinching offers several benefits, including disease control, promotion of lateral bud growth, and increased fruit formation (Jyothi et al., 2018). By stimulating the growth of multiple terminal shoots that bear flowers, pinching has the potential to enhance chili yield (George, 2004).

Despite the potential advantages of pinching, there is limited information available regarding the optimal timing and application of this technique in chili cultivation. Therefore, this study aims to determine the appropriate timing for pinching in chili production, with the goal of increasing growth and yield.

2. Materials and methods

2.1. Plant materials

The experiment was carried out from March 2021 to August 2021 at the Gokuleshwor Agriculture and Animal Science area in Baitadi, Nepal. The field's coordinates are 29.6880° N latitude and 80.5494° E longitude at an elevation of 850 m above mean sea level. This region falls within the subtropical and temperate climate zone, with average summer and winter temperatures of 21.1°C and 7.7°C, respectively. The experimental design was laid out in a Randomized Complete Block Design (RCBD) with four treatments (Table 1) and each treatment was replicated by five times. Each individual plot was of 1.8 × 1.8 m dimensions.

Table 1. Different treatments used in the experiment

Treatment	Treatment detail
T1	Pinching at 20 DAT
T2	Pinching at 30 DAT
T3	Pinching at 40 DAT
T4	No Pinching

The main field was plowed multiple times, and farmyard manure (FYM) was applied and incorporated into the soil during the final plowing. The recommended basal dose of fertilizer, including urea, single super phosphate, and muriate of potash, was applied. NS1701 seeds were sown in seedling trays and about a month after sowing, they were planted with between-row and within-row spacing of 45 x 30 cm in well-prepared soil on 24th April, 2021.

The remaining half dose of nitrogen was applied as a top dressing four weeks after transplanting. Regular cultural operations and plant protection measures were carried out as per requirement.

2.2. Methods

Five plants were randomly selected, excluding the border plants, and tagged accordingly to record observations on various growth and yield parameters. Observations were made on the plants on the 30th, 40th, 50th, 60th, 70th, 80th and 90th days after planting (DAT). The height of the plant was measured from the base to the tip of the apical bud. The number of leaves per plant was determined by counting fresh fully developed leaves. The number of branches, number of fruits, and total yield of chili were measured on tagged plants.

2.3. Statistical analysis

The collected data were compiled and entered into Microsoft Excel for analysis. GenSTAT C software (15th Edition) was used for the Analysis of variance. In this study groupings were established based on LSD (Least Significant Differences).

3. Results and discussion

3.1. Effect of pinching on plant height

Pinching did not significantly affect plant height at 30, 40, 60, and 70 DAT but it did have a significant impact on plant height at 50 DAT (Table 2). The control group (no pinching) showed the highest plant height, which was statistically similar to the plants subjected to pinching at 30 DAT.

On the other hand, the lowest plant height was observed in the group where pinching occurred at 40 DAT, and this was statistically similar to the plants in the pinching at 20 DAT and pinching at 30 DAT treatments. The reduced height of the pinched plants can be attributed to the removal of the apical portion during pinching, while the control plants showed greater height due to the absence of pinching. Nain et al. (2017) also reported similar results, noting that plants without pinching exhibited maximum height, possibly due to the limited distribution of nutrients towards lateral branches. This promotes continuous vegetative development, photosynthesis, and the production of auxin hormones, which aid in cell elongation. Consistent findings have been reported by Sahu and Biswal (2020) and Rajput et al. (2020). Meena et al. (2015) found that repeated pinching leads to the development of multiple side branches, resulting in reduced plant height.

Table 2. Effect of pinching on plant height (cm) of chili var. NS-1701.

Treatments/Days After Transplanting (DAT)	30 DAT	40 DAT	50 DAT	60 DAT	70 DAT
Pinching at 20 DAT	15.34^{ab}	26.00^{b}	37.20^{b}	54.84^{b}	59.40^{b}
Pinching at 30 DAT	14.00^{b}	26.48^{b}	37.08^{b}	58.64^{b}	64.14^{ab}
Pinching at 40 DAT	17.08^{a}	28.63^{ab}	38.31^{b}	54.64^{b}	59.14^{b}
No pinching	17.28^{a}	31.68^{a}	48.04^{a}	63.18^{a}	70.10^{a}
LSD	2.93	4.91	8.11	7.66	8.60
CV (%)	13.4	12.6	14.6	9.6	9.9

LSD= Least Significant Differences, NS= non-significant, *significant at 5% level

3.2. Effect of pinching on the number of leaves per plant

The effects of pinching on the number of leaves were not statistically significant at 30, 40, 50, 60, and 70 DAT (Table 3). At 70 DAT, the highest number of leaves per plant was observed in the group where pinching occurred at 30 DAT, but this was statistically similar to the plants subjected to pinching at 40 DAT and the control group (no pinching). The lowest number of leaves per plant was recorded in the group where pinching occurred at 20 DAT.

Similar findings were reported by Kattel et al. (2023) in okra plants, where pinching at different stages did not significantly affect the number of leaves. Their study compared at no pinching, first node pinching,

second node pinching, third node pinching after transplanting and found no significant differences in leaf number among the treatments. Likewise, Kumar et al. (2018) found no significant effect of nipping on leaf number in field bean.

Table 3. Effect of pinching on the number of leaves of chili var. NS-1701

Treatment/ Days After Transplanting (DAT)	30 DAT	40 DAT	50 DAT	60 DAT	70 DAT
Pinching at 20 DAT	47.68^{b}	93.72^{a}	104.6^{a}	105.8^{a}	115.3^{b}
Pinching at 30 DAT	60.22^{a}	101.40^{a}	119.2^{a}	129.1^{a}	139.8^{a}
Pinching at 40 DAT	52.76^{ab}	93.04^{a}	106.6^{a}	122.8^{a}	129.6^{ab}
No pinching	51.48^{ab}	90.96^{a}	101.0^{a}	114.8^{a}	133.1^{ab}
LSD	11.07	18.11	21.61	24.03	21.15
CV (%)	15.1	13.9	14.5	14.8	11.9

LSD= Least Significant Differences, NS= non-significant, *significant at 5% level

3.3. Effect of the pinching on the number of branches per plant

Pinching significantly impacted the number of branches at 40, 50, and 60 DAT, but not at 30 and 70 DAT (Table 4). The highest number of branches per plant was observed in the group where pinching occurred at 30 DAT, which was statistically partial similar to the group subjected to pinching at 20 DAT. On the other hand, the lowest number of branches was recorded in the control group without any pinching.

The increase in the number of branches per plant can be attributed to the removal of terminal buds during pinching, which reduces the concentration of auxin and limits vertical plant growth (Ali et al., 2021). Similarly, Maharnor et al. (2011) found that pinching at 30 DAT resulted in the maximum number of primary branches per plant, increased plant spread, and larger stem diameter.

Table 4. Effect of pinching on the number of branches of chili var. NS-1701

Treatments/Days After Transplanting (DAT)	30 DAT	40 DAT	50 DAT	60 DAT	70 DAT
Pinching at 20 DAT	6.56^{a}	7.52^{a}	8.38^{ab}	10.08^{ab}	11.64^{ab}
Pinching at 30 DAT	6.42^{a}	7.80^{a}	9.94^{a}	11.60^{a}	12.90^{a}
Pinching at 40 DAT	5.96^{a}	6.72^{ab}	8.05^{b}	9.11^{b}	10.46^{b}
No Pinching	5.48^{a}	6.22^{b}	7.36^{b}	8.63^{b}	9.94^{b}
LSD	1.258	1.059	1.612	1.606	2.245
CV (%)	15.0	10.9	13.9	11.8	14.5

LSD= Least Significant Differences, NS= non-significant, *significant at 5% level

3.4. Effect of pinching on the number of fruits per plant

Table 5 shows that the highest number of fruits per plant was observed in the pinching occurred at 30 DAT. The lowest number of fruits per plant was recorded in the group where pinching occurred at 40 DAT, which was statistically similar to the groups subjected to pinching at 20 DAT and the control group without any pinching.

The greater fruit production observed in the group subjected to pinching at 30 DAT could be attributed to the accumulation of additional synthetic compounds that were later utilized for the production of more flowers, resulting in a higher number of fruits. These findings align with a study by Eve et al. (2016) on butternuts, which reported similar outcomes. Tswanya et al. (2017) also found that pinching at around 30 DAT significantly increased the number of fruits in eggplant plants. Similarly, Mardhiana et al. (2016)conducted a study on cucumber plants and found that pruning significantly increased fruit yield, especially at the right time, by about 30 DAT. The development of lateral branches induced by pinching can be attributed to the increased number of fruits, with more sites for flower formation and subsequent fruit sets being provided, thereby supporting the findings of this study.

Table 5. Effect of pinching on the number of fruits of chili var. NS-1701

Treatments/Days After Transplanting (DAT)	50 DAT	60 DAT	70 DAT	80 DAT	90 DAT
Pinching at 20 DAT	1.24^{b}	15.68^{b}	23.72^{a}	35.40^{a}	30.50^{a}
Pinching at 30 DAT	2.48^{a}	21.02^{a}	29.09^{a}	41.23^{a}	34.62^{a}
Pinching at 40 DAT	1.90^{a}	17.83^{ab}	26.03^{a}	33.70^{a}	29.68^{a}
No pinching	1.20^{b}	10.95^{c}	17.20^{b}	31.56^{a}	31.76^{a}
LSD	0.640	4.417	6.068	10.76	5.877
CV (%)	27.2	19.6	18.3	22.0	13.5

LSD= Least Significant Differences, NS= non-significant, *significant at 5% level

3.5. Effect of pinching on yield

Pinching has significant variations in yield across the different treatments. The highest yield was observed when pinching was performed at 30 DAT, followed by pinching at 40 DAT, which was statistically similar to pinching at 20 DAT. The treatment without pinching resulted in the lowest yield. The average gross yield achieved was 25.12 tons per hectare.

The increased yield in the pinched treatments can be attributed to the stimulation of branching stems, flowers, and fruits as a result of the pinching technique. These findings align with previous research by Rajbeer & Kumar (2009), who reported similar outcomes. Singh and Kaur (2018) conducted a study on bell pepper plants and found that pinching at the appropriate stage significantly enhanced yield. They explained that pinching induced lateral branching, leading to an increased number of flowering sites and subsequent fruit production, resulting in an overall higher yield. Tswanya et al. (2016) investigated tomato plants and reported that pinching around 30 DAT led to increased lateral branching, flowering, and fruit production. Similarly, Sarkar et al. (2007) studied sweet pepper plants and found that pinching at the appropriate time significantly increased the number of branches and fruit yield, providing further support for the results observed in this study.

Table 6. Effect of pinching on yield of chili var. NS-1701

Treatment	Yield (ton per hectare)
1	23.81^{b}
2	33.06^{a}
3	24.58^{b}
4	19.05^{c}
LSD	3.819
CV (%)	11

LSD= Least Significant Differences, NS= non-significant, *significant at 5% level

4. Conclusion

The results of the study imply that pinching can significantly affect the growth and yield of chili plants. Pinching at 30 days after transplanting (DAT) was found to be the most effective technique, leading to increased plant height, maximum leaves and branches, as well as improved fruit output and yield. These results offer valuable insights for chili farmers, highlighting the potential benefits of incorporating pinching techniques into their cultivation practices. Further research can expand on these findings by exploring additional factors and parameters related to pinching's effects on chili cultivation.

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Compliance with Ethical Standards

Conflict of Interest

Authors have no conflict of interest to declare.

Authors' Contributions

Sabina Aryal and Pooja Thapa prepared the research proposal, field work, data collection, analysis, interpretation, and manuscript preparation. All other authors supported in data collection and editing. Sabina Aryal finalized the manuscript. All authors collectively reviewed and approved the final manuscript for submission.

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In vitro CULTURE OF NODAL CUTTINGS IN KIWIFRUIT

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ABSTRACT

This study aimed to determine the effects of plant growth regulators and different medium on *in vitro* propagation of 'Hayward' and 'Zespri Gold' kiwifruits. Micro-cuttings were used as explant sources and cultured in MS and WPM medium containing different concentrations of BA and GA_3. Subcultures were carried out at intervals of 4-6 weeks. Contamination rate (%), blackening rate (%), callus development rate (%), shoot rate (%), and propagation coefficient (plantlet/explant) were determined. The micropropagation experiment was carried out according to the randomized plot design. The arc-sin transformation was applied to the percentage values before analysis. Significance levels of the means were compared with the LSD test. It was determined that 0.1% mercury chloride application increased the sterilization efficiency. As the BA concentration in the medium increased, the rate of callus formation of the explants increased. While there was no difference in shoot rates of explants cultured on MS and WPM medium, the propagation rate was higher in MS medium. The propagation coefficient of the 'Hayward' kiwi cultivar was 3.08 in MS medium containing 1.0 mgL^{-1} BA + 0.5 mgL^{-1} GA_3. MS medium can be recommended as a basic medium for *in vitro* kiwi propagation.

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1. Introduction

Commercially produced kiwifruits consist of 1-2 species within the genus *Actinidia*. The genus *Actinidia* includes 55 species and approximately 76 taxa (Wang and Gleave, 2012). The kiwifruits originated in Eastern China, and they grow spontaneously in the forest foothills, in regions with high relative humidity (70-80%) at an altitude of at least 300, mostly 800-1400 m above sea level (Üçler et al., 2000). According to paleobiological studies, *Actinidia* species are estimated to be 20-26 million years old (Ying-qian and Yu, 1991). Although the homeland of kiwi fruit is China, the first commercial garden was established in New Zealand in the 1930s. The cultivation studies conducted on kiwifruit growing have shown that the cultivation in the Black Sea, Marmara, and Aegean Regions of Türkiye is suitable for cultivation (Alp, 2017). Today, it is also grown economically in the Mediterranean Region. While world kiwifruit production was over 4.4 million tons in an area of approximately 270 thousand hectares in 2020, it was approximately 73.8 thousand tons in 3261 hectares in Türkiye (FAO, 2021).

Like other plant products, the kiwi plant is propagated by generative or vegetative methods. However, generative propagation is not preferred for commercial production purposes. A major problem is the high variation in propagated plants due to the genetic expansion in generative production. In addition, due to the dioecious plant structure, 80% of the seedlings obtained from propagation by seed are male, and 20% are female. Therefore, vegetative propagation methods are preferred in commercial seedling production (Tanimoto, 1994; Sivritepe and Tuğ, 2011).

Studies on the propagation of the kiwi plant by tissue culture started with Harada's study in 1975, and this research was followed by many studies using different species and different explant types (Gui, 1979; Monette, 1986; Lin et al., 1994; Kumar and Sharma, 2002; Kim et al., 2007). In the studies, the medium developed by Murashige and Skoog (1962) was mostly used for shoot and callus stimulation. In addition, Gamborg B5 (Barbieri and Morini, 1987) and N6 medium (Lin et al., 1994) are other medium that have been used successfully. The literature has reported that regeneration can be achieved in kiwifruit by the indirect organogenesis method using different explant sources (Kumar and Sharma, 2002; Rugini and Gutierrez-Pesce, 2003). However, since regeneration is achieved from callus in this way, there are drawbacks in the mass production of plants, and the most important of these is the inability to control genetic stability (Kumar and Sharma, 2002). Prado et al. (2007) found genetic variation between donor plants in their AFLP analysis of male plants obtained by indirect organogenesis technique. Therefore, it is seen that single-node cuttings with axillary buds and shoot tips are used as starting materials in *in vitro* propagation of kiwis (Monette, 1986; Wang and Gui, 1988; Marino and Bertazza, 1990; Wiyaporn et al., 1990; Pedroso et al., 1992; Ding et al., 1997; Kumar et al., 1998; Souad et al., 1998).

This study aimed to determine the effect of MS and WPM medium containing different concentrations of BA and GA_3 on the *in vitro* propagation of single-node micro steel explants taken from 'Hayward' and 'Zespri Gold' kiwifruit cultivars.

2. Material and methods

2.1. Plant materials

'Hayward' and 'Zespri Gold' kiwi cultivars planted in the research area of Ondokuz Mayıs University Faculty of Agriculture were used as explant sources. Young shoots were taken from the plants in the spring and brought to the laboratory environment (Figure 1A). Micro cuttings containing a single node, prepared by cutting 3-5 cm long from these shoots (Figure 1B, C), were used as explants.

2.2. The surface sterilization of explants

During sterilization, the explants taken from the field were kept under running tap water for 60 min in all sterilization experiments to remove surface contaminants. Four different sterilization protocols were tested. The explants were placed in a sterile environment and soaked in 70% ethyl alcohol (EtOH) for 1-2 min and then in 20% commercial NaOCl (Domestos) containing 1-2 drops of Tween-20 for 20 min. Finally, explants were rinsed with sterile pure water in the first protocol.

Figure 1. Preparation of micro cuttings, A: Shoots, B: A cutting with leaf, C: Explants

In the second sterilization protocol, only the commercial NaOCl concentration was increased to 30%. In the third, unlike the first protocol, explants were treated with alcohol, and they were kept in a 10% H_2O_2 solution for 10 min. In the last protocol, unlike the first, the explants were kept at 0.1% $HgCl_2$ for 20 min before being treated with alcohol. After all sterilization procedures, the explants were rinsed again with sterile pure water in the final stage.

2.3. *In vitro* culture of micro cuttings

After sterilization, the single-node explants were taken into the laminar flow hood and prepared for *in vitro* culture by cutting the upper and lower parts of the node, leaving approximately 3 cm of material. In order to obtain shoots from micro cuttings, WPM (Lloyd and McCown, 1980) and MS (Murashige and Skoog, 1962) medium containing BA (0, 0.5, 3.0 mgL^{-1}) and GA_3 (0, 0.3, 0.5 mgL^{-1}) concentrations were used in the experiment. While preparing the medium, 20 gL^{-1} sucrose was added as a carbon source and 7 gL^{-1} agar was used as a solidifier. The pH of the medium was adjusted to 5.7-5.8 before autoclaving. 50 mL of the medium was poured into 660 cc glass jars. The medium and other equipment were autoclaved under 1.5 p.s.i at 121 °C for 15 min.

2.4. Examined criteria and statistical analyses

Surface sterilization experiments were conducted using a factorial randomized trial design with ten replications in both cultivars, using three explants in each replication. Observations were taken four weeks after the culture initiation, and the contamination rate (%) and blackening rate (%) were determined. An experiment was set up for micropropagation according to the random plot design. The experiment was conducted in two nutrient medium with four different plant growth regulators (PGRs) concentrations, including a control group. Each combination had four replications, and four explants were used in each replication. Subcultures were carried out in 4-6 weeks periods. In the experiment, callus development rate (%), shooting rate (%) and propagation coefficient (plantlet/explant) were determined. The number of plantlets was observed after three subcultures.

The arc-sin transformation was applied to the percentage values before analysis. The data were subjected to variance analysis using the JMP (version 8.01) package program, and the significance levels of the means were compared with the LSD ($P<0.05$) test.

3. Results and discussion

The contamination rates in surface sterilization experiments were evaluated statistically, and no significant difference was found among protocols ($P>0.05$).

The highest contamination rate in the culture medium was observed in the first protocol. A 79.4% contamination rate was observed in the 'Zespri Gold' cultivar and a 73.9% contamination rate in the 'Hayward'. The lowest contamination rates were 52.4% and 43% in the 'Zespri Gold' and 'Hayward' cultivars, respectively (Figure 2). Although there were no statistically significant effects of different sterilization protocols, it was observed that hydrogen peroxide (H_2O_2) and mercuric chloride ($HgCl_2$) applications relatively reduced the contamination rate (Figure 2). Observations showed that the contamination was caused by bacterial and mostly fungal contamination.

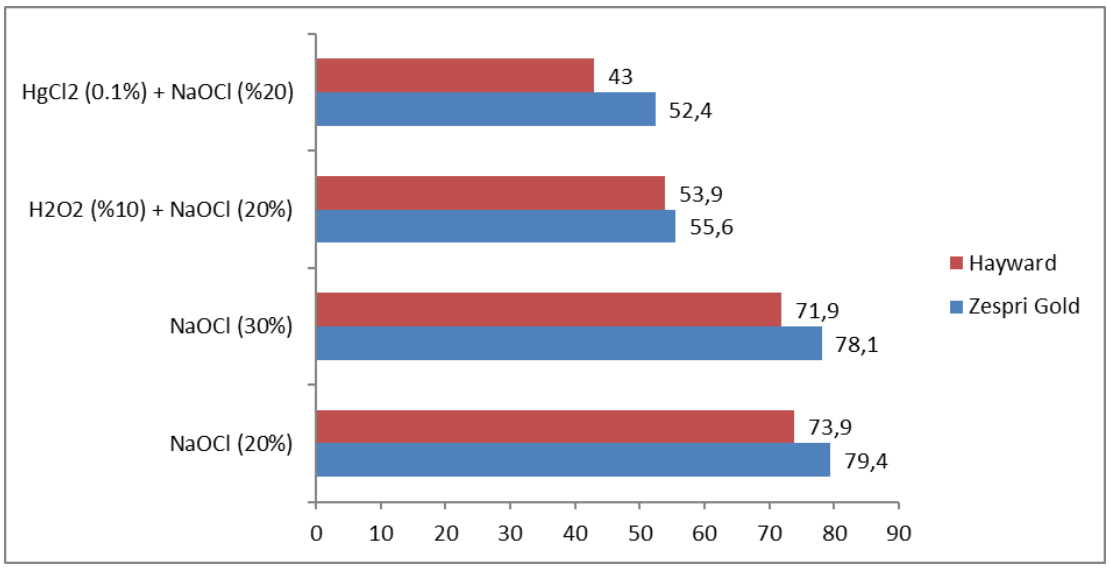

Figure 2. Contamination rate (%) in explants subjected to different sterilization agents.

Although no contamination problems were observed in the first weeks of culture, in the following weeks, fungal or bacterial contaminations occurred on the explants, suggesting that the source of contamination may be internal. Debenham et al. (2016) used nodal segments in *in vitro* propagation studies on *Actinidia arguta* (Siberian kiwi), *A. chinensis*, *A. deliciosa* (kiwi) and *A. polygama* (Silver vine) species and explants subjected to 4.2 mgL^{-1} sodium hypochlorite for 30 min. They observed intense contamination in the *in vitro* culture. Researchers reported that even biocide and fungicide applications used in surface sterilization applications seem beneficial in the first weeks, but contaminations are observed in the later stages of culture. Similarly, Cassells (1991) and Leifert et al. (1994) indicated that the reason for the contamination observed in explants taken from plants grown under field conditions was endogenous. Sivritepe and Tuğ (2011) found that contamination rates ranged from 10 to 30% in their study on *in vitro* propagation of 'Hayward' and 'Matua' kiwifruit cultivars. However, the means of contamination rates were not statistically significant, and absolute sterilization success was not achieved in their studies. In the current study, due to the contamination observed in the culture environment, it became clear that there was fungal and bacterial contamination in the donor plants. Therefore, the limited number of donor plants of 'Zespri Gold' cultivars continued the study with a few sterile explants. Similar results were observed in explants from two commercial plantations of 'Hayward' cultivars. However, the results were affected by contamination problems, so the experiment was continued using non-contaminated explants.

No statistically significant difference was found in the blackening rate in micro cuttings placed in the culture medium. When the blackening rates were examined according to the nutrient medium, blackening occurred in 14.87% of the explants cultured in the MS medium and 13.68% cultured in the WPM medium (Table 1). It was observed that the blackening rate increased as the PGR concentrations increased, although it was not statistically significant. It is thought that the reason for the blackening of explants in the culture medium is related to surface sterilization practices. Although chemicals are necessary to prevent microbial contamination in surface sterilization processes, they can also lead to phytotoxicity.

On the other hand, the oxidation of phenolic compounds secreted from the cut surface of explants by polyphenoloxidases and peroxidases can also be the reason for blackening (Singh (1996). Therefore, optimizing surface sterilization processes and using clean materials is necessary for *in vitro* propagation of kiwifruit.

Table 1. Blackening rate in cultured explants

Medium No	PGR (mgL^{-1}) ($BA+GA_3$)	MS 'Hayward'	MS 'Zespri Gold'	WPM 'Hayward'	WPM 'Zespri Gold'	Medium x PGR
0	0 + 0	24.98 (22.57)	8.33 (8.94)	8.33 (8.94)	0.0 (0.0)	10.41 (10.16)
1	0.5 + 0.3	8.33 (8.94)	16.65 (13.80)	0.0 (0.0)	8.33 (8.94)	8.33 (7.97)
2	0.5 + 0.5	24.98 (22.57)	16.65 (17.71)	16.65 (17.71)	8.33 (8.94)	16.65 (16.73)
3	1.0 + 0.3	8.33 (8.94)	24.98 (22.57)	24.98 (22.57)	16.65 (17.71)	18.73 (17.95)
4	1.0 + 0.5	16.65 (13.80)	8.33 (8.94)	24.98 (22.57)	24.98 (22.57)	18.73 (16.97)
5	3.0 + 0.3	24.98 (22.57)	16.65 (17.71)	24.98 (22.57)	8.33 (8.94)	18.73 (17.95)
6	3.0 + 0.5	8.33 (8.94)	0.0 (0.0)	16.65 (13.80)	8.33 (8.94)	8.33 (7.97)
	Cultivar x Medium	16.65 (15.48)	13.08 (12.84)	16.65 (15.48)	10.71 (10.89)	
	Mean of Medium	14.87 (14.16)		13.68 (13.18)		

There was no statistically significant difference between the averages (P>0.05), and the values obtained from arc-sin transformation are given in parentheses.

Callus structures are formed from explants placed in the culture medium, and callus formation rates are affected mainly by genotype, culture medium and plant growth regulators. According to the results, the effects of PGR concentrations and the nutrient medium on callus formation were statistically significant. In contrast, the interaction of cultivars and factors was not statistically significant. The highest callus formation rate was 66.62% in the 'Hayward' cultivar placed on MS medium containing 3.0 mgL^{-1} BA and 0.5 mgL^{-1} GA_3 growth regulator, and 58.30% was in the 'Zespri Gold' cultivar. Similarly, callus formation in the WPM medium containing the same concentration of PGR was 41.65% in the 'Zespri Gold' cultivar, while it was 24.98% in the 'Hayward' cultivar. It has been determined that the callus formation rate decreases as the PGR concentration decreases. When PGR concentrations were evaluated individually, the highest callus formation was observed in the medium containing 3.0 mgL^{-1} BA and 0.5 mgL^{-1} GA_3, with a rate of 47.88%. The lowest callus formation rate was observed in the control group. Compared to the nutrient medium, it was determined that the rate of callus formation in MS nutrient medium was higher than in WPM medium (Table 2).

Table 2. Callus formation rates in explants

Medium No	PGR (mgL^{-1}) ($BA+GA_3$)	MS 'Hayward'	MS 'Zespri Gold'	WPM 'Hayward'	WPM 'Zespri Gold'	Medium x PGR**
0	0 + 0	16.65 (17.90)	8.33 (9.24)	8.33 (9.24)	0.0 (0.57)	8.33 (9.24) c
1	0.5 + 0.3	8.33 (9.24)	33.30 (31.43)	0.0 (0.57)	16.65 (17.90)	14.57 (14.79) bc
2	0.5 + 0.5	8.33 (9.24)	16.65 (17.90)	16.65(17.90)	16.65 (17.90)	14.57 (15.74) bc
3	1.0 + 0.3	24.97 (26.57)	24.98 (22.77)	24.97(26.57)	24.98 (22.77)	24.97 (24.67) bc
4	1.0 + 0.5	41.62 (36.30)	0.0 (0.57)	16.65(17.90)	24.98 (22.77)	20.81 (19.38) bc
5	3.0 + 0.3	41.65 (40.26)	41.65 (40.26)	24.98(22.77)	16.65 (17.90)	31.23 (30.30) ab
6	3.0 + 0.5	66.62 (58.65)	58.30 (53.79)	24.98(22.77)	41.65 (40.26)	47.88 (43.87) a
Cultivar x Medium*		29.74 (28.31)	26.17 (25.14)	16.65 (16.82)	20.22 (20.01)	
Mean of Medium**		27.95 (26.72) a		18.44 (18.41) b		

* There was no statistically significant difference between the averages (P>0.05),

** The difference between the means is statistically significant (P<0.05); the values obtained from angle transformation are given in parentheses. LSD PGR=16.20, LSD Medium=8.25

When micropropagation studies on kiwifruit are examined, callus formation from explants generally emerges as undesirable. Debenham et al. (2016) reported that excessive callus formation causes unstable growth and a decreased proliferation rate in explants. Sivritepe and Tuğ (2011) used single node cuttings in 'Hayward' and 'Matua' kiwifruit cultivars, similar to our study, and reported that callus formation occurred at a rate of 40-90%. Researchers reported that callus formation may depend on the explant type. Our study showed that callus formation from explants was similar to this study, and excessive callus development was observed in explants. However, callus formation may be caused by the explant source and the effect of the plant growth regulators used. The effect of the growth regulator concentrations used in our study was statistically significant.

After culture initiation, the dormant buds on the explants formed shoots. Except for BA and GA_3 concentrations, the effects of cultivars, mediums, and their interactions on shooting were not statistically significant ($P>0.05$). The mean shoot formation percentage was approximately 55%. The effects of PGR concentrations on shoot formation were statistically significant, and it was determined that the shoot formation rate differed by 41-62%. The highest shoot formation rate, 62.46%, was observed in medium containing 0.5 mgL^{-1} BA + 0.5 mgL^{-1} GA_3 and 1 mgL^{-1} BA + 0.3 mgL^{-1} GA_3. The lowest shoot formation rate was determined in medium without PGR (Table 3).

Table 3. Shooting rate in single node cuttings cultivated

Medium No	PGR (mgL^{-1}) (BA+GA_3)	MS 'Hayward'	MS 'Zespri Gold'	WPM 'Hayward'	WPM 'Zespri Gold'	Medium x PGR**
0	0 + 0	49.95 (44.97)	33.3 (35.24)	41.62 (40.10)	41.62 (40.10)	41.62 (40.10) c
1	0.5 + 0.3	49.95 (44.97)	41.62 (40.10)	41.62 (40.10)	49.95 (44.97)	45.78 (42.53) bc
2	0.5 + 0.5	66.62 (58.20)	66.62 (58.20)	58.3 (53.34)	58.3 (53.34)	62.46 (55.77) a
3	1.0 + 0.3	58.3 (53.34)	74.97 (66.57)	49.9 (44.97)	66.62 (58.20)	62.46 (55.77) a
4	1.0 + 0.5	58.27 (49.83)	49.95 (44.97)	58.3 (53.34)	58.27 (49.83)	56.20 (49.50) abc
5	3.0 + 0.3	41.62 (40.10)	66.62 (58.20)	58.3 (53.34)	58.3 (53.34)	56.21 (51.25) ab
6	3.0 + 0.5	58.3 (53.34)	58.3 (53.34)	66.6 (58.20)	58.3 (53.34)	60.38 (54.55) ab
	Cultivar x Medium*	54.71 (49.25)	55.92 (50.95)	53.5 (49.06)	55.91 (50.44)	
	Mean of Medium*	55.31 (50.10)		54.72 (49.75)		

* There was no statistically significant difference between the averages ($P>0.05$).
** The difference between the means is statistically significant ($P<0.05$). The values obtained from the arc-sin transformation are given in parentheses. LSD PGR = 12.71

Sivritepe and Tuğ (2011) reported that the shoot emergence rate in single node cuttings taken from 'Hayward' and 'Matua' cultivars was between 3-10%. According to the results of our study, the percentage of shoot emergence from dormant buds was higher than in the previous study. This may be due to the difference in genotype, the period in which the explants were taken, and the effects of other internal and external factors. However, our study may suggest that the difference in the nutrient medium at the initial stage and the use of GA_3 increased the shoot emergence. On the other hand, they obtained a similar shoot emergence (50%) only from shoot tip explants.

After shoot formation occurred in micro cuttings, the shoots were cut and subcultured in the same medium to ensure propagation. Among the kiwi explants, especially in the 'Hayward' cultivar, the growth and development of the explants differed to the extent that they were visually distinguishable according to the nutrient medium (Figure 3).

The propagation was not observed in the first subculture of explants, while it was determined that the leaves were visually enlarged instead of having shoot growth. It is thought that the disproportionate growth of the leaves is due to the increase in the concentration of cytokinin used in the nutrient medium since the developmental difference was observed visually in explants cultured on medium containing constant GA_3 concentrations (MS-2, MS-4, MS-6) (Figure 3).

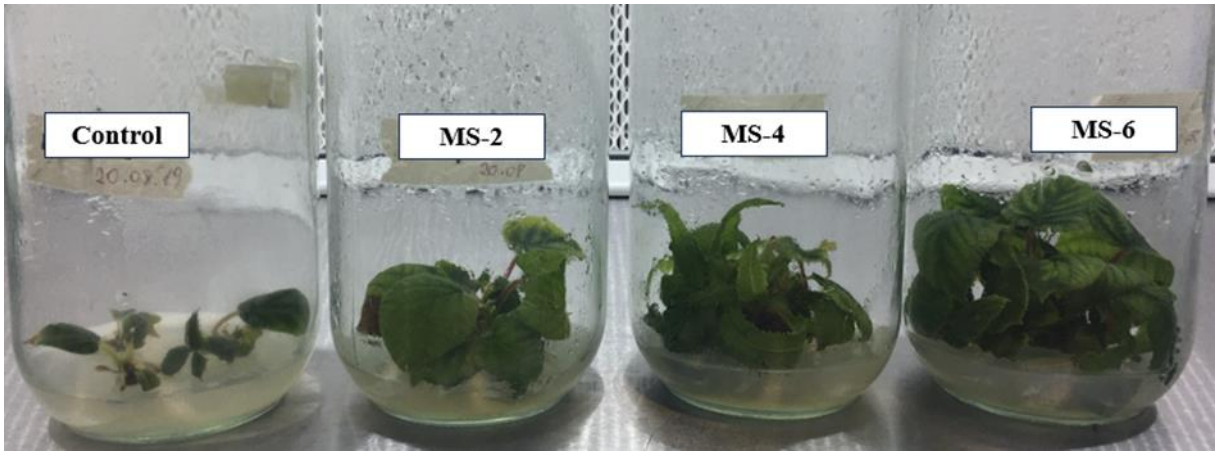

Figure 3. Developmental differences in explants in the 'Hayward' cultivar

As a result of the statistical analysis, an average of 1.82 plantlets per explant was obtained in the 'Hayward' cultivar. The effect of the medium on the propagation coefficient was not statistically significant (P>0.05). However, it was determined that the propagation coefficient in the MS medium (2.00) was higher than in the WPM medium (1.64). The effect of BA and GA_3 concentrations on the propagation coefficient was statistically significant (P<0.05). The highest propagation coefficient was 2.62, obtained from the medium containing 1.0 mgL^{-1} BA + 0.5 mgL^{-1} GA_3. The lowest propagation coefficient was observed in the medium without PGR (Table 4).

Table 4. Propagation coefficient in Hayward kiwi cultivar

Medium No	(BA+GA_3) (mgL^{-1})	'Hayward'		Medium *x* PGR**
		MS	WPM	
0	0 + 0	1.33	1.16	1.25 b
2	0.5 +0.5	1.83	1.66	1.75 b
4	1.0 + 0.5	3.08	2.16	2.62 a
6	3.0 + 0.5	1.75	1.58	1.66 b
	Mean of Medium*	2.00	1.64	
	Mean of Cultivar	1.82		

* There was no statistically significant difference between the averages (P>0.05),
** The difference between the means is statistically significant (P<0.05), LSD PGR=0.753

As a result of the observations during *in vitro* culture, limited shoot propagation was observed in the WPM medium. Shoot growth and development in the WPM medium were restricted (Figure 4A). MS medium supplemented with 0.5 mgL^{-1} BA + 0.5 mgL^{-1} GA_3, which contained a lower cytokinin concentration, plants were similarly observed to be smaller but larger in volume (Figure 4B). It was determined that increasing the concentration of cytokinin further increased volumetric growth in leaves (Figure 4C). However, this growth and development has not been fully reflected. Although the effect of the nutrient medium on shoot formation and propagation is not statistically significant, the visual weakness observed in the plant's growth and development suggests that the nutrient medium's content is important in obtaining healthy plantlets. Considering the medium components, it is known that the nitrogen (N), potassium (K), and calcium (Ca) content of the MS medium is more than three times higher than that of the WPM medium.

Therefore, the higher volume growth of explants placed in the MS medium may be due to the richer medium content. In the later stages of the culture, it was observed that some shoots spontaneously rooted as the subculture time increased (Figure 4D). No spontaneous rooting was observed from any explants on the WPM medium.

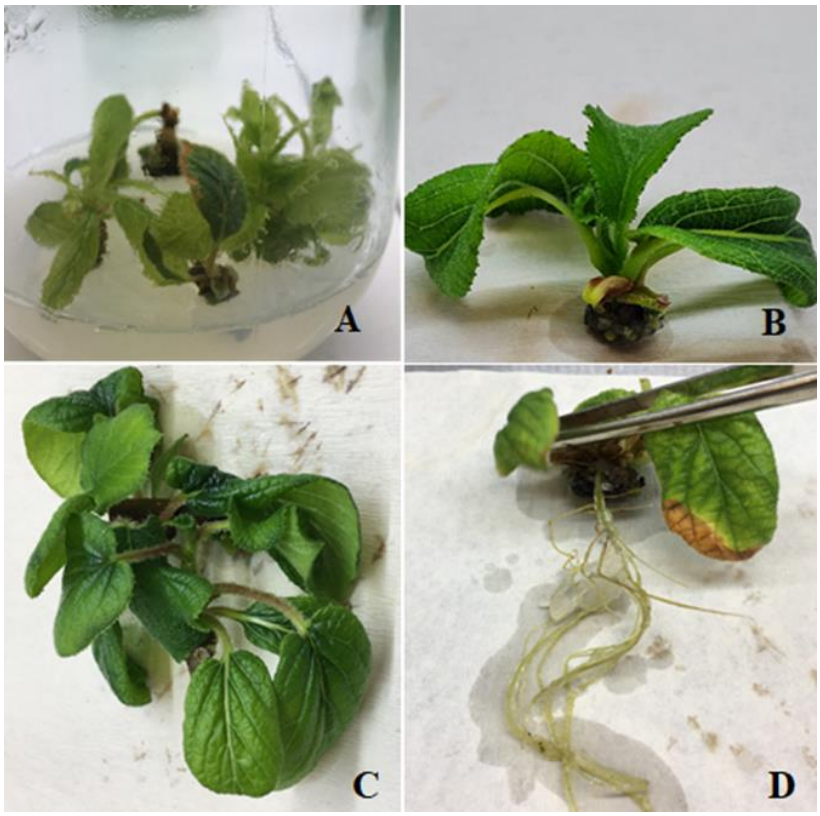

Figure 4. Different developmental stages of Hayward kiwi cultivar (A: Plantlets developed from explants cultured on WPM medium + 1.0 mgL^{-1} BA + 0.5 mgL^{-1} GA_3, B: MS medium + 0.5 mgL^{-1} BA + 0.5 mgL^{-1} GA_3, C: MS medium + 3.0 mgL^{-1} BA + 0.5 mgL^{-1} GA_3, D: rooting of plantlets in culture medium).

4. Conclusion

Propagation by tissue culture has disadvantages, such as constant research and development, high initial costs, skilled labor, and protocols based on plant material. However, when the necessary protocols for plant material are optimized, mass production can be made cheaply and quickly with the automation system. At the beginning of our study, which aimed at micropropagation of 'Hayward' and 'Zespri Gold' kiwifruit cultivars in *in vitro* culture, different experiments were set up to overcome the contamination problems observed in plant materials. However, the donor plant was contaminated with internal contaminants, which did not allow the 'Zespri Gold' cultivar micropropagation. On the other hand, testing different sterilization protocols in the study gives an idea about which sterilization is more successful for future studies. The propagation coefficient of the 'Hayward' cultivar was determined. Although researchers could not agree on the starting medium in previous studies, using MS medium as the basic medium can be recommended. However, testing different cytokinin derivatives in future studies suggests that micropropagation success may be increased.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Mehmet TÜTÜNCÜ: Investigation, Methodology, Data curation, Validation, Writing - original draft. **Muharrem ÖZCAN**: Investigation, Conceptualization, Data curation, Review and editing.

Ethical approval

Not applicable.

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EFFECT OF PLANTING DATE AND BULB CIRCUMFERENCE WIDTH ON BULBLET YIELD OF NARCISSUS (*Narcissus tazetta* L.) FLOWER

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A B S T R A C T

In this study, the effects of planting date and bulb circumference on bulb yield were investigated in *Narcissus tazetta* flower. *Narcissus* spring bulbs, which were picked from nature in August, were divided into three groups (12.1-14, 10.1-12 and 8.1-10 cm) according to their circumference and planted in open field at different dates (September, October and November). In the research, bulb sprout rate, bulb circumference increase, and bublet formation rate were determined. As a result of the study, the best planting date (September) in terms of bulb circumference increase values (15.25 cm) and bulblet formation number (1.39 per plant) was revealed as a result of the study. The highest bulb circumference increase rate (34%) was obtained from bulbs with a circumference of 8-10 cm, while the lowest value (25%) was obtained from bulbs with a circumference of 12-14 cm. In terms of bulblet formation rates, there was no difference between circumference length. In the light of these data, it has been determined that bulbs with a circumference of 8-10 and 10-12 cm should be used to increase the bulb circumference. Bulbs with a circumference of 12-14 cm and larger should be used to obtain bulblet.

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1. Introduction

In recent years, the demand for Türkiye's ornamental plants has been increasing and production is developing in line with these demands. Türkiye has suitable climate and ecological conditions for ornamental plant production and is close to foreign markets. In order to transform these advantages into added value, it is necessary to prevent foreign dependency in purchasing materials. However, hybrid ornamental plant seeds used in ornamental plant production in Türkiye are mostly imported. In addition to seeds, bulbs used in the production of bulbous plants are also imported. This situation increases foreign dependency and production costs in ornamental plants, causing the country's resources to be exported (Çelikel, 2015).

The ornamental plants sector is known as the sector that provides the highest added value per unit area when compared to other areas of the agricultural sector (SÜSBİR, 2016). Although Türkiye's ornamental plant production and export has increased in recent years, it has not yet reached the desired target. Ornamental plants imports amounted to 37517 dollars and exports amounted to 114391 dollars. Türkiye's ornamental plants production areas have reached approximately 56865 da. Natural flower bulb production areas in this area are very low, approximately 506 da (TUIK, 2023). In order to develop the sector, it is very important to introduce local species to the sector and increase domestic production. Utilizing our existing wealth, protecting our endangered species and increasing R&D studies for this purpose will contribute to our country's production and therefore its economy.

Natural flower bulbs, known as geophytes, are economically important in the ornamental plants sector (Aksu et al., 2002). *Narcissus* (*N. tazetta*), which is one of our important geophytes and the subject of this study, is a species from the *Narcissus* family (Amaryllidaceae). *N. tazetta* species have naturally spread from the Mediterranean coast to China and Japan (Grey-Wilson and Mathew, 1981; Mathew, 2002; Zeybekoğlu, 2010). In Türkiye, it has a natural distribution in Adana, Siirt, Antalya, Diyarbakır, Mersin, İzmir, Muğla, Samsun, Ordu (Ünye) and Van (Sari and Çelikel, 2018a; TÜBİVES, 2023). Obtaining production material is an important issue in the production of bulbous plants. As a matter of fact, obtaining bulbs from bulbous plants is quite laborious and takes a long time. The most important criterion in determining bulblet formation and other vegetative characteristics in bulbous plants is the width of the bulb circumference. This issue has been touched upon in previous studies on daffodils.

In the study of Özel and Erden (2008) on *N. tazetta*, bulbs are classified into three different sizes: 8-10 cm, 10-12 cm, and 12-14 cm. In the research, it varied between the circumference of the mother bulb is 13.40-14.90 cm, the weight of the mother bulb is 47.32-67.25 g, the number of bulblet is 1.68-2.21 per plant, the circumference of the bulblet is 8.50-9.83 cm, the weight of the bulblet is 15.67-17.17 g, the bulblet yield is kg m^{-2}. In addition, Özel and Erden (2018) determined increase rate of bulb circumference in *N. tazetta* subsp. *tazetta* by comparing the initial and final circumference of bulbs. The researchers initially divided bulbs into 8-10, 10-12, and 12-14 cm circumferences and found that the highest increase rate was 42.22-43.7% in the first group, while the lowest was 2.05-6.92% in the third group. Additionally, they indicated that the number of bulblet formations per plant was 0.48 in the 8-10 cm group, 2.12 in the 10-12 cm group and 4.88 in the 12-14 cm group.

Ünye district of Ordu, the *Narcissus* (*N. tazetta* L.), with many fragrant and multi-layered flowers on a long stem, which spreads mostly at the bottom of the hazelnut trees, blooms from the end of autumn to the beginning of spring (Sari and Çelikel, 2019a; Sari and Çelikel, 2019b). In this period when cut flowers are scarce, they are sold in bunches, creating an additional source of income for the district farmer. Determining the appropriate production methods to ensure the production of bulbs required for the production of daffodil flowers will be instructive for the producer. For this reason, the main purpose of this research study is to determine the most suitable bulb circumference width and planting date in terms of bulblet yield of the layered narcissus flower, which spreads naturally in Ünye.

2. Material and methods

2.1. Plant materials

In the study, bulbs from the natural populations of *Narcissus tazetta* located in Saca village locality of Ordu/Ünye district were used as plant material (Figure 1).

2.2. Bulb circumference

Measurements were made to determine the most suitable bulb circumference for cultivating bulbs collected from their natural environment. Bulb circumference was measured with a tape measure from the widest part of the bulb with the longest diameter perpendicular to the axis of the bulb and grouped as 0-8, 8.1-10, 10.1-12, 12.1-14 and above 14.1cm. The ones to be used in planting were divided into the first circumference (12.1-14 cm), the second circumference (10.1-12 cm), and the third circumference (8.1-10 cm), and planting was carried out. Bulbs of three circumferences were used at the first and second planting dates. At the third planting date, only the first and second circumference bulbs were used due to insufficient bulbs with a circumference of 8.1-10 cm.

2.3. Planting dates and climate conditions

After the bulbs were divided into three circumferences, they were sprayed with fungusit (Captan 50 wp). Afterwards, the bulbs, which were taken to the dry, were dried and placed in plastic crates according to their circumference and dried in a cool place. Bulbs were kept until September 23 and the first plantings were made on this date. Those planted on September 23 were kept in a shaded environment at an average of 20 °C, those planted on October 23 at 19.2 °C and those planted on November 12 were kept in a shaded environment at an average of 18 °C.

Table 1. Climatic values of the trial period

Months	Average temperature (°C)	Max. temperature (°C)	Min. temperature (°C)	Rains (mm)	Relative humidity (%)	Number of days with snow
January	6.3	18.0	-2.4	96.2	66.3	2
February	6.7	15.4				
March	8.1	18.6	0.5	151.0	77.0	1
April	9.6	26.1	4.8	79.2	81.2	
May	14.7	23.4	6.5	57.2	82.2	
June	20.8	28.5	14.6	64.3	74.0	
July	24.8	31.3	16.2	28.8	73.2	
August	23.9	32.0	19.0	109.2	71.3	
September	21.2	28.3	13.7	80.7	68.7	
October	20.2	28.3	7.9	70.2	70.2	
November	8.1	16.4	1.6	223.2	73.4	
December	9.5	21.9	3.2	97.0	65.8	

Ankara records of the General Directorate of Meteorology Affairs (Anonymous, 2012)

The experimental site is located in the Eastern Black Sea region. It has a warm and rainy summer and a mild climate in winters. When the dismantling was carried out, the average temperature in August was determined to be 23.9 °C. When the planting was done, the average temperatures in September, October and November were 21.2 °C, 20.2 °C and 8.1 °C, respectively. Table 1 shows that the lowest precipitation amount in the growing season is in October (70.2 mm), and the highest precipitation is in November (223.2 mm). It was observed that the lowest relative humidity was in December (65.8%), and the highest relative humidity was in November (73.4%). Average precipitation was 80.7 mm, 70.2 mm and 223.2 mm in September, October and November, when bulbs were planted, and average relative humidity was 68.7%, 70.2%, and 73.4% (Table 1).

Before planting, the land was arranged to have a plot length of 200 cm, a plot width of 100 cm and a plot height of 15 cm. Plantings were made at 15 x 15 distances between rows and over rows.

Weed control, hoeing and irrigation were done only on the hot days of the first planting date in the trial area from planting to dismantling. During the plant development process, spraying and plant feeding were not carried out.

Figure 1. Natural distribution area of *Narcissus tazetta* flower

With the beginning of development, morphological and phenological measurements started to be carried out on plants, and bulb yield values were examined during the examinations made during the development and resting periods.

2.4. Measurement

The research measured bulb sprout rate, bulb circumference increase, and bublet formation rate. The bulbs were removed, and measurements were made on the 15th of August when the upper part of *Narcissus tazetta* was completely dry.

2.5. Bulb sprout rate (%)

The first sprout and the completion dates were determined by observations with 1-2 days intervals. The growth rate of bulbs in the plots at each planting date was determined.

2.6. Bulb circumference increase (cm)

Bulbs were removed from the field one year after planting and subjected to drying, and their circumference was measured and recorded with a tape measure. The increase rates were found by comparing the obtained data with the data at planting date.

2.7. Bulblet formation rate (%)

Bulbs with different circumferences, planted according to planting dates, were removed from the field at the end of the trial period and the bulblet formation rates were determined.

2.8. Experimental design and statistical analysis

The research was carried out in three replications according to the split-plot design. At each planting date, 32 bulbs (32 x 3=96 total) were used for each replication plot. However, third circumference length bulbs (8-10 cm) could not be used in the experiment due to the lack of bulbs at the third planting date. Bulbs were planted in rows of 4 on each plot.

The data obtained were subjected to statistical analysis in the SPSS package program were determined. All analyses were statistically calculated within 5% error limits, and the differences between the applications were compared with the Duncan test.

3. Results and discussion

3.1. Bulb sprout rate (%)

Regarding bulb lengths and planting dates, the first sprout dates for the first and second planting dates were 11 and 26 October, respectively, and for the plantings made at the third planting date, it was November 21. The sprout rate of bulbs in the plots of each planting date was determined (Table 2).

Table 2. According to the planting dates and bulb circumference in *Narcissus tazetta* cultivation, the number of bulbs planted, the number of bulbs that have sprouted, the date of sprouting, and the number of bulbs that have sprouted %

Planting date	Bulb circumference (cm)	Number of bulbs planted	Number of bulbs sprout	Sprout date (days)	Sprout percentage (%)
September	12-14	96	92	20	95.8
	10-12	96	96	19	100
	8-10	96	96	19	100
October	12-14	96	96	14	100
	10-12	96	95	14	96.8
	8-10	96	96	20	100
November	12-14	96	96	9	100
	10-12	96	96	9	100

For the September planting, the percentage of sprouts was 95.8% for the bulbs with the largest circumference and 100% for the other two bulbs. In plantings in October, the yield was 100% for 12-14 cm and 8-10 cm bulb circumferences and 96.8% for 10-12 cm bulb circumferences. The bulb sprout was 100% in both bulb circumference lengths (12-14 cm, 10-12 cm) used in November planting. In terms of sprouting dates, the shortest sprouting date was determined in the November planting of the bulbs, and the longest sprouting date was determined in the September planting.

3.2. Bulb circumference increase (cm)

Planting date and bulb circumference had a statistically significant effect on the increase in bulb circumference in *N. tazetta* cultivation. Regarding planting date, the highest (15.25 cm) value was obtained from September planting, and the lowest (13.84 cm) was obtained from October planting. In terms of bulb circumference, the highest value (16.3 cm) was obtained from bulbs with the largest circumference (12-14 cm), and the lowest (12.1 cm) was obtained from bulbs with the third bulb circumference (8-10 cm). However, when compared to the circumference of the bulb before planting, the increase rate in bulbs with a circumference of 8-10 cm was 34%, while the circumference of bulbs with a circumference of 10-12 cm followed it with 30%. The lowest value (25%) was determined in bulbs with a circumference of 12-14 cm (Table 3). An increase in the circumference of the bulb occurred in all groups. Pala (2006) found in his study that the average bulb circumference before planting was 13.69 cm, and the average bulb circumference at harvest was 13.62 cm, and a decrease in the average bulb circumference increase rate (-0.20%). Özel and Erden (2008) found the bulb circumference to be 13.40-14.90 cm in their study on *N. tazetta* L. Again, Özel and Erden (2018) in their study on *N. tazetta* subsp. *tazetta* L. determined the bulb circumference as 12.93 cm in the 8-10 cm group, 13.53 cm in the 10-12 cm group and 13.90 cm in the 12-14 cm group. While the researchers found the highest increase rate between 42.22-43.70% at 8-10 cm circumference, they found the lowest increase rate between 2.05-6.92%. These similar results, also reported by Özel and Erden (2018), are thought to be due to the low rate of increase in bulbs with the largest circumference length since the bulb circumference has approached the final stage and the bulbs are now at the division stage.

Table 3. The bulb circumference (cm) increases according to planting date and bulb circumference in *N. tazetta* cultivation

Planting date	Bulb circumference			Mean
	8-10 cm	10-12 cm	12-14 cm	
September 23	12.6	15.4	17.7	15.25 a
October 23	11.6	14.2	15.7	13.84 b
November 12	-	13.5	15.5	14.47 ab
Mean	12.1 c	14.3 b	16.3 a	

Different letters indicate differences among planting dates according to Duncan's multiple range test at P≤0.05

3.3. Bulblet formation rate (%)

The effect of planting date was statistically significant on the bulblet formation rate in *N. tazetta* cultivation. In terms of average planting date, October and November plantings were statistically in the same group, while planting in September was higher (1.39 per plant).

Regarding bulb circumference, the bulblets' formation rate was found to be statistically insignificant. However, more bulblets (0.84 per plant) were obtained with 10-12 cm bulb circumference lengths compared to other circumference lengths (Table 4). Pala (2006) found the average number of bulblets of *N. tazetta* species to be 2.20 per plant. Özel and Erden (2008) found that bulblets varied between 1.68 and 2.12 per plant in their study of *N. tazetta*. Again, Özel and Erden (2018) *N. tazetta* subsp *tazetta* L. Their study determined bulblets' formation as 0.48 per plant in the 8-10 cm group, 2.12 per plant in the 10-12 cm group and 4.88 per plant in the 12-14 cm group. The values obtained were lower than those found by the researchers in all groups. It is thought that this situation may be caused by factors such as planting date, soil structure and cultivation. It has been reported by different researchers that genotype, location, ecological factors and growth techniques affect bulb quality and yield (Kebeli and Çelikel, 2013; Khan et al., 2013).

Table 4. Bulblet formation rate (%) according to planting date and bulb circumference in *N. tazetta* cultivation

Planting date	Bulb circumference			Mean
	8-10 cm	10-12 cm	12-14 cm	
September 23	0.98	1.61	1.60	1.39 a
October 23	0.42	0.55	0.52	0.49 b
November 12	-	0.37	0.25	0.31 b
Mean	0.70	0.84	0.79	

Different letters indicate differences among planting dates according to Duncan's multiple range test at P≤0.05

4. Conclusion

When the effects of planting date on bulb characteristics were examined in 12-14 cm bulbs, In terms of bulb emergence dates, the shortest date from planting (9 days) was taken from the November planting, followed by the October planting (14 days) and the longest 20 days. It has emerged from the study that the best planting date for bulb circumference increase values and bulblet formation in September. The highest increase in bulb circumference was obtained from bulbs with a circumference of 8-10 cm, while the lowest value was obtained from bulbs with a circumference of 12-14 cm. In terms of bulblet formation rates, there was no difference between circumference and length. However, other researchers obtained more bulblets from 12-14 cm circumferences than those with other circumferences. In light of these data, it has been determined that bulbs with a circumference of 8-10 and 10-12 cm should be used to increase the circumference of bulbs, and bulbs with a circumference of 12-14 cm and larger should be used to obtain bulblets.

Compliance with Ethical Standards

Conflict of Interest

The author of article declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

Ömer SARI: Methodology, original draft investigation, conceptualization, validation, writing. **Fisun Gürsel ÇELİKEL**: Methodology, investigation, conceptualization, validation, review and editing.

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Not applicable.

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We humbly give consent for this article to be published.

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EFFECT OF SOLAR COLLECTOR DRYING ON THE NUTRITIONAL PROPERTIES OF ÇAKILDAK HAZELNUT

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A B S T R A C T

This study investigated the effects of drying hazelnut in shell with husk samples from the 'Çakıldak' cultivar (*Corylus avellana*) using hot air heated by solar panels at different speeds (3.0 m s^{-1}, 4.0 m s^{-1}, 5.0 m s^{-1}) on hazelnut properties. The hazelnuts were dried and their drying curve was determined by measuring their mass losses at regular intervals. Additionally, the total phenolics, DPPH radical scavenging activity, FRAP, free fatty acidity, peroxide value, and moisture content. For comparison, some of the samples were dried in the sun. The drying rate increased as the air speed increased and hazelnut samples dried the fastest at 5.0 m s^{-1} air speed. As a result of drying treatments, the total phenolic content ranged from 264.11 to 376.91 mg GAE 100 g^{-1}, while the free fatty acidity ranged from 0.337% to 0.374%. The DPPH value ranged from 1.64 to 2.72 µg TE mg^{-1}, and the FRAP value ranged from 1.23 to 2.29 µg TE g^{-1}. The peroxide value ranged from 1.87 to 4.24 meq O_2 kg^{-1}, and the moisture content ranged from 3.43% to 5.18%. The hazelnut samples dried with an air speed of 3.0 m s^{-1} had the highest total phenolics, DPPH and FRAP values, as well as the lowest free fatty acidity and peroxide value. These values were statistically significantly different ($p<0.05$) from those of the sun-dried hazelnut samples. The study found that drying with a solar collector was more effective in preserving fruit quality. Additionally, the drying process was significantly impacted by different flow rates.

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1. Introduction

Hazelnut (*Corylus avellana* L.) is a hard-shelled nut produced on 996,196 hectares of orchard in temperate regions worldwide. In Türkiye, 68% of the world's hazelnut production comes from 728,381 hectares of orchard, primarily in the Black Sea region (TUIK, 2021). The main hazelnut-producing provinces in Türkiye are Ordu, Giresun, Samsun, Sakarya, Düzce, and Trabzon (TUIK, 2021). In these provinces, hazelnut harvesting starts in August and continues until mid-October, although it varies from year to year. Hazelnut harvesting generally starts after August 1-10 in the coastal line (0-250 m), August 10-20 in the middle section (250-500 m) and after August 20 in the high (500-750 m) areas (Kontaş, 2022). The drying of the harvested hazelnuts by different methods is called threshing, where hazelnuts with high moisture content are sorted by threshing machines after withering for 3-5 days. The nuts after sorting are generally laid on soil, concrete or grass and dried in the sun for 5-15 days. Harvesting operations in the middle and high section often coincide with the end of summer and the middle of autumn, exposing the region to heavy rain and fog. Rainfall can make hazelnut harvesting and threshing difficult, and also lead to a decrease in nut quality. Hazelnuts can be damaged in terms of quality parameters during the drying process, depending on the prolonged process and climatic factors. When hazelnuts are dried in sun dried, there is a risk of pathogen contamination, microbial spoilage, aflatoxin formation, deterioration in antioxidant and fatty acids, as well as quality and yield losses (Kontaş, 2022). Hazelnuts are a food with strong antioxidant properties. Antioxidants can prevent or delay oxidation in the human body, which can help prevent diseases such as cancer, heart disease, diabetes, and lung disease (Cornelli, 2009; Alasalvar and Bolling, 2015). Hazelnuts contain not only the main components of fat, carbohydrates, and protein but also secondary metabolites with antioxidant properties, such as phenolic acids, flavonoids, vitamins that are water and fat-soluble, and tannins. The presence of these properties is dependent on the conditions of harvesting and drying.

Various techniques have been developed to prevent hazelnuts from deteriorating due to threshing conditions and to dry them quickly and efficiently with minimal energy consumption. Conventional dryers are commonly used for this purpose, where the flow rate, temperature, and humidity of the mass transfer fluid are adjusted. New technologies such as infrared, microwave, heat pump, LED dryers, and hybrid dryers, where two or more drying systems are used together, are becoming increasingly popular in drying systems (Gürlek et al., 2015; Akgün et al., 2018; Aksüt et al., 2018).

Nuts, including hazelnuts, walnuts, almonds, and peanuts, require drying and storage. Hazelnuts are typically grown in rainy and humid regions, making them more challenging to sun-dried than other fruits. Therefore, an environmentally friendly drying system is necessary to preserve fruit quality, minimize energy costs, and be accessible to producers (Danso-Boateng, 2013; Topdemir, 2019). Recently, there has been a growing emphasis on drying methods that utilize energy from solar panels and the design of such systems (Ceylan et al., 2006; Mohana et al., 2020).

This experimental study investigates the drying of 'Çakıldak' hazelnuts, harvested with hazelnut husks, before and after patching. The study examines the effects of air heated by air-type solar collectors, at different flow rates, on hazelnut drying times and nut traits.

2. Material and methods

This experimental study was conducted at sea level in Altınordu district of Ordu province (in Türkiye), not at high altitude where hazelnuts are harvested. Following the harvest, the hazelnuts were transported to a lower altitude where the climatic conditions were more suitable for drying.

2.1. Plant materials

'Çakıldak' (*Corylus avellana* L) is intensively grown in Gölköy district of Ordu province, which is located in the high section growing area, was used as plant material in the study. The initial moisture content of hazelnut varies between 30.7% and 33.3%, while the initial moisture content of hazelnut husk varies between 70.4% and 76.3%. Hazelnuts used as drying material are not classified by size. 'Çakıldak' cultivar is suitable for high section.

Figure 1 shows a picture of 'Çakıldak' hazelnuts being harvested by hand from the branch. The harvest period for this variety of hazelnut is between August 20th and September 30th, during which time the high

section experience significant rainfall and fog. Due to the unique characteristics of hazelnuts, they should be sun-dried by laying them on the ground to separate them from their husks. The drying time for hazelnuts varies between 3 and 10 days depending on the climate. Shelled hazelnuts are dried in the sun until they reach 6% humidity, but this process can take a long time (5-15 days) due to rain and fog. Unfavorable drying conditions can also lead to the formation of aflatoxins in hazelnuts.

Figure 1. Picture of undried 'Çakıldak' cultivar with husks

2.2. Drying equipment

In the drying process, 4 air type solar collectors designed and manufactured by us were used as heat source (Figure 2). The collector radiation surface is 80 x 125 cm. Air flow rate adjustable fans were placed at each collector inlet. Fan speeds were measured with a thermo-anemometer at the inlet of the hazelnut drying box. Air temperature was measured from the collector inlet and outlet in a time dependent manner. Temperature measurement was carried out with a K-type thermocouple. The heated and accelerated air passing through the collector leaves the environment through the spiral pipe through the nuts laid on the net in the Polyfoam boxes (Figure 3). The hazelnuts in the polyfoam box are covered with a perforated cover through which air can pass so that the hazelnuts are not exposed to the sun.

Figure 2. Solar collectors used in the system

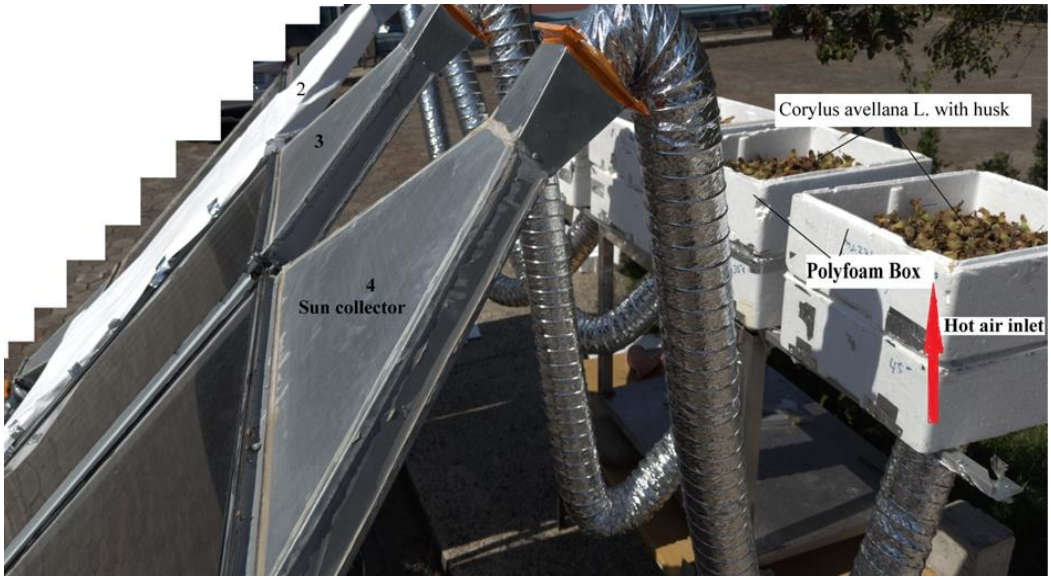

Figure 3. Experimental setup

2.3. Methods

Hazelnuts harvested from the orchard were weighed without separation and placed in Polyfoam boxes, with 3 kg per treatment. The air velocities passing over the hazelnuts were 3.0 m s^{-1} for Collectors 1 and 2, 5.0 m s^{-1} for Collector 3, and 4.0 m s^{-1} for Collector 4. Collector 2's radiation surface was covered, and hazelnuts dried with ambient air temperature. The drying process was carried out using hot air obtained from Collectors 1, 3, and 4. For comparison, hazelnuts were also sun-dried (S).

Mass losses were measured by weighing at regular intervals during drying. When the mass losses of the samples with the husks were approximately constant, they were manually sorted and separated from the husks and the moisture content of each sample was measured. The sorted fresh hazelnut samples were weighed and placed in Polyfoam boxes again with 1.5 kg per treatment and mass losses were determined by weighing every hour.

The nuts in each treatment were weighed using a 0.01 g precision scale at the start of the drying process and at hourly intervals. During sun drying, the surface temperature of the hazelnuts was measured with an infrared thermometer. Hazelnut moisture was determined using an infrared moisture meter of the Precisa XM60. After the drying process, the fruit quality characteristics associated with the drying conditions were evaluated.

2.3.1. Oil extraction

Cold extraction procedure was applied for oil extraction from hazelnut samples (Dordoni et al., 2019; Çakır et al., 2023). Hexane was added to the homogenized hazelnut samples at a ratio of 1:5 and mixed in a shaker (MR-12 Rocker-Shaker, Biosan, Latvia) at 50 rpm for 2 h at 20 °C and then the mixture was centrifuged at 3000 g for 10 min (Nüve 800R, Türkiye). The resulting supernatant was filtered through a filter paper (Whatman 595) and collected in a measuring flask. The hexane in the hexane-oil mixture was removed by means of a rotary evaporator (Heidolph Laborota 4000, Germany) at 45 °C. The oil obtained was used for free fatty acidity and peroxide value analysis.

2.3.2. Free fatty acidity

2.0 g of hazelnut oil obtained by the cold extraction method was mixed with 12 mL of diethyl ether:ethanol (1:1, v:v) mixture. Then 2-3 drops of 1% phenolphthalein indicator were added to the mixture and titration was carried out with 0.01 N ethanol-KOH solution until a pink color was obtained. The results were expressed in terms of oleic acid (AOAC, 1990).

2.3.3. Peroxide value

The peroxide values of hazelnut oil samples were determined using the titrimetric method (AOAC, 2000). To do this, hazelnut oil samples (2.0 g) obtained by cold extraction were dissolved in 25 mL of a chloroform and glacial acetic acid mixture (2:3, v/v). Next, 1 mL of saturated potassium iodide solution was added, and the mixture was kept in the dark for 5 min. After that, 75 mL of distilled water was added to the mixture and titrated with a 0.002 N solution of sodium thiosulfate. The titration used a 1% starch indicator. The results are presented in meq O_2 kg^{-1} oil.

2.3.4. Bioactive component

For the extraction of bioactive compounds from hazelnut samples, defatted hazelnut samples were treated with a 1:10 (w/v) methanol-distilled water mixture (80:20 v/v) and subjected to extraction for 6 h at 50 rpm on a shaker (MR-12 Rocker-Shaker, Biosan, Latvia) at room temperature. Then, the mixture was centrifuged at 3500 g for 10 min (Nüve 800R, Türkiye) and the supernatant was separated. This procedure was repeated for the residue and the combined extracts were used for total phenolic matter and antioxidant activity analysis.

2.3.5. Total phenolics

Total phenolics was determined according to the Folin-Ciocalteu test. Accordingly, 1 mL of sample extract transferred to the test tube was mixed with 500 µl Folin-Ciocalteu solution and 250 µL sodium carbonate (20% w/v) and the total volume was adjusted to 10 mL with distilled water. The resulting mixtures were kept in the dark at room temperature for 30 min and the absorbances were read at 760 nm in a spectrophotometer (Shimadzu UV mini- 1240, Japan). The results were calculated as mg gallic acid equivalent (GAE) 100 g^{-1} dry weight from the standard curve obtained using gallic acid (Singleton et al., 1999).

2.3.6. Antioxidant activity

The antioxidant activity of hazelnut samples was determined by two different in vitro antioxidant tests. The results of DPPH and FRAP tests were calculated as µg Trolox equivalent (TE) mg^{-1} dry weight (dw) and µg TE g^{-1}, respectively.

For DPPH free radical reducing activity, 100 µL of sample extract was transferred into a test tube and treated with 2900 µL of DPPH solution (0.1 mM). After vortexing, the mixtures were incubated at 30 °C for 30 min and at the end of incubation, absorbance measurements against the control were performed at 517 nm (Brand Williams et al., 1995).

FRAP (ferric ion reducing antioxidant power) assay was performed following the method described by Benzie and Strain (1996) with some modifications. First, FRAP reagent was prepared by mixing TPTZ (10 mmol L^{-1}), $FeCl_3.6H_2O$ (20 mmol L^{-1}) and acetate buffer (0.3 mol L^{-1}, pH 3.6) solutions in appropriate volume ratios (1:1:10 v/v). The absorbance values of the mixture prepared with the sample extract and FRAP reagent were then measured at 593 nm in a spectrophotometer after a 4 min incubation at 37 °C.

2.4. Statistical analysis

Statistical tests were performed using SAS-JAMP v. 10.0 (SAS Institute Inc., Cary, North Carolina, USA). Statistical differences were assessed using the Tukey multiple comparison test. The difference between the results was determined at the $p<0.05$ level.

3. Results and discussion

In this section discusses the results of the study in two parts: the drying of hazelnuts and the changes in kernel quality attributes resulting at the end of the drying process.

3.1. Hazelnut drying

The time-dependent mass loss change in 'Çakıldak' during pre-drying (wilting) for the purpose of removing the hazelnut from the husk is given in Figure 4. In the given mass loss curves, the discontinuous part represents the night and the curves represent the mass losses occurring in sunny moments. The pre-drying process was completed in 1.5 days.

At the end of 940 min of operation of the system (night was not added to the time), the mass loss of the hazelnuts with the husk was 3 (28.6%), 4 (27%), 1 (24%), S (19.8%) and 2 (17.5%) respectively. Sun drying lost 2.3% more mass than the system 2 with unheated air. The reason for this is that, as shown in Figure 5, the surface temperature of the hazelnut reached 40.6 °C in solar drying while the ambient temperature reached 29.4 °C in system 2. In addition, the fact that the environment was quite sunny and windy (average air speed 2.5 m s^{-1}) was also effective in sun drying. Under normal conditions, it was necessary for the moisture loss of the Sun and sample 2 to fall below 20% to complete the pre-drying, but the withering study was terminated to ensure that the experimental conditions were the same.

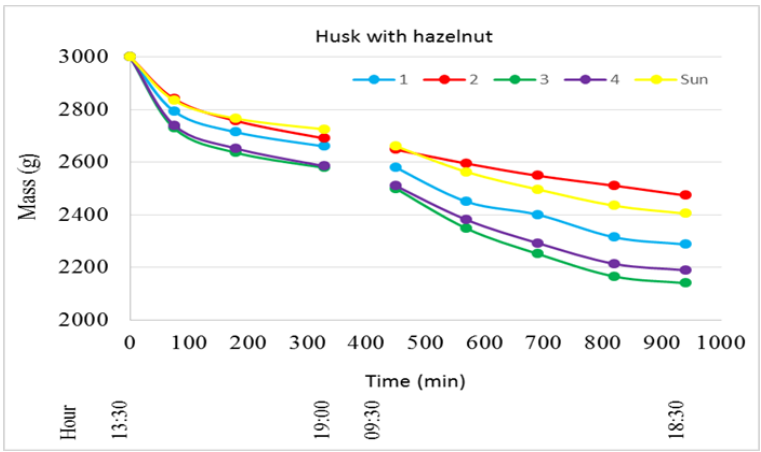

Figure 4. Time graph of mass loss of In-husk hazelnuts during pre-drying

After the initial drying process, the husk moisture content of sample 1 was 36%, while the hazelnut moisture content was between 24.8% and 25.2%. Sample 2 had a husk moisture content of 46%, and the hazelnut moisture content was between 30.6% and 32%. Sample 3 had a husk moisture content of 34%, and the hazelnut moisture content was measured as 26.6% to 27.6%. Sample 4 had a husk moisture content of 35%, and the hazelnut moisture content was between 28.3% and 29%. Finally, the sun sample had a husk moisture content of 44%, and the hazelnut moisture content was between 29% and 31.2%.

The variation of ambient temperature with time during pre-drying of hazelnuts is given in Figure 5. The temperature at night when the system was not operated was not measured and is given as intermittent in the graph. The high mass loss of samples 3 and 4 is due to the ambient temperature is higher than the others (41 °C) and the flow rates are high, as can be understood from the data in Figure 5. This result is similar with previous studies (Demirtaş, 1996; Akgün et al., 2017). As the temperature of the sun-dried hazelnut (max. 40.6 °C) was higher than the ambient temperature due to radiation, the sun treatment dried earlier than sample 2 (max. 29.4 °C, Figure 4).

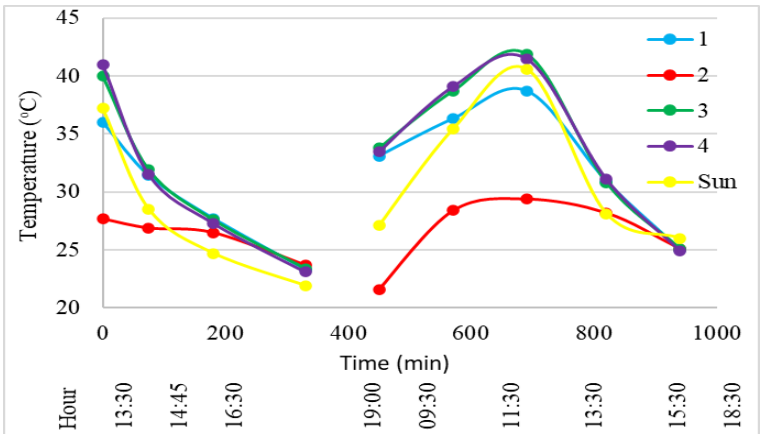

Figure 5. Variation of in-husk hazelnut drying ambient temperature over time

The time-dependent mass loss of shelled, which were separated from the husk and dried again, is given in Figure 6. As expected, sample 2 and sun drying were dried more slowly than the others. The drying curve of sample 2 shows that the hazelnuts dried for a longer time only by increasing the air velocity without heating. In rainy regions, passing air over the hazelnut under cover will prevent the hazelnut from spoiling and the hazelnut will dry in a shorter time.

The time-dependent mass loss of shelled hazelnuts with different moisture contents extracted from the husk is given in Figure 6. Sample 2 and the Sun sample had the highest mass loss on the first day due to their high moisture content. Sample 2, which was dried at normal air temperature, was the last to dry as expected. However, it dried faster than samples 1, 3, and 4 during sun drying. The reason for the difference in drying rates can be seen in Figure 7, which shows the temperature-time curves for the drying environment. The maximum surface temperature of the hazelnut during solar drying was 50 °C, while during collector drying, with air speeds of 3.0, 4.0, and 5.0 m s^{-1}, it was 44 °C. After four days (2240 min), sun drying resulted in a 21.7% loss of mass, while drying with air speeds of 3.0, 4.0, and 5.0 m s^{-1} (samples 1, 4, 3) resulted in losses of 17.4%, 17.6%, and 18.5%, respectively. The rates are similar. Sample 2, which was not exposed to high temperatures (maximum 34 °C) and dried with an air speed of only 3.0 m s^{-1}, experienced a 16.8% decrease in mass.

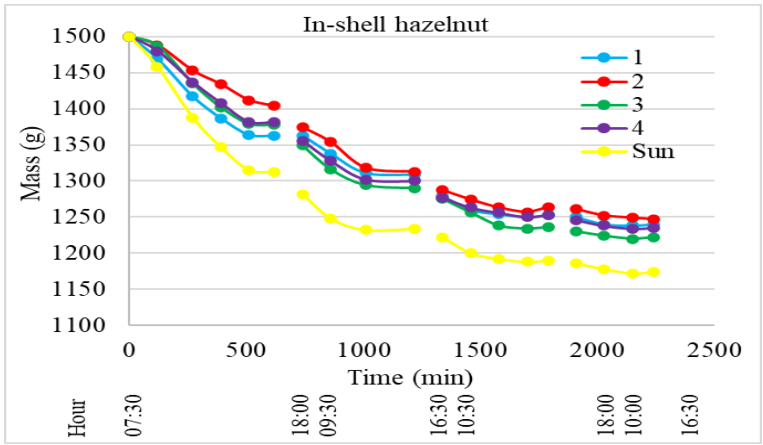

Figure 6. In-shell hazelnut mass loss time graph

After drying, the moisture levels of hazelnuts were measured and recorded as follows: Sample 1 (4.7% - 4.8%), sample 2 (8.6% - 9.3%), sample 3 (4.7% - 5.8%), sample 4 (4.6-5.5%), and Sun (4% - 4.9%). The difference in moisture values under the same treatment is largely due to the size of the hazelnut. Drying slows down as the size increases, and the nut is unable to inshell. At the end of the experiments, Sample 2 was not fully dried. Therefore, it was dried separately until it reached an equilibrium moisture level of 6%.

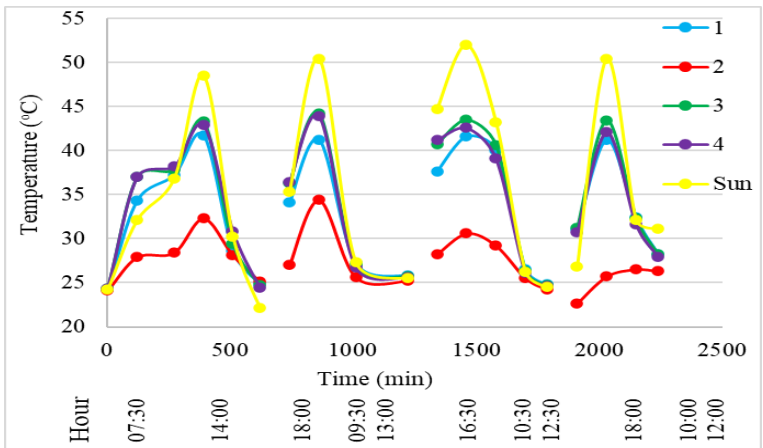

Figure 7. Variation of in-shell hazelnut drying ambient temperature with time

3.2. Nut traits

The study examined the impact of varying drying rates on oxidation parameters. Statistical analysis revealed that both free fatty acid and peroxide values were significant ($p<0.05$). Treatment 1 had the lowest free fatty acid value (0.337%, oleic acid) while treatment 3 had the highest (0.374%). Compared to the control conditions (0.356%), treatment 1 was able to maintain low levels of free fatty acid. Table 1 shows that the peroxide value of the sun-dried fruit samples was 3.67 meq O_2 kg^{-1}. Treatment number 1 resulted in a decrease to 1.87 meq O_2 kg^{-1}, indicating an improvement in nut quality.

Table 1. Effect of drying treatments on oil oxidation of hazelnut

Methods	Free Fatty Acidity (%)	Peroxide Value (meq O_2 kg^{-1})
S	0.356 ±0.01ab	3.67±0.57a
1	0.337±0.01b	1.87±0.68b
2	0.353±0.01ab	3.41±0.29ab
3	0.374±0.01a	4.24±0.57a
4	0.346±0.01ab	1.95±0.75b

a-b The difference between the means shown with different letters in the same column is significant (Tukey test; P<0.05)

Numerous studies have investigated oil oxidation in hazelnuts (Turan, 2018a-b; Turan, 2019; Cui et al., 2022; Gao et al., 2022; Sun et al., 2022). These studies have shown that oxidation parameters can vary significantly. For instance, Turan (2018a) found that oxidation parameters differed depending on the drying method of Ordu levant hazelnuts, but the peroxide value was 0.20 meq O_2 kg^{-1}. Turan (2018b) also reported that oxidation parameters varied according to the hazelnut variety. However, it was found by Turan (2019) that the free fatty acidity value of the 'Çakıldak' ranged from 0.06-0.12% (oleic acid). Additionally, Turan and İslam (2019) reported that the oxidation parameters of the 'Tombul' hazelnut variety varied depending on the drying method. The free fatty acidity value ranged from 0.15-0.28% oleic acid and the peroxide value ranged from 0.00-0.06 meq O_2 kg^{-1}. These findings suggest that hazelnut oxidation parameters are influenced by various factors. The study found that the levels of free fatty acids and peroxide in hazelnuts vary depending on the drying conditions. Therefore, it is crucial to optimize these conditions to ensure high nut quality.

The effect of different drying rates on total phenolics, radical scavenging activity (DPPH) and FRAP parameters of 'Çakıldak' was found statistically significant ($p<0.05$). When Table 2 was examined in detail, it was determined that the lowest value of total phenolics was found in treatment sample 3 (238.29 mg GAE 100 g^{-1}), the highest value was found in treatment sample 1 (376.91 mg GAE 100 g^{-1}) and the same statistical value was found in treatment sample 4 (360.82 mg GAE 100 g^{-1}). When compared with the control conditions (0.264.11 mg 100 g^{-1}), it is seen that sample 1 and 4 were able to keep the total phenolic high. When the radical scavenging activity (DPPH, µg TE mg^{-1}) values of the nut samples were analyzed (Table 2), it was determined that the sun-dried and sample 3 treatments were 1.90 and 1.64 µg TE mg^{-1}, respectively, while the sample 1 treatment was 2.72 µg TE mg^{-1} and gave the best result in terms of fruit quality.

Table 2. Total phenolic content and antioxidant activity of hazelnut

Method	Total Phenolics (mg GAE 100 g^{-1})	DPPH Radical Scavenging Activity (µg TE mg^{-1})	FRAP (µg TE g^{-1})
S	264.11±14.29 bc	1.90±0.07 c	1.32±0.03d
1	376.91±20.40 a	2.72±0.14 a	2.29±0.10 a
2	283.79±4.23 b	2.21±0.03 b	1.59±0.02 c
3	238.29±11.90 c	1.64±0.08 c	1.23±0.05d
4	360.83±2.29 a	2.50±0.17 ab	2.05±0.09 b

a-d The difference between the means shown with different letters in the same column is significant (Tukey test; P<0.05)

In previous studies, the 'Çakıldak' cultivar grown in Giresun ecological conditions was found to contain 246.0 mg of total phenolics 100 g^{-1} (Pelvan et al., 2012), while a subsequent study reported a higher amount of 741.0 mg GAE 100 g^{-1} (Balık et al., 2017). Yılmaz et al. (2019) conducted a study on hazelnuts grown under the same variety and conditions. The results showed that the total phenolic content varied between 662.3 (medium)-763.5 (small) mg GAE 100 g^{-1} depending on the size of the kernel.

The study suggests that the amount of total phenolics in hazelnuts is influenced by various factors. The total amount of phenolic substances, total flavonoid content and antioxidant capacity (according to FRAP and DPPH tests) in hazelnut kernel depending on the variety, nut size and extraction method (Yılmaz et al., 2019; Kurtça, 2021). In addition, ecological conditions, genotype, cultural practices, maturity of the nut, the region where it is grown, altitude and orientation have an effect on the chemical structure of hazelnuts (Cristofori et al., 2015; Tonkaz et al., 2017; Yaman, 2019). When the data we obtained from the research are examined; While it is between the values found by Pelvan et al., (2012) and the values found by Balık et al., (2017), it reveals the positive effects of drying practices on the total amount of phenolic substances in 'Çakıldak' cultivar.

4. Conclusion

The study investigated the impact of solar-heated air at varying speeds on 'Çakıldak' drying and the following conclusions were reached.

1. At the end of pre-drying, the mass loss of the husk (approximately 52%) was greater than the mass loss of the hazelnut (approximately 15%).
2. Although the drying process with accelerated air without heating took a long time, it made it possible to dry the hazelnuts without spoiling.
3. In pre-drying, the shortest drying process was achieved at 5.0 m s^{-1} air speed, as expected.
4. In drying with a solar collector, as the air speed increased, the drying time also shortened.
5. Drying the nut at an air speed of 3.0 m s^{-1} yielded the best results in terms of free fatty acidity and peroxide values. However, applying the same air speed gave the best results in terms of total phenolic substance amount, radical scavenging activity (DPPH), and FRAP values.

It is recommended to use solar collectors for drying hazelnuts, which have no energy costs, environmentally friendly air and preserve food properties.

Compliance with Ethical Standards

Conflict of Interest

The author of article declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' Contributions

Mithat AKGÜN: Design and manufacture of drying equipment. Evaluation of the data, article writing. **Mehmet AKGÜN**: Analyzing samples, obtaining data, article writing.

Ethical approval

Not applicable.

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Not applicable.

Consent for publication

We humbly give consent for this article to be published.

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