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UTJECAJ ROKA SADNJE NA PRINOS KUKURUZA ŠEĆERCA U AGROEKOLOŠKIM UVJETIMA SARAJEVSKOG POLJA

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Sažetak

Kukuruz šećerac (*Zea mays* var. *saccharata*) je podvrsta kukuruza koja je prepoznatljiva po mekanom, sočnom i slatkom zrnu. Glavni izazov u uzgoju ove vrste je tehnološka zrelost koja traje kratko, što dovodi do ograničene sezone berbe. Kako bi se zadovoljila sve veća potražnja potrošača za kukuruzom šećercom i produžila sezona berbe proizvođači u posljednje vrijeme primjenjuju različite agrotehničke mjere. Cilj ovog rada je istražiti utjecaj različitih rokova sadnje na komponente prinosa i prinos kukuruza šećerca. Poljsko istraživanje je provedeno tokom 2024. i 2025. godine na eksperimentalnom polju Poljoprivredno-prehrambenog fakulteta u Sarajevu, na lokalitetu Butmir. Istraživanje je obuhvatilo tri različita roka sadnje sa razmacima od po deset dana. Tokom tehnološke žetve evidentirani su visina biljke, dužina klipa sa listom, masa klipa sa listom, dužina klipa i masa klipa bez lista, te prinos. Rezultati istraživanja pokazuju da je rok sadnje tokom dvogodišnjeg perioda (2024. i 2025. godina) značajno utjecao samo na prinos klipa. Tačnije, prinos klipa (s listom i bez lista) bio je najveći u drugom roku sadnje (14.056 i 8.818 kg ha^{-1}), zatim su slijedili prvi (10.258 i 7.027 kg ha^{-1}) i treći rok (11.643 i 7.628 kg ha^{-1}). Značajan utjecaj na komponente prinosa pokazala je godina istraživanja. Promjene u ovim vrijednostima mogu se pripisati različitim vremenskim uvjetima u godinama istraživanja.

Ključne riječi: *komponente prinosa, kukuruz šećerac, prinos, rok sadnje, sadnja*

UVOD

Kukuruz šećerac (*Zea mays* var. *saccharata*) je podvrsta kukuruza koja se odlikuje mekanim, sočnim, slatkim i ukusnim zrnom, po čemu se razlikuje od ostalih podvrsta. Posjeduje zrno koje je bogato prostim šećerima, proteinima i mastima (Budak i sar., 2018). Osim toga, ova podvrsta kukuruza je dobar izvor bioaktivnih fitokemikalija, kao što su flavonoidi, fenolne kiseline, karotenoidi, antocijanini itd. (Cruz i sar., 2022). U svježem stanju najčešće se koristi za kuhanje, pečenje, smrzavanje, konzerviranje, te industrijsku preradu u prehrambenoj industriji (Gavrić i Omerbegović, 2021). Najvišu

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kvalitetu zrno kukuruza šećerca postiže u fazi tehnološke zrelosti. Međutim, glavni izazov u uzgoju ovog usjeva predstavlja kratko trajanje navedene faze, što rezultira ograničenom sezonom berbe. Kako bi se zadovoljila sve veća potražnja potrošača za kukuruzom šećercom i produžila sezona berbe, proizvođači primjenjuju različite agrotehničke mjere. Među najčešće korištenim agrotehničkim mjerama su sjetva u različitim rokovima, korištenje hibrida različitih grupa zrenja, upotreba tamnog malča, uzgoj u plastenicima, te uzgoj kukuruza šećerca iz presadnica (Gavrić i Bezdrob, 2025). Najjednostavniji način produženja sezone berbe je sjetva u različitim rokovima. Međutim, sjetva izvan uobičajenih termina, bilo da se radi o ranijim i kasnijim rokovima nosi određene rizike (Tabaković i sar., 2020). Tako na primjer, suviše rana sjetva izlaže usjev hladnom stresu, što dovodi do opadanja poljske klijavost, reduciranja sklopa i prinosa. S druge strane u kasnijim rokovima sjetve, usjev je najčešće izložen suši i toplotnom stresu što reducira prinos. Kako bi se izbjegli navedeni negativni utjecaji, posebno u ranijim rokovima uzgoja, pojedini proizvođači prakticiraju uzgoj kukuruza šećerca iz presadnica. Tokom ranog proljeća, presadnice se uzgajaju u plastenicima, a zatim se presađuju u polje kada vremenski uvjeti postaju povoljni. Pojedini istraživači navode da kukuruz šećerac uzgojen na ovakav način ima veći sklop i prinos, ujednačen usjev, te da je ranostasniji (Adesina i sar., 2014; Gavrić i Omerbegović, 2021). S obzirom na činjenicu da uzgoj kukuruza šećerca iz presadnica nije dovoljno istražen u agroekološkim uvjetima BiH, cilj ovog rada je bio ispitati utjecaj različitih rokova sadnje na prinos kukuruza šećerca.

MATERIJAL I METODE

Poljsko istraživanje je sprovedeno tokom 2024. i 2025. godine na eksperimentalnom polju Poljoprivredno-prehrambenog fakulteta Univerziteta u Sarajevu, koji se nalazi na Butmiru. Za analizu vremenskih uvjeta tijekom istraživanog razdoblja korišteni su podaci Federalnog hidrometeorološkog zavoda BiH. Poljski eksperiment je sadržavao tri različita roka sadnje. U prvoj godini istraživanja (2024) sadnje su obavljene 26. aprila, te 6. i 16. maja. Sadnje u drugoj godini su obavljene 8., 18. i 28. maja 2025. godine. Ogled je bio dizajniran po split-plot sistemu. Svaki plot je predstavljao vrijeme sadnje. Veličina jednog plota iznosila je 56 m^2 (2,8 m x 20 m). Unutar svakog plota nalazila su se po četiri reda usjeva. Razmak sadnje je iznosio 70 x 25 cm. Za sadnju su korištene presadnice kukuruza šećerca starosti dvije sedmice. Neposredno prije sadnje, presadnice su uzgojene u zaštićenom prostoru (plasteniku) na privatnom poljoprivrednom gazdinstvu ″Gavrić″ u Kaknju. Za sjetvu je korišteno hibridno sjeme kukuruza šećerca (Bonaza F1). Prema deklaraciji proizvođača, korišteni hibrid dostiže tehnološku zrelost za 65-75 dana nakon sjetve. Formira blago sužen klip s 16 do 18 redova sa nježnim zrnom žute boje. Namijenjen je za svježu potrošnju i industrijsku preradu.

Uzgoj presadnica je obavljen u polistirenskim kontejnerima (104 otvora) napunjenim s komercijalnim supstratom ″Klasmann potground H″.

Nakon postavljanja poljskog ogleda, u usjevu je obavljeno prihranjivanje i međuredna kultivacija s ciljem suzbijanja korova.

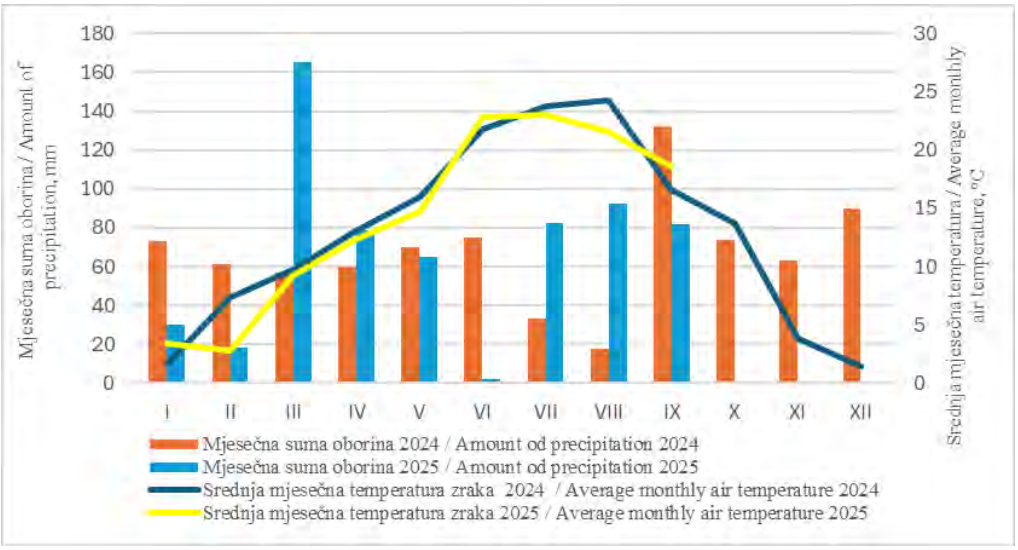
Slika 1. Presadnice kukuruza šećerca
Figure 1. Sweet corn seedlings

Optimalno vrijeme za uzorkovanje, odnosno tehnološka zrelost kukuruza šećerca, određena je periodičnom kontrolom stanja zrelosti usjeva. U vrijeme uzorkovanja evidentirane su visina biljke (cm), dužina klipa sa listom (cm), masa klipa sa listom (g), dužina klipa (cm), kao i masa klipa (g). Sva mjerenja su obavljena u deset ponavljanja. Žetva u prvoj godini istraživanja obavljena je 23. jula, 29. jula i 4. avgusta 2024. godine. U drugoj godini istraživanja, žetva je realizovana 6, 14 i 21. avgusta 2025. godine. Svi dobiveni podaci obradili su se odgovarajućim statističkim metodama korištenjem SPSS programa.

REZULTATI I DISKUSIJA

Za analizu vremenskih uvjeta u 2024. i 2025. godini korišteni su podaci Federalnog hidrometeorološkog zavoda Bosne i Hercegovine, te su isti prezentirani na grafikonu 1. Prosječne mjesečne temperature zraka varirale su u zavisnosti od mjeseca i godine istraživanja. Tokom perioda izvođenja ogleda (maj–avgust) u 2024. godini, najniža prosječna mjesečna temperatura zabilježena je u maju (16,0 °C), a najviša u avgustu (24,3 °C). Srednje mjesečne temperature zraka u 2025. godini bile su relativno niže u poređenju s prethodnom sezonom istraživanja. Odnosno, prosječne temperature zraka su bila niže za 1,3 °C u maju, za 0,8 °C u julu, te 2,7 °C u avgustu. Također, analizom količina oborina utvrđene su određene oscilacije. U prvoj godini istraživanja (2024. godina), najmanja količina kiše u periodu poljskog istraživanja zabilježena je u avgustu (18 mm), dok je najveća količina evidentirana u julu (75 mm). U drugoj godini

istraživanja (2025) najsušniji mjesec je bio juli (1,9 mm), a najkišovitiji avgustu (92,6 mm).



Grafikon 1. Srednja mjesečna temperatura zraka i mjesečnea suma oborina u 2024. i 2025. godini

Graph 1. Average monthly temperature and monthly rainfall in 2024 and 2025

Rezultati utjecaja roka sadnje na komponente prinosa kukuruza šećerca prezentirani su u tabeli 1. Najveći prinos klipa (sa i bez lista) evidentiran je u drugom roku sadnje (14.056 i 8.818 kg ha^{-1}), zatim slijede treći (11.643 i 7.628 kg ha^{-1}) i prvi rok sadnje (10.258 i 7.027 kg ha^{-1}). Iako je rok sadnje ispoljio sličan utjecaj i na ostale komponente prinosa, statistički značajne razlike između tretmana nisu pronađene. Khana i sar. (2018) su istraživali utjecaj različitih rokova sadnje na prinos kukuruza šećerca, te su došli do saznanja da se kasniji rokovi sjetve negativno odražavaju na komponente prinosa. Oni svoje rezultate objašnjavaju činjenicom da kukuruz šećerac u kasnijim rokovima sadnje ima kraći vegetacioni period zbog visokih temperatura, uslijed čega se skraćuju sve faze rasta i razvoja, što se negativno odražava na nalijevanje zrna i prinos. Rezultati navedenih autora objašnjavaju razlog zbog kojeg je i u ovom istraživanju došlo do opadanja prinosa nakon drugog roka sadnje. Međutim, u ovom istraživanju prinos kukuruza šećerca u prvom roku odstupaju od istraživanja Khana i sar. (2018). Odnosno, u ovom radu je evidentirano da prvi rok sadnje ima niži prinos od drugog roka. Ovakvi rezultati se mogu objasniti nepovoljnim agroekološkim uvjetima u prvim rokovima sadnje. Naime, temperature zraka i zemljišta sarajevskog polja tokom proljetnog perioda su relativno niže te negativno utječu na razvoj kukuruza šećerca. Ovu pretpostavku potvrđuje i činjenica da je kukuruz šećerac osjetljiv na hladni stres, te za rast u početnim fazama zahtijeva više toplote u poređenju s ostalim podvrstama kukuruza. Optimalna temperatura njegovog rasta je između 21 i 27 °C, dok temperature

ispod 10 °C zaustavljaju rast i uzrokuju oštećenje biljaka (Hacisalihoglu i sar., 2018; Mao i sar., 2017).

Tabela 1. Utjecaj roka sadnje na visinu biljke i komponente prinosa kukuruza šećerca (dvogodišnji prosjek)
Table 1. Influence of transplanting date on plant height and yield components of sweet corn (two-year average)

Rok sadnje / Sowing time	Visina biljke Plant height	Dužina klipa s listom / Dehusked ear lenght	Masa klipa s listom / Dehusked ear mass	Dužina klipa / Ear lenght	Masa klipa/ Ear mass	Prinos klipa s listom/ Dehusked Ear yield	Prinos klipa/ Ear yield
	cm	cm	g	cm	G	kg ha^{-1}	kg ha^{-1}
I	163,3c	31,2ns	282,6ns	18,5ns	193,6ns	10.258b	7.027b
II	180,8b	30,0ns	331,7ns	19,4ns	216,9ns	14.056a	8.818a
III	190,2a	29,4ns	309,8ns	19,6ns	200,8ns	11.643ab	7.628ab
Prosjek Average	178,1	30,2	308,0	19,2	203,8	11.985	7.825

Različita slova označavaju statistički značajne razlike na razini od 0,05; ns: nema značajne razlike
Different letters indicate significant differences at the 0.05 level; ns: nonsignificant differences

Značajna odstupanja u vrijednostima komponenti prinosa evidentirana su između godina istraživanja (Tabela 2). Konkretno, kukuruz šećerac uzgojen 2024. godine imao je manju masu klipova sa i bez listova (259,1 g odnosno 179,7 g) u poređenju s onim uzgojenim 2025. godine (364,4 g odnosno 232,2 g). Razlike u vrijednostima komponenti prinosa najvjerojatnije su posljedica različitih vremenskih uvjeta, to jest razlika u količini oborina. Dakle, iz grafikona 1. vidljivo je da je u tokom jula i avgusta 2025. godine, odnosno u periodu nalijevanja zrna, evidentirano više oborina, u odnosu na 2024. godinu, što je najvjerovatnije pozitivno utjecalo na masu klipa. Nalazi ovog rada su u skladu s nalazima Gavrića i Bezdroba (2025) koji su otkrili da se masa klipa kukuruza šećerca značajno povećavaju s većim količinama oborina. Prema njihovim tvrdnjama, smanjena dostupnost vode dovodi do smanjenog turgora biljaka, što usporava razvoj ćelija i rast biljke, a time negativno utiče na visinu biljaka i prinos. Pozitivan utjecaj oborina na produktivne i kvalitativne osobine kukuruza šećerca potvrđen je i u nekoliko drugih istraživanja (Ertek i Kara, 2013; Viswanatha i sar., 2002). Ipak, prema Kimu i sar. (2024) prekomjerna količina može imati i negativne posljedice na usjev kukuruza šećerca. Oni smatraju da prevelika količina oborina stvara povoljne uslove za razvoj biljnih bolesti, koje mogu narušiti prinos i kvalitetu kukuruza šećerca.

Tabela 2. Utjecaj godine istraživanja na visinu biljke i komponente prinosa kukuruza šećerca

Table 2. Effect of research year on plant height and yield components of sweet corn

Godina istraživanja Research year	Visina biljke/ Plant height	Dužina klipa s listom/ Dehusked ear lenght	Masa klipa s listom/ Dehusked ear mass	Dužina klipa/ Ear lenght	Masa klipa/ Ear mass	Prinos klipa s listom/ Dehusked Ear yield,	Prinos klipa/ Ear yield
	cm	cm	g	cm	g	kg ha^{-1}	kg ha^{-1}
2024	176,8ns	28,2b	259,1b	17,6b	179,7b	11.907ns	8.257ns
2025	179,5ns	32,3a	364,4a	20,7a	232,2a	12.065ns	7.392ns
Prosjek Average	178,1	30,2	308,0	19,2	203,8	11.985	7.825

Različita slova označavaju statistički značajne razlike na razini od 0,05; ns: nema značajne razlike
Different letters indicate significant differences at the 0.05 level; ns: nonsignificant differences

Iako je ovo istraživanje pružilo vrijedan uvid u utjecaja roka sadnje na pokazatelje prinosa kukuruza šećerca ono ima i određene nedostatke. Istraživanje je obuhvatilo samo tri najuobičajenija roka sadnje što ograničava širinu zaključka. Stoga bi buduća istraživanja trebala razmotriti potencijalni utjecaj većeg broja različitih rokova sadnje, kao i njihovo poređenje s konvencionalnom sjetvom. Osim toga, preporučuje se da buduća istraživanja razmotre i utjecaj rokova sadnje na pokazatelje kvaliteta kukuruza šećerca, u prvom redu na sadržaj prostih šećera koji su ključni za primamljiv ukus zrna. Unatoč navedenim ograničenjima, ovo istraživanje pokazalo je određene praktične koristi. Naime, uzgojem kukuruza šećerca iz rasada i odabirom ranog roka sadnje omogućava raniji početak sezone berbe, dok se odabirom srednje ranog roka sadnje može pozitivno uticati na prinos.

ZAKLJUČAK

U ovom istraživanju zabilježeno je da različiti rokovi sadnje značajno utječu na prinos kukuruza šećerca. Najveća prinos je zabilježen kad je usjev uzgojen u drugom roku sadnje. Niži prinos u prvom roku sadnje je posljedica nižih temperatura tokom proljeća na koje je kukuruz šećerac jako osjetljiv. S druge strane, relativno niži prinos u trećem roku sadnje je posljedica viših srednjih dnevnih temperatura koje ubrzavaju sve faze rasta i razvoja što negativno utječe na nalijevanje zrna.

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THE INFLUENCE OF TRANSPLANTING DATE ON THE YIELD OF SWEET CORN IN THE AGROECOLOGICAL CONDITIONS OF SARAJEVO FIELD

Abstract

Sweetcorn (*Zea mays* var. *saccharata*) is a subspecies of corn that is recognized by its soft, juicy, and sweet kernels. The primary challenge in cultivating this species is its limited technological maturity, which results in a short harvest season. To meet the increasing demand for this species from consumers and extend the harvesting season, producers have recently implemented various agrotechnical measures. This study aimed to research the impact of different transplantation dates on sweet corn yield. Field research was conducted at the experimental field of the Faculty of Agriculture and Food in Sarajevo, located at Butmir, from 2024 to 2025. The study encompassed three distinct transplantation dates, spaced ten days apart. During the technological harvest, we recorded plant height, dehusked ear length, dehusked ear mass, ear length, ear mass, and yield. The research results indicate that the planting date during the two years (2024 and 2025) significantly affected the ear yield, while it did not have a statistically significant effect on other traits. More specifically, the ear yield (dehusked and husked) was the highest in the second transplantation dates (14,056 and 8,818 kg ha^{-1}) compared to the first (10,258 and 7,027 kg ha^{-1}) and the third (11,643 and 7,628 kg ha^{-1}). The year of the research also showed a significant influence on the yield components. Changes in research traits were a consequence of different weather conditions in the research years.

Keywords: *yield components, sweet corn, yield, transplanting date, seedlings*

OPTIMIZING LETTUCE PRODUCTION THROUGH GEOTHERMAL HEATING: IMPACTS ON MORPHOLOGY AND BIOACTIVE COMPOUND ACCUMULATION

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Abstract

Lettuce (*Lactuca sativa* L.) is a highly valued and nutritionally important crop. The goal of new production technologies is to shorten the vegetation period, allowing for a higher number of harvests, while preserving the environment and improving the nutritional quality of lettuce. This study investigated the effect of geothermal heating on growth dynamics and the accumulation of bioactive compounds in lettuce. Two production systems were compared: a greenhouse with geothermal heating and one without heating. The geothermal system provided a more stable soil temperature, which significantly shortened the vegetation period by 31 days. In contrast, lower soil temperatures in the unheated greenhouse enhanced secondary metabolism, leading to higher concentrations of phenolic compounds (80.5 mg GAE/100 g), flavonoids (2.37 mg/100 g), and increased antioxidant capacity (112.7 μmol Fe^{2+}/100 g). These results indicate that temperature regimes strongly influence both primary growth processes and the synthesis of bioactive compounds in lettuce. Geothermal heating ensures faster crop development but may reduce the accumulation of certain antioxidants. Future research should aim to optimize temperature management to balance yield, energy efficiency, and nutritional quality in greenhouses lettuce production.

Keywords: *geothermal energy, sustainable agriculture, primary and secondary metabolism, lettuce*

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is one of the most important vegetable crops worldwide. Global production reached 27,660,187 Mt on 1226,370 ha in 2024 (FAOSTAT, 2024), with the leading producers being China, India, and Spain. According to the same source, in Bosnia and Herzegovina (B&H) during the year 2023 lettuce was grown on 217 ha, which yielded a yield of 1,810 t.

Lettuce is a low-calorie vegetable, rich in minerals, vitamins, and other bioactive compounds. Its chemical composition and nutritional value are influenced not only by agroclimatic conditions but also by the cultivar (Kim *et al*., 2016).

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The quality of lettuce is further affected by cultivation practices, which determine nutrient availability, microbial activity, and the content of bioactive substances influencing growth and overall quality (Song *et al*., 2020). Among its chemical constituents, secondary metabolites particularly phenolic compounds play a crucial role. Phenolic compounds are a large group of plant derived molecules characterized by at least one aromatic ring with an attached hydroxyl group. They exhibit numerous beneficial properties, including antiinflammatory, antimicrobial, antimutagenic, and anticarcinogenic effects, as documented in multiple studies (Alberto *et al*., 2006; Scalbert and Williamson, 2000). Phenols contribute significantly to the antioxidant capacity of plants and influence color, aroma, taste, and adaptability to environmental conditions (Shi *et al*., 2022). Additionally, they are involved in plant defense mechanisms, such as protection against pathogens and competing species (Čižmárová *et al*., 2023; Dai and Mumper, 2010; Stiller *et al*., 2021; Tijjani *et al*., 2020). Given the importance of phenolic compounds in the human diet, it is essential to develop cultivation strategies that not only optimize yield but also ensure a high content of antioxidant compounds.

Bosnia and Herzegovina is experiencing a clear warming trend, with average temperatures rising between 0.4°C and 0.8°C per decade and a projected increase of 1 to 6°C by the end of the century, depending on the emission scenario (FNC, 2021). Extreme events such as cold and heat waves, the droughts of 2012 and 2017, and the floods of 2014 have caused severe agricultural losses, with the rising frequency of heatwaves and irregular precipitation patterns making both open-field and greenhouse cultivation increasingly vulnerable (Čadro *et al*., 2024; UNDP, 2020). Consequently, geothermal heating systems emerge as a sustainable adaptation measure that can stabilise microclimatic conditions, reduce fossil-fuel dependence, and mitigate production risks under the intensifying climate variability projected for central BiH (World Bank, 2024; Čadro *et al.*, 2024). Such systems enable the year-round cultivation of high-value winter crops, including lettuce, spinach, parsley, radish, etc. Which are typically not produced during the colder months by local farmers. This extended production season offers significant economic advantages, allowing continuous market supply, reduced import dependence, and improved income stability for small and medium agricultural producers (UNDP, 2020).

Beyond its nutritional benefits lettuce helds significant economic importance. Lettuce is an economically important crop due to its short growing season and commonly consumed by the population. To optimize lettuce growth and development, increase yield, and shorten the vegetative period, various technological solutions, such as greenhouse heating, are being explored. In Bosnia and Herzegovina, the use of geothermal heating is still under investigation, however, renewable energy sources already account for about 40% of total electricity production, with small hydropower plants dominating, while the use of solar and wind energy remains in its early stages (Energy Community, 2023). Geothermal energy represents a particularly promising solution for greenhouse heating, as it provides a stable heat supply throughout the year, enabling continuous production even during the winter season (Lund and Boyd, 2015).

Moreover, geothermal heat pump systems are highly efficient, achieving up to 300–400% efficiency, and can reduce CO_2 emissions by as much as 66% compared to conventional fossil fuel heating systems (Saeidavi, 2021). Tomaszewska *et al*. (2022) highlighted the positive effects of geothermal heating on shortening the vegetation period and increasing yields in both soil and soilless lettuce cultivation. Similarly, Čadro *et al.* (2022) demonstrated that geothermal heating in greenhouses positively influences lettuce growth, shortens the vegetative period, and increases yield. However, there are still no studies investigating the effect of geothermal heating on the content of secondary metabolites, which largely determine the nutritional quality of lettuce.
While its effects on lettuce growth and the length of the vegetative period are of particular interest to producers, assessing the impact of geothermal heating on the nutritional composition of lettuce is equally important for consumers. Therefore, this research aimed to examine how geothermal heating affects the length of vegetation, yield, morphological characteristics, and content of bioactive compounds in lettuce.

MATERIALS AND METHODS

Geothermal heat pump was installed to heat the greenhouse, using soil as a stable energy source (7-13°C at 1.5-2 m depth). Soil collectors made of plastic pipes were placed in three trenches per location (50 m each, 1.2 m deep, 0.6 m wide) and insulated with EPS boards and PVC foil. Heat pump was connected via glycol-filled pipes, supplying heated water to warm soil and air. Pump operated at 25°C output, switched on below 10°C and off above 10°C air temperature (Čadro *et al.*, 2022).
The experiment was conducted during the 2023-2024 growing season in two identical greenhouses, each 100 m² (6.3 × 16 m) in size, covered with PVC foil. One greenhouse was equipped with geothermal heating, while the other, without heating, served as a control. The experiment was conducted on lettuce (*Neil F1*), which is commonly grown vegetable in greenhouses in Bosnia and Herzegovina during the autumn-winter period. Lettuce was planted (20 x 20 cm) on November 24, 2023, in both greenhouses simultaneously. Two weeks before lettuce planting, an agrochemical analysis was performed.

Table 1. Agrochemical properties of the studied soil

	pH [H_2O]	**pH [KCl]**	**Humus [%]**	**Phosphorus [mg/100 g]**	**Potassium [mg/100 g]**
Heated	7.60	6.50	3.20	47.00	64.50
Control	7.55	6.45	3.00	40.00	62.00

Based on the results, the soil had high levels of phosphorus and potassium, a medium humus content, and a slightly alkaline pH reaction (Table 1), indicating favorable fertility for intensive greenhouse production. Pedological analysis from previous research in the same area confirmed that the soil is alluvial clay loam, with approximately equal proportions of clay, silt, and sand, and neutral to slightly alkaline

pH (7.4–7.6), making it highly suitable for vegetable cultivation under protected conditions (Čadro *et al.*, 2022). Fertilization was performed five days before planting, by applying 150 kg of organic pelleted fertilizer and 3.5 kg of NPK (10:20:30) per 100 m². All agrotechnical operations were applied equally in both the heated and control greenhouse.

To measure climate conditions inside the greenhouses, *Spectrum Technologies, Inc. WatchDog Micro Stations* were used, equipped with *SMEC300* sensors for soil temperature and moisture, as well as sensors for air temperature and humidity. Soil sensors were inserted at the depth of the root system (approximately 20 cm), while air sensors were positioned at plant height (30 cm above the ground). All data were recorded at 60-minute intervals.

To monitor the experiment, 30 plants were taken from each greenhouse, which were marked and monitored until the harvest. Growth diameter measurements were made every seven days on selected plants. Harvesting was conducted on February 12, 2024, in the heated greenhouse, and on March 15, 2024, in the control greenhouse. Lettuce was harvested at technological maturity. The duration of the growing period was determined from planting until lettuce harvest. Fresh mass of each head was measured with a digital scale (*DWAG WPX 4500* with 0.01 g accuracy), and damaged leaves were removed to determine the proportion of waste. Total yield was calculated from plant density and average head mass. Leaf number was assessed following the lettuce harvest.

Determination of dry matter was carried out in a drying oven at a temperature of 50°C. 50 g of chopped plant material was added to a dry container that had been previously weighed. After that, the sample vessel was dried for 72 hours until it reached a constant weight. The proportion of dry matter in biomass was calculated according to the equation:

$$Dry\ matter\ [\%] = \frac{c-a}{b-a}\ x\ 100$$

A 30% aqueous ethanol solution was used for the extraction of phenolic compounds. Samples of plant material (1 g dry weight) were extracted in a water bath at 60°C under reflux for 60 minutes. After filtration, the extracts were made up to 50 ml with 30% ethanol and stored at 4°C until further analysis. The obtained extracts were used to determine total phenols, flavonoids and antioxidant capacity.

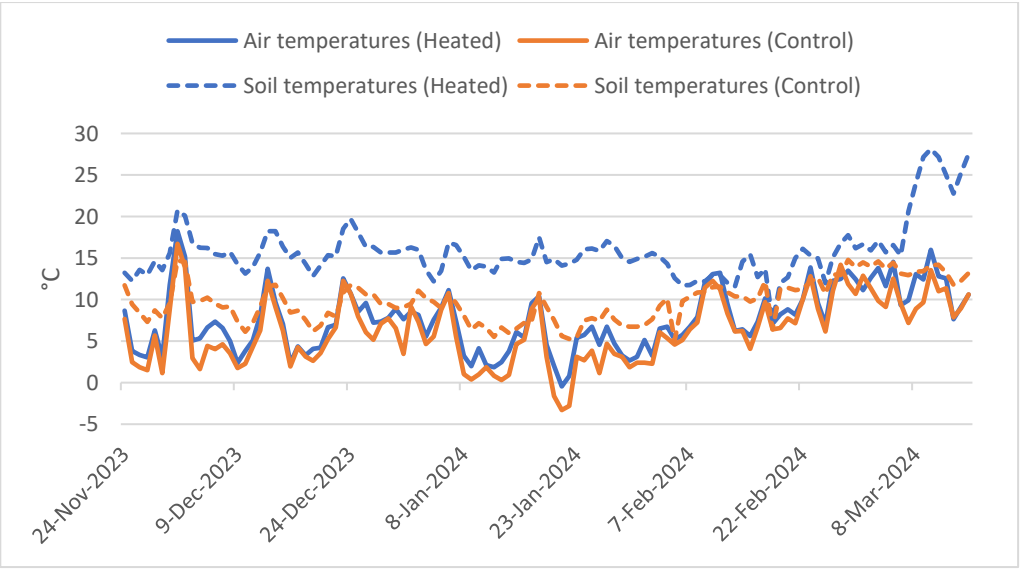
The content of total phenols was determined by UV/VIS spectrophotometric method using *Folin–Ciocalteu* reagent (Ough and Amerine, 1988). The reaction is based on the formation of a blue complex whose intensity was measured at 765 nm. Quantification was performed based on the gallic acid calibration curve, and the results are expressed as mg gallic acid equivalents (GAE) per g dry weight.

Total flavonoids were determined spectrophotometrically using the aluminum chloride method (Zhishen *et al.*, 1999). The principle is based on the formation of flavonoid complexes with $AlCl_3$, and the color intensity was measured at 510 nm. Catechin was used to create a standard curve, and the results were expressed as mg catechin equivalents (CE) per g dry weight.

The antioxidant capacity was determined by the FRAP method (Benzie & Strain, 1996), based on the reduction of the Fe^{3+}–TPTZ complex to Fe^{2+} at acidic pH and elevated temperature (37°C). The change in blue color intensity was measured spectrophotometrically at 595 nm. A standard $FeSO_4$ solution was used for quantification, and the results were expressed as mM Fe^{2+} equivalents per g dry weight. The results are presented as average ± standard deviation (SD). Statistical data processing was performed using the *IBM Statistics SPSS v20* software package. Independent t-test was used to compare mean values.

RESULTS AND DISCUSSION

Temperature plays a key role in regulating plant growth and productivity in greenhouse conditions. To examine the effect of geothermal heating on temperature stability, air and soil temperatures were monitored throughout the experiment. Graph 1 shows the recorded differences between the heated and control greenhouses during the vegetation period of lettuce.

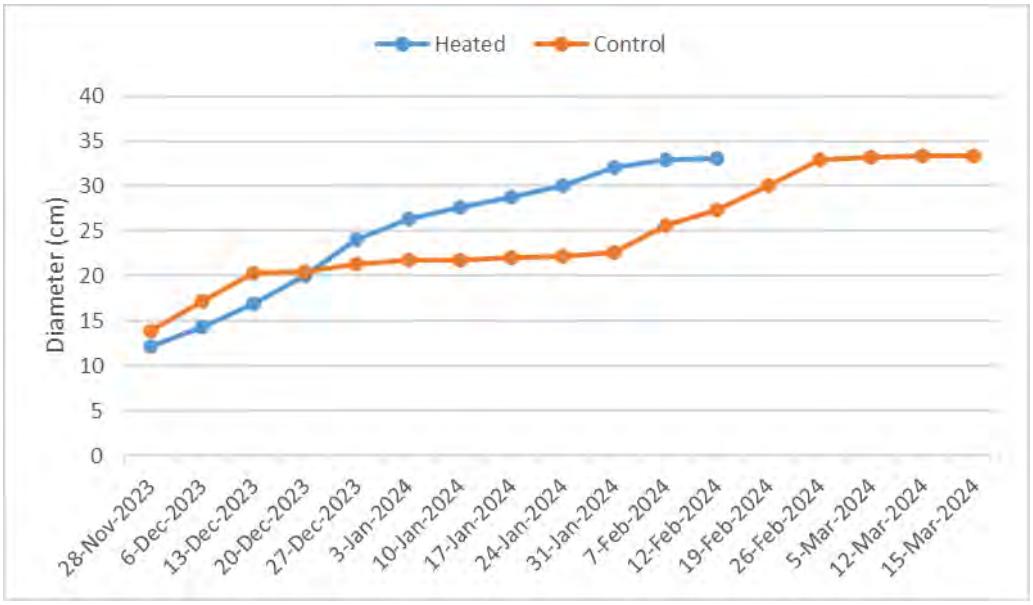


Graph 1. Daily mean air and soil temperatures during the vegetation period of lettuce

Based on Graph 1, air temperature patterns were generally similar in both the heated and control greenhouses throughout the experimental period. Although occasional fluctuations were observed, the differences in air temperature were relatively small, with slightly higher values recorded in the heated greenhouse. A notable exception occurred in late January, when temperatures in the control greenhouse dropped below 0°C. In contrast, soil temperatures exhibited a more pronounced difference between treatments. The soil in the heated greenhouse remained more stable, maintaining an average

temperature of around 15°C, which was approximately 5°C higher than in the control greenhouse. The Graph clearly demonstrates the stabilizing effect of geothermal heating on soil temperature compared to the unheated control.

The difference in lettuce growth dynamics between the heated and control greenhouses was pronounced (Graph 2). In the heated greenhouse, lettuce diameter increased steadily throughout the growth period, whereas in the control greenhouse, growth stagnated between December 20 and February 12. This stagnation was associated with air and soil temperatures falling below the biological minimum required for lettuce growth and development.



Graph 2. Effect of greenhouse heating on lettuce diameter during vegetation period

In the heated greenhouse, lettuce diameter increased steadily throughout the 81-day growth period (November 24-February 12), whereas growth in the control greenhouse stagnated due to air and soil temperatures falling below the biological minimum required for lettuce growth and development. Although no statistically significant difference in final head diameter was observed between the two greenhouses (Table 2), differences were evident in the timing at which a given diameter was reached, reflecting distinct growth dynamics and length of the growth period (Graph 2). Lettuce in the heated greenhouse reached technological maturity on February 12 (81 days after planting), while in the unheated greenhouse, maturity was reached only on March 15 (112 days after planting).

Table 2. Effect of greenhouse heating on morphologic and productive parameter of lettuce

Parameter	Heated greenhouse	Control greenhouse	Significance
Diameter [cm]	33.10 ± 2.40	33.35 ± 1.95	n.s.
Head weight [g]	341.75 ± 60.40	430.25 ± 59.72	**
Leaves number [n]	64.95 ± 8.41	74.95 ± 7.30	**
Yield [kg m^{-2}]	5.36 ± 0.55	6.88 ± 0.96	**

n.s. = not significant, * = $p<0.05$, ** = $p<0.01$

The data indicate that while lettuce diameter did not differ significantly between the heated and control greenhouses, other growth parameters were notably affected by the heating system. Head weight, number of leaves and overall yield were all significantly higher in the control greenhouse compared to the heated one (430.25 g; 74.95 leaves; 6.88 kg/m²), indicating that the length of the growing period has a substantial influence on lettuce development and productivity. These findings emphasize the importance of optimizing both temperature conditions and vegetation duration to achieve maximum yield.

Table 3 presents the chemical composition and antioxidant properties of lettuce plants grown under different greenhouse conditions. The results highlight the influence of temperature management on the accumulation of bioactive compounds and antioxidant capacity.

Table 3. Effect of greenhouse heating on phenolic, flavonoid, and total antioxidant content in lettuce

Parameter	Heated greenhouse	Control greenhouse	Significance
Dry matter [%]	3.56 ± 0.25	4.66 ± 0.21	**
Total phenols [mg GAE/100 g]	49.15 ± 3.94	80.50 ± 2.82	**
Flavonoids [mg/100 g]	1.67 ± 0.014	2.37 ± 0.034	**
Antioxidant capacity [µmol Fe^{2+}/100 g]	53.48 ± 1.04	112.67 ± 8.78	**

n.s. = not significant, * = $p<0.05$, ** = $p<0.01$

Dry matter content (4.66%), total phenolics (80.50 mg GAE 100 g^{-1} FW), total flavonoids (2.37 mg QE 100 g^{-1} FW), and total antioxidant capacity (112.67 mg Fe^{2+} 1000 g^{-1} FW) were significantly higher in plants grown in the control greenhouse (Table 3).

DISCUSSION

The present study aimed to assess the effects of different greenhouse temperature conditions on lettuce growth, head formation, and secondary metabolite content. Although harvesting in both greenhouses was carried out at the same head diameter, higher temperatures in spring and a longer growth period in the unheated greenhouse promoted the formation of a greater number of inner leaves composing the head, which significantly influenced the average head weight and, consequently, the total yield. In our experiment, the vegetation period was shorter in the heated greenhouse, whereas the yield was slightly higher in the unheated one, consistent with our previous findings (Čadro *et al.*, 2022). However, no statistically significant difference in yield was observed between the heated and unheated greenhouses.

On the other hand, regarding the content of phenols, flavonoids, and antioxidant capacity, significantly higher values were observed in lettuce grown in the greenhouse without geothermal heating. Similar trends have been reported in previous studies, where lower temperatures led to an increase in secondary metabolites (Becker *et al.*, 2014; Hayashi *et al.*, 2024). These differences in secondary metabolites can be attributed to lower soil and air temperatures, particularly when they fall below the biological minimum for lettuce (Yang *et al.*, 2024). At such temperatures, primary metabolic processes, including photosynthesis and growth related biosynthesis, are largely suppressed, while secondary metabolic pathways are activated as part of the plant's adaptive response to stress (Treutter, 2010; Qu *et al*., 2021). This shift enhances the synthesis of compounds such as phenols and flavonoids (Qaderi *et al*., 2023), helping to protect the plant (Jan *et al*., 2021) and contributing to increased antioxidant capacity (Belew *et al*., 2025). Optimum temperatures for lettuce growth are around 17–20°C for air and 10–12°C for soil (Maynard and Hochmuth, 2006). In the heated greenhouse, soil temperatures were within the optimal range and air temperatures slightly below optimum (Graph 1), supporting almost normal primary metabolism. In contrast, in the unheated greenhouse, both soil and air temperatures were below optimal, imposing stress that further suppressed primary metabolic activity and stimulated secondary metabolism, which in turn led to the higher phenolic and flavonoid content, and increased antioxidant capacity observed under these conditions.

Exposure of plants to short-term stress conditions that stimulate the biosynthesis of biologically active secondary metabolites can be considered beneficial, as it enhances the nutritional and functional quality of edible crops (Boo *et al*., 2011; Muthusamy and Lee, 2024). Conversely, prolonged or chronic stress exerts adverse effects and may cause persistent disturbances in key physiological processes (Way and Yamori, 2014).

According to Murtić (2025), even short-term fluctuations in soil temperature, which often occur on a diurnal basis, can trigger stress responses in plants. The author further emphasizes the importance of implementing appropriate agronomic practices to alleviate the impact of such temperature oscillations. Moreover, the plant's developmental stage plays a crucial role in determining its sensitivity to stress.

As reported by Becker *et al*. (2014), low temperature stress appears to have a more pronounced effect during the early growth stages of lettuce. While small, immature heads accumulated significantly higher levels of secondary metabolites under cool cultivation, this effect was transient, and mature heads showed only minor, non-significant differences. This suggests that the impact of low temperature on phenolic compound accumulation diminishes as the plant approaches full maturity. In our study, harvesting lettuce at different times in heated and unheated greenhouses may have reduced the observed differences, indicating that the effects of low temperature could have been even more pronounced if the harvest conducted simultaneously.

CONCLUSIONS

The study demonstrated that geothermal heating in the greenhouse maintained a significantly more stable soil temperature, which strongly influenced both the duration of the vegetation period and the dynamics of primary and secondary metabolism in lettuce. The vegetation period in the heated greenhouse was 31 days shorter compared to the unheated one. Conversely, lower soil temperatures in the unheated greenhouse stimulated secondary metabolism, resulting in higher accumulation of phenolic compounds, flavonoids, and other antioxidant substances, thereby enhancing the overall antioxidant capacity of lettuce.

Future studies should focus on quantifying the balance between energy efficiency and crop quality under geothermal heating, as well as identifying optimal temperature regimes that simultaneously promote yield and bioactive compound synthesis in lettuce.

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OPTIMIZACIJA PROIZVODNJE SALATE UZ GEOTERMALNI SISTEM GRIJANJA: UTICAJ NA MORFOLOGIJU I AKUMULACIJU BIOAKTIVNIH SPOJEVA

Sažetak

Salata (*Lactuca sativa* L.) je veoma cijenjena i nutricionistički važna kultura. Cilj novih tehnologija proizvodnje je skratiti vegetacijski period, omogućiti veći broj berbi, uz očuvanje okoliša i poboljšanje nutritivne vrijednosti salate. Ovo istraživanje se bavilo uticajem geotermalnog grijanja na dinamiku rasta i akumulaciju bioaktivnih komponenti u salati. Poređena su dva proizvodna sistema: plastenik s geotermalnim grijanjem i kontrolni plastenik bez grijanja. Geotermalni sistem je omogućio stabilniju temperaturu tla, što je značajno skratilo vegetacijski period za 31 dan. Nasuprot tome, niže temperature tla u kontrolnom plasteniku poticale su sekundarni metabolizam, što je rezultiralo višim koncentracijama fenolnih spojeva (80,5 mg GAE/100 g), flavonoida (2,37 mg/100 g) i povećanom antioksidativnom sposobnošću (112,7 μmol Fe^{2+}/100 g). Ovi rezultati pokazuju da režimi temperature snažno utiču i na primarne procese rasta i na sintezu bioaktivnih spojeva u salati. Geotermalno grijanje omogućava brži razvoj biljaka, ali može smanjiti akumulaciju određenih antioksidanata. Buduća istraživanja trebala bi težiti ka optimizaciji upravljanja temperaturom kako bi se postigla ravnoteža između prinosa, energetske efikasnosti i nutritivne kvalitete u proizvodnji salate u plastenicima.

Ključne riječi: *geotermalna energija, održiva poljoprivreda, primarni i sekundarni metabolizam, salata*

CONTENT OF BIOACTIVE COMPOUNDS IN LEMON BALM (*Melissa officinalis* L.) SAMPLES GROWN IN BOSNIA AND HERZEGOVINA

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Original scientific paper

Abstract

Lemon balm leaves are a potential source of biologically active compounds, especially phenolic compounds. These compounds contribute to its antioxidative activity, serving as the plant's natural response to stress. The aim of the research was to determine the content of bioactive compounds and antioxidative activity in lemon balm samples grown in different parts of Bosnia and Herzegovina. Total phenolics, total flavonoids, and antioxidative activity were analyzed using aqueous and ethanolic extracts with the Folin-Ciocalteau and method with $AlCl_3$ for phenolics and flavonoids, respectively. The pFRAP method was used for antioxidative activity. Research showed that geographic location had an impact on bioactive compound content and their antioxidative activity. It can also be concluded that the extraction solvent influenced the antioxidant activity of lemon balm leaves.

Keywords: *lemon balm, bioactive compounds, antioxidant activity, location, extraction solvent*

INTRODUCTION

Herbs are known to be used to enhance the sensory properties of foods, as natural preservatives, and for their health-promoting and nutritional characteristics. Nowadays, focus is on the development of new phytocomplexes from food and plant-derived compounds (Tsoukalas *et al*., 2021). Plants with potent health benefits for human health were recognized among the *Melissa* genus (Burlec, 2020). *Melissa officinalis*, known as lemon balm, is indigenous to the Mediterranean region, but is known and cultivated worldwide (Verma *et al*., 2015). It is called the "elixir of life" by Paracelsus (Sawicka *et al*., 2020), who believed it could completely restore a human´s strength. Extracts of *Melissa officinalis* can be applied in pharmaceutical products, cosmetics, and biopesticides, contributing to the production of bioactive metabolites with potential therapeutic effects against various diseases (Sawicka *et al*., 2020). Previous research confirmed that lemon balm, especially its ethanolic extracts, showed strong antidiabetic and antihyperlipidemic effects (Moacă *et al*., 2018). Its health benefits are reflected in β-cell prevention, improved insulin sensitivity, and regulation of glucose and lipid metabolism (Chung *et al*., 2010). Numerous studies indicated a significant role of lemon balm extracts in the treatment of diabetes type 2, dyslipidemia and metabolic syndrome

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(Changizi-Astiyani *et al*., 2013; Weidner *et al*., 2015). Due to increasing resistance to antibiotics, lemon balm (*Melissa officinalis* L.) stands out as a natural alternative with antibacterial propertie, particularly effective against Gram-positive bacteria, attributed to its bioactive compounds (Mimica-Dukic *et al*., 2004; Cimpeanu *et al*., 2025).
Phenolic compounds, classified as secondary metabolites, represent the predominant group of phytochemicals. They are characterized by the presence of one or more aromatic rings bearing hydroxyl groups, with structural complexity ranging from simple monomeric phenolics to large, high-molecular-weight polymers (Nile and Park, 2014). With regard to these compounds, several studies of lemon balm showed high content of phenolic acids, especially rosmarinic acid (Awad *et al*., 2009; Spiridon *et al*., 2010; Barros *et al*., 2013), caffeic and p-coumaric acid (Astani *et al*., 2012; Miraj *et al*., 2017), as well as tartaric, malic, citric, quinic, succinic, salicylic, and chicoric acids (Aubert *et al*., 2019). Moreover, several glucosides were identified, including luteolin 3´-O-β-D-glucoside and ethyl caffeate (Aubert *et al*., 2019). Polyphenolic acids, such as rosmarinic acid, promote antiviral activity, particularly against the HSV-1 virus (Sharifi-Rad *et al*., 2021), due to their ability to inhibit virus binding to cell receptors, consequently limiting the spread of the infection (Astani *et al*., 2012). Flavonoids, isolated from a wide range of vascular plants, are known to be phenolic substances that act as antioxidants, antimicrobials, and photoreceptors and exhibit biological activities with a major interest in antioxidant activity due to their ability to reduce free radical formation (Pietta, 2000). The form in which they circulate in vivo will influence their polarity, thus their localization and bioactivities (Rice-Evans, 2001).
Many authors reported that growing conditions, along with genotype, ripeness, storage time, and seasonal differences, had a major influence on the accumulation of phenolic compounds (Josuttis *et al*., 2013; Raudone *et al*., 2021).

The present study aimed to quantify the bioactive constituents, including total phenolics and flavonoids, and to assess the antioxidant activity of lemon balm (*Melissa officinalis* L.) samples collected across various regions of Bosnia and Herzegovina. Additionally, the study sought to investigate the influence of different extraction solvents on the levels of these bioactive components and their associated antioxidant properties.

MATERIALS AND METHODS

Materials

Approximately 1 kg of whole lemon balm was collected at different locations in B&H. The location´s altitude varied from 900 m, being the highest, to 384 m, being the lowest. Samples were classified based on their location altitude from S1 (the highest altitude) to S5 (the lowest altitude). Samples were grown in an open field. Samples were prepared for analysis as follows: only green, healthy leaves with no signs of damage were subjected to the drying process prior to analysis; every damaged leaf was discarded, and undamaged leaves were kept in a dark place at ambient temperature for seven days. The purpose of drying was to decrease the content of water in order to avoid the growth of

the fungus. Once it was dry, the sample was crushed in a mortar with a pestle and used for further analysis.

Extraction

Bioactive compounds were extracted using two solvents: a 70% (v/v) ethanol solution and distilled water. Extractions were performed under controlled conditions to ensure reproducibility and maximal yield of target metabolites. 1 g of dried and crushed lemon balm sample was mixed with 70% ethanol, previously heated at 50°C, manually homogenized, transferred to a volumetric flask with a round bottom, and heated in an ultrasonic bath at 24°C for 30 minutes. After sonication, the sample was filtered through Whatman no. 1, and another portion (20 mL) of ethanol was added to the residue. The mixture was sonicated repeatedly in an ultrasonic bath three times. Samples were transferred to a volumetric flask and adjusted to the volume (100 mL). The extraction procedure was repeated with distilled water.

Total phenolic content determination (TPC)

The spectrophotometric method based on a color reaction between phenolics and the Folin-Ciocalteau reagent was used for total phenolics content determination (Ough and Amerine, 1988). Briefly, 1 mL of extract was mixed with 2.5 mL Folin-Ciocalteau reagent (1:10, v/v), and after 5 minutes, 6.5 mL of saturated sodium carbonate Na_2CO_3 was added. The mixture was placed in a water bath (50°C) for 20 minutes, and absorbance was read at 750 nm against a blank. Calibration was performed using gallic acid, and the content of phenolic compounds was reported as gallic acid equivalents per 100 g of lemon balm.

Total flavonoid content determination (TFC)

The spectrophotometric method based on a color reaction between flavonoids and $AlCl_3$ was used for the determination of total flavonoid content, and the intensity of the colored complex was measured at 510 nm (Zhinsen *et al*., 1999). Briefly, 1 mL of extract was mixed with 4 mL of distilled water and 300 μL of 5% $NaNO_2$, after 5 minutes, 300 μL of 10% $AlCl_3$ was added, and 1 minute after, 2 mL of 1M NaOH. A calibration curve (0-100 mg/L) was made with catechin and used for the calculation of flavonoid content. Results were expressed as catechin equivalents /100 mg of dry weight.

Antioxidant activity determination

The spectrophotometric method based on a color reaction of phenolic compounds with $K_3[Fe(CN)_6]$ and $FeCl_3$ was used for the determination of antioxidant activity. The intensity of the blue colored complex was measured at 700 nm (Meng *et al.*, 2011).
Briefly, 1 mL of extract was mixed with 1 mL of K3[Fe(CN)6], and after 5 minutes, 1 mL of FeCl3 and 7 mL of water were added. Gallic acid was used as a standard for calibration (0-100 mg/L), and the results were expressed as gallic acid equivalents.

Statistical data analysis

The obtained data were statistically analyzed using program PAST (*ver* 5.1) (Hammer *et al*., 2001). In order to examine the influence of location on the investigated parameters (content of bioactive compounds and antioxidative activity), one-way ANOVA with Tukey *post hoc* test was used. To examine the influence of extraction solvents on the investigated parameters the non-parametric Mann-Whitney (MW) test was selected. Differences with $p<0.05$ were considered significant.

RESULTS AND DISCUSSION

The lemon balm samples were collected during the summer of 2024 from various locations across Bosnia and Herzegovina, including the Nevesinje area in eastern Herzegovina, Butmir and Trnovo near Sarajevo, and the Vareš and Kakanj area in central Bosnia. The location sites and their corresponding coordinates are given in Table 1. Samples were classified based on their location altitude, ranging from S1 (the highest altitude) to S5 (the lowest altitude). Notably, samples S3 and S4 were collected in close proximity, resulting in nearly identical coordinates.

Table 1. Locations of lemon balm (*Melissa officinalis* L.) samples collected in Bosnia and Herzegovina

Sample No. Location of sample	Latitude	Longitude	Altitude (m)
S-1 (Nevesinje)	43.2575°	18.1124°	898
S-2 (Vareš)	44.1644°	18.3283°	845
S-3 (Trnovo)	43.6658°	18.4459°	817
S-4 (Butmir)	43.8191°	18.3257°	506
S-5 (Kakanj)	44.1272°	18.1181°	387

The total phenolic content (Table 2) of lemon balm samples ranged from 289.1±6.60 to 512.99±2.21 mg GAE/100 g of dry weight in ethanolic extracts and 162.60±12.30 to 360.40±21.20 mg GAE/100 g of dry weight in aqueous extracts (Fig. 1). Levels of phenolics varied in dependance on altitude, and for both types of extractions, it was found that the samples from locations of the highest altitute had the highest TPC. This is in accordance with previous research. It is well established that higher altitudes can affect the accumulation of phenolic compounds (Taamalli *et al*., 2018). Bilgin and Sahin (2013), in their research on olive leaves, showed TPC decreased with decreasing geographical altitude. The content of bioactive compounds is highly dependent on geographical location due to variations in environmental factors such as soil composition, climate, altitude, and sun exposure (Bilgin *et al.*, 2013; Zhang *et al*, 2022), all of which influence plant growth and biosynthesis of bioactive compounds. Zakraoui *et al*. (2023) showed significant variation in phenolic compounds in olive leaves across different altitudes, which can affect plant height and density, contributing to differences

in bioactive compound content. Urbonaviciene *et al*. (2022), in their study on wild bilberries reported total phenolics to be the highest in the most northern regions and the lowest in the most southern regions. The observed results align partially with previous studies, potentially reflecting the influence of environmental conditions, including sunlight, precipitation, and related factors. Other researchers (Klimiene *et al.*, 2021) found that TPC and TFC are affected by the chemical properties of the soil (pH, N, P_2O_5, Ca, Mg, and soil humus).

The high content of phenolic compounds observed in this study is consistent with the findings reported by Slowianek and Leszcynska (2016). This characteristic is typical of the Lamiaceae family, to which *Melissa officinalis* belongs. Consequently, plants belonging to this family are widely employed in traditional medicinal practices and are valued for their beneficial effects on health (Modnicki and Blacerek, 2009).

Statistical analysis showed no significant effect ($p>0.05$) of sampling locations on the average values of total phenolic content (TPC). Sampling locations had a statistically significant effect ($p<0.05$) on total flavonoids content (TFC) (Table 2). The highest TFC content was determined at sampling site S-5 and it was statistically significantly higher than the TFC content at sampling sites S-1 and S-3. Statistically significant differences in the content of the mentioned parameter were also found between sampling localities S-1 and S-3 (Table 2).
Statistical analysis showed no significant effect ($p>0.05$) of the extraction solvent on the average values of TPC and TFC. Although certain differences in the examined parameters were observed among the extraction methods, but these differences were not statistically significant (Table 2).

One of the most commonly applied methods for isolating bioactive compounds from plant materials is solvent extraction. Nevertheless, the efficiency of extraction and the corresponding antioxidant potential of the obtained extracts are greatly influenced by the type of solvent used. The heterogeneous distribution of phenolic compounds across plant tissues may limit the extraction efficiency of antioxidant compounds (Antolovich *et al*., 2000). Our research revealed higher TPC and TFC values in ethanolic extracts (ethanol:water, 70:30), which is in accordance with previous results, confirming that aqueous ethanol is more effective in recovering the highest amounts of bioactive compounds with a phenolic nature. The impact of extraction solvent on phenolic and flavonoid levels has been reported (Khatode and Deshmukh, 2022) and was reflected in our study, where 70% ethanol extracts contained higher amounts of these compounds than extracts obtained with water. Sultana *et al*. (2009) reported that aqueous ethanolic and methanolic solutions had the highest content of TPC among selected medicinal plants. Jovanović *et al*. (2022) found that the highest content of polyphenols was found in methanolic and aqueous extracts of lemon balm.

Binello *et al*. (2017) focused their study on green extraction of polyphenolics in lemon balm, suggesting ultrasound and microwave-assisted extraction protocols, with ethanol as the best solvent for this type of extraction. Previous studies (Kamdem *et al.*, 2013; Duda *et al*., 2015) reported higher amounts of phenolic compounds in methanolic extracts. Methanolic and ethanolic extraction solvents can improve the solubility of phenolic compounds, which was the topic of the study conducted by Singapurwa *et al*. (2024). These authors studied the influence of polarity of extraction solvents on components with antioxidant properties and showed that solvents with high polarity (methanol, ethanol) can exhibit higher values for TPC of higher molecular weight.

Table 2. Total phenolic and flavonoids content in 70% ethanolic extracts and aqueous extracts

Parameters	TPC			TFC		
Extraction solvents	Ethanolic extracts	Aqueous extracts	Average	Ethanolic extracts	Aqueous extracts	Average
Location						
S-1	446.69	162.60	304.65 A	3.93	0.73	2.33 A
S-2	289.18	328.60	308.89 A	2.91	4.49	3.70 AB
S-3	340.7	282.67	311.69 A	3.70	5.40	4.55 B
S-4	496.17	165.89	331.03 A	3.54	2.06	2.80 AB
S-5	512.99	360.40	436.70 A	5.55	4.68	5.12 C
Average	417.15 a	260.03 a		3.93 a	3.47 a	

* capital letters indicate differences between sampling locations; lowercase letters indicate differences between extraction solvents

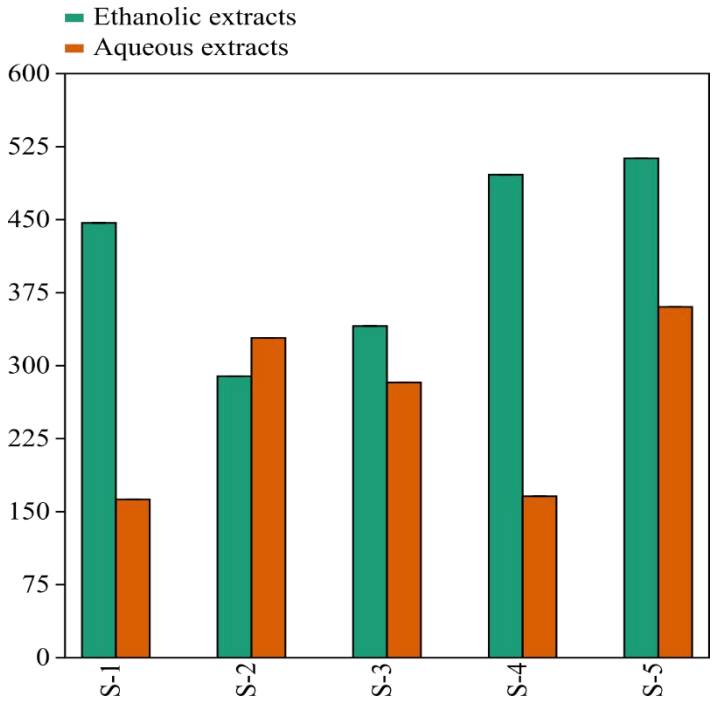

Figure 1. Total phenolic content (TPC) in lemon balm samples in mg of gallic acid equivalents

The content of phenolic compounds can also be influenced by various external and internal factors, such as temperature, extraction time, physical state of the sample (fresh or dehydrated), plant used for extraction, etc. Ordaz *et al*. (2018) used different temperature / time conditions for aqueous extraction of lemon balm samples, which resulted with a range of 5.58-49.16 mg GAE/g of sample and a strong influence of variable parameters. Interactions temperature/time showed a positive influence on the liberation of antioxidants (Ordaz *et al*., 2018). Our results were slightly lower than reported, which can be explained by the extraction conditions and quantity of samples. Fernandes *et al*. (2016) showed that an increase in time of infusion favors the extraction, which can enhance solute solubility. Šic Žlabur *et al*. (2016) reported an increasing trend in the time of ultrasonic extraction for phenolic compounds. Tülek *et al*. (2020) showed optimum extraction conditions to be 100°C for temperature and 120 minutes for the time (6365 mg GAE/ 100g), although this type of extraction affected phenolic acids content, which was undesirable, knowing that rosmarinic acid is the most abundant phenolic acid in lemon balm (Silva *et al*., 2023).

Table 3. Antioxidant activity measured by pFRAP method in 70% ethanolic and aqueous extracts

Parameter	Antioxidant activity		
Extraction solvents	Ethanolic extracts	Aqueous extracts	Average
Location			
S-1	2531.58	1548.63	2040.11 A
S-2	2579.77	2034.20	2306.99 A
S-3	2614.16	2093.13	2353.65 A
S-4	2562.58	1786.7	2174.64 A
S-5	2628.32	2173.27	2400.80 A
Average	2583.26 a	1927.19 b	

* capital letters indicate differences between sampling locations; lowercase letters indicate differences between extraction solvents

The pFRAP method was employed to evaluate the antioxidant potential of *Melissa officinalis* (lemon balm) samples. and the results are given in Table 3. As expected. the S5 samples exhibited the highest antioxidant capacity. indicating the greatest reducing power among the tested extracts. The results obtained from the pFRAP method, based on the reaction of components with antioxidant activity indicate a high Fe(II) - chelating capacity of both ethanolic and aqueous extracts of lemon balm, thereby enhancing their overall antioxidant potential.
Statistical analysis showed no significant effect ($p>0.05$) of sampling locations on the average values of *M. officinalis* antioxidant potential (Table 3).

Statistical analysis revealed significant differences in the antioxidant activity of lemon balm leaves between the extraction solvents used. On average, the antioxidant activity of the leaves was significantlly higher in the ethanolic extract compared to the aqueous extract (Table 3). This can be explained by the presence of additional antioxidant compounds in lemon balm leaves that are more efficiently extracted with ethanol due to their lipophilic properties.
The antioxidant activity is largely attributed to phenolic constituents, including rutin, quercetin, kaempherol, and phenolic acids, known for their high radical-scavening capacity (Omoba *et al*., 2019). In general, higher concentrations of phytochemicals are associated with increased antioxidant activity. as these compounds can neutralize free radicals. Flavonoids, in particular, act as primary antioxidants by donating hydrogen atoms to stabilize reactive species (Speisky *et al*., 2021). Furthermore, extracts of lemon

balm have demonstrated efficacy against both naturally occurring and synthetic free radicals (Dastmalchi *et al*., 2008).

Antioxidant activity of lemon balm samples found to be in a positive correlation with total phenolic content (Table 4).

Table 4. Correlation

	TPC	TFC	pFRAP
TPC	1	0.978	0.964
TFC		1	0.973
pFRAP			1

The extracts with a high amount of phenolic components exhibit high antioxidant activity. The content of total phenolics and flavonoids is directly correlated with antioxidant activity, which is consistent with previous *in vitro* studies (Wong *et al*., 2006). Li *et al*. (2008) also reported a strong positive correlations between phenolic compounds and antioxidant activity, confirming the significant role of phytochemicals in scavening free radicals and enhancing antioxidant capacity. Our results are in agreement with previous studies of lemon balm extracts (Firuzi *et al*., 2005; Encalada *et al*., 2011).

CONCLUSIONS

The findings of this study demonstrated notable variations in the phenolic and flavonoid content and antioxidant activity of lemon balm originating from different geographical locations. Such differences suggest that environmental factors, as well as the type of extraction solvent used, play an important role in determining the antioxidant potential of lemon balm. Future research should focus on the phenolic profiling of lemon balm samples cultivated in Bosnia and Herzegovina, the development of green extraction techniques for antioxidant phytochemicals, and the influence of cultivar and production methods on the chemical composition and bioactivity of lemon balm.

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SADRŽAJ BIOAKTIVNIH KOMPONENTI U UZORCIMA MATIČNJAKA (*Melissa officinalis* L.) UZGOJENIM U BOSNI I HERCEGOVINI

Sažetak

Listovi matičnjaka (*Melissa officinalis* L.) predstavljaju vrijedan izvor biološki aktivnih spojeva, posebno fenolnih jedinjenja. Ove supstance doprinose antioksidativnoj aktivnosti biljke, djelujući kao dio njenog prirodnog odgovora na stresne uslove okoline. Cilj ovog istraživanja bio je utvrditi sadržaj bioaktivnih spojeva i antioksidativnu aktivnost uzoraka matičnjaka uzgojenih u različitim područjima Bosne i Hercegovine. Sadržaj ukupnih fenola, flavonoida i antioksidativna aktivnost analizirani su u vodenim i etanolnim ektsraktima. Za određivanje ukupnih fenola i flavonoida korištene su Folin-Cioacalteau i $AlCl_3$ spektrofotometrijske metode, dok je za ispitivanje antioksidacijske aktivnosti primjenjena pFRAP metoda. Dobijeni rezultati ukazuju da lokalitet i sredstvo za ekstrakciju imaju značajan uticaj na sadržaj bioaktivnih spojeva, te njihov antioksidacijski potencijal.

Ključne riječi: *matičnjak, bioaktivni spojevi, antioksidacijska aktivnost, lokalitet, ekstarkciono sredstvo*

THE INFLUENCE OF THE DRYING PROCESS ON PLANT PIGMENT CONTENT IN SELECTED HERBS

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Original scientific paper

Abstract

Plant pigments are important functional molecules in photosynthetic organisms and have been recognized as photoprotective compounds. This research aimed to determine the content of plant pigments in selected herbs and the influence of the drying process on the stability of chlorophylls and carotenoids. Coriander (*Coriandrum sativum*), parsley (*Petroselinum crispum*), dill (*Anethum graveolens*), and basil (*Ocimum basilicum*) were selected for analysis. Fresh herb material (0.5 g) was analyzed for plant pigment composition, including total chlorophyll, chlorophyll *a* and *b*, and total carotenoids. Following the initial assessment, samples were subjected to two dehydration treatments: air-drying and oven-drying at 45°C. Plant pigments were extracted from fresh and dried herbs using 80% (v/v) acetone. The concentrations of individual pigment fractions were determined spectrophotometrically by measuring absorbance at 470 nm, 648.6 nm, and 663.2 nm, following standard procedures for the quantification of photosynthetic pigments. Fresh parsley showed the highest total chlorophyll content (524.38±7.13 mg/100g), which was followed by the highest chlorophyll a (Chl a) and chlorophyll b (Chl b) content, with a Chl a/Chl b ratio of 1:2. Oven-dried basil had the lowest total chlorophyll content (196.83±4.95 mg/100 g dw). Fresh parsley showed the highest carotenoid content (114.99±2.04 mg /100 g dw), and air-dried basil samples had the lowest carotenoid content (23.85±0.95mg/100 g dw). The drying process showed a significant impact on plant pigments, with a consistent trend toward their degradation during dehydration. Nevertheless, the specific drying technique employed exerted only a minimal effect on the overall pigment content.

Keywords: *plant pigments, chlorophyll, carotenoids, drying, herbs*

INTRODUCTION

Herbs have been recognized as a valuable source of phytochemicals; hence, they have been utilized in traditional medicine for their therapeutic properties, thanks to the presence of essential oils (Muminović, 1998), and in culinary applications for enhancing

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the taste of foods. There is a wide range of phytochemicals in herbs, with a particular emphasis on plant pigments. Plant pigments represent a chemically diverse class of biomolecules that may be systematically classified according to their structural characteristics. This classification encompasses tetrapyrrolic compounds (chlorophylls), carotenoids (e.g., β-carotene), phenolic pigments (anthocyanins), and N-heterocyclic pigments (betalains) (Schoefs, 2002). Chlorophylls play an essential role in photosynthesis, together with carotenoids, which fight against photooxidative destruction (Giri *et al*., 2013). Plant pigments exhibit significant antioxidative activity against peroxide radicals as follows: chlorophyll a > lutein > pheophytin a > chlorophyll b > β-carotene > pheophytin b (Loranty *et al*., 2010). Chlorophyll and carotenoids are, due to their chemical structure, liposoluble compounds: carotenoids with long carbon chains in the form of isoprenoid units and chlorophylls as tetrapyrrole compounds with an esterified phytol group (Schwartz *et al*., 2008). Considering the fact that chlorophylls are found in green plants, their use in human nutrition is also significant. Anticancer and antimutagenic activity have been found in chlorophylls and their derivatives (Ferruzzi and Blakeslee, 2007). Chlorophyll stability, besides autumn plant aging, depends on heat and acidity, which can inhibit the degradation process (Schwartz *et al*., 2008). Acting as antioxidants, carotenoids neutralize free radicals and reactive oxygen species while also reducing the detrimental effects of solar radiation (Howitt and Pogson, 2006; Matos, 2017). Compounds produced during carotenoid oxidation can act as signaling stress molecules (Havaux, 2013). The biological relevance of carotenoids is reflected in their antioxidant capacity and their function as provitamin A, demonstrating their importance in physiological processes (Hamed *et al.*, 2023). Beyond providing yellow, orange, and red pigmentation to plant tissues, carotenoids also serve as essential precursors in the biosynthetic pathways leading to various aromatic compounds. Meléndez-Martínez *et al*. (2022) emphasized the crucial role of carotenoids in reducing the risk of several chronic diseases (macular degeneration, cardiovascular diseases, and cancer).

Apiaceae is a family with more than 3000 species known for their aromatic characteristics, specific odor, and taste, which is the reason for their use as spices (Aćimović and Milić, 2017). Plants such as basil, mint, rosemary, oregano, and others from the Lamiaceae family are used in culinary and mostly in traditional medicine as a remedy for many conditions, thanks to bioactive compounds with antioxidative, anti-inflammatory, and antiviral properties (Kivilompolo and Hyotylainen, 2007).

Herbs, chosen for this research, have a wide range of applications in human nutrition and are regular components of herb mixes produced in the industry. Although the selected herbs do not belong to the same family (parsley, dill, and coriander belong to Apiaceae, and basil to the Lamiacea*e* family) and were collected in different stages of maturity, their physiological properties and significance are very similar. These herbs are susceptible to spoilage after harvesting due to tissue damage, inadequate temperatures, and water loss during storage, which can lead to metabolic processes similar to spoilage. Biochemical changes, such as increased breathing rate, as well as decreased water content, favor microbial growth and development (Ouzounidou *et al*.,

2013). For this reason, drying is employed as a preservation method, enabling prolonged storage and maintaining the usability of these herbs over extended periods (Akpınar, 2006).
This study aimed to quantify the plant pigment content in selected herbs and to evaluate the impact of different drying methods on the stability of chlorophylls and carotenoids.

MATERIALS AND METHODS

Materials
Herbs used in the research were sourced fresh after harvest from local producers in the Kakanj area, Bosnia and Herzegovina. The herbs included parsley (*Petroselinum crispum* cv. *Rialto*), dill (*Anethum graveolens* cv. *Ella*), basil (*Ocimum basilicum* cv. *Italiano classico*), and coriander (*Coriandrum sativum*). Parsley and basil were greenhouse-grown, while dill and coriander were cultivated in open fields.

Drying process
The herbs were subjected to two different drying methods to examine the effects on their properties:

a) shade drying without sunlight for seven days at room temperature (average 25°C); and
b) laboratory oven drying (MEMMERT, Germany) at 45±1°C for 4 hours, with periodic mixing.

Both drying processes were applied on fresh herb leaves with initial moisture as follows: parsley 83.32%, dill 84.12%, coriander 85.67%, and basil 89.21%.

Methods
Photosynthetic pigments (Chl a, Chl b, and total carotenoids) were determined with the method suggested by Sumanta *et al*. (2014). The method is based on a pigment extraction with an 80% acetone solution from fresh and dried herbs. Pigment content was determined using a spectrophotometric method (measuring absorbance at 470 nm, 648.6 nm, and 663.2 nm, respectively). Briefly, 0.5 grams of the sample was mixed with 10 mL of 80% acetone, homogenized, and centrifuged at 10000 rpm for 15 minutes at 4°C. 0.5 mL of supernatant was then mixed with 4.5 mL of acetone, and the absorbance was read at three wavelengths. The content of photosynthetic pigments was calculated using the equations below:

$$Ch - a = 12{,}25A\,663{,}2 - 2{,}79A646{,}8$$

$$Ch - b = 21{,}5A646{,}8 - 5{,}1A663{,}2$$

$$\mathrm{Cx + c} = \frac{1000\mathrm{A470} - 1{,}82\mathrm{Ca} - 85{,}02\mathrm{Cb}}{198}$$

The obtained results were expressed as micrograms of sample/mL, and calculated as mg of sample/100 g of dry weight (dw).

Statistical analysis
Obtained data were expressed as mean ± SD and statistically analyzed with a comparison of data by a one-way analysis of variance (ANOVA) with the level of significance at $p<0.05$.

RESULTS AND DISCUSSION

The results for pigment content (Chl a, Chl b, total chlorophyll, Chl a/Chl b ratio, and carotenoids) are shown in Table 1. The results were expressed as mean ± SD.

Table 1. Plant pigment content (leaves) as mg/100 g dw

Herb	Sample type (leaf)	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll	Total carotenoids
Parsley	Fresh	332.92 ± 7.58^a	192.56 ± 0.45^a	524.38 ± 7.13^a	114.99 ± 2.04^a
	Air-dried	215.71 ± 7.54^b	104.80± 3.95^b	319.58 ± 22.45^b	34.40 ± 2.10^c
	Oven-dried	208.37 ± 1.21^b	116.62 ± 0.75^b	323.54 ± 21.64^b	41.15 ± 1.28^b
Dill	Fresh	269.14 ± 10.98^a	183.63 ± 2.16^a	460.08 ± 7.95^a	80.72 ± 3.86^a
	Air-dried	237.89 ± 4. 23^a	121.94 ± 3.45^b	360.89 ± 7.32^b	35.43 ± 1.18^c
	Oven-dried	214.63 ± 4.71^b	126.76 ± 3.45^b	346.11 ± 2.31^b	48.57 ± 1.46^b
Coriander	Fresh	214.12 ± 3.88^a	156.21 ± 7.02^a	363.15 ± 1.85^a	47.60 ± 3.19^a
	Air-dried	208.37 ± 2.39^a	106.28 ± 0.98^b	327.46 ± 1.44^a	37.87 ± 1.61^b
	Oven-dried	191.65 ± 1.21^b	101.92 ± 0.95^b	297.07 ± 8.27^b	41.82± 0.98^c
Basil	Fresh	252.38 ± 17.71^a	138.41 ± 6.57^a	387.70 ± 24.28^a	64.07 ± 5.81^a
	Air-dried	233.06 ± 3.38^a	135.32 ± 1.61^a	371.46 ± 2.95^a	23.85± 0.95^c
	Oven-dried	134.18 ± 6.30^b	62.65 ± 3.36^b	196.83 ± 4.95^b	40.01± 1.37^b

Values marked with different letters are significantly different ($p<0.05$)

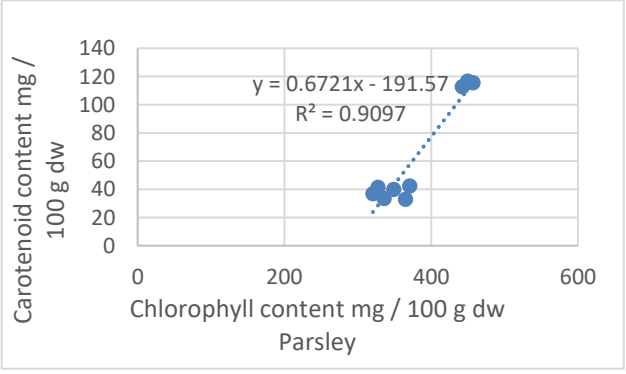
It can be seen that the extract from fresh parsley showed the highest total chlorophyll content (524.38 ± 7.13 mg/100 g dw), and oven-dried basil showed the lowest content (196.83 ± 4.95 mg/100 g dw). Analyzed samples had a Chl a to Chl b ratio of 1:2, which is in accordance with previous research and literature (Śledź and Witrowa-Rajchert, 2012). Kathirvel *et al*. (2006) reported 130.7, 159.4, and 304.9 mg/100 g of total chlorophyll content in coriander, dill, and parsley, respectively. According to Hawrylak-Novak (2009), basil had 118 and 28 mg/100 g of chlorophyll a and chlorophyll b, whilst Jangra *et al*. (2018) reported 141-172 mg/100 g for chlorophyll a, and 70-93 mg/100 g for chlorophyll b for different coriander varieties. In this same research (Jangra *et al*.,

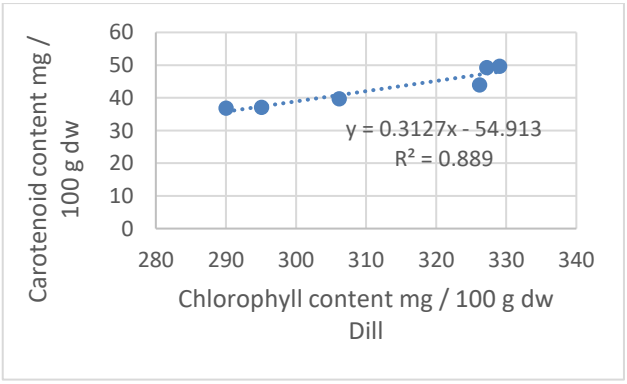
2018), it was reported that the type of extraction solvent had a high influence on chlorophyll content. Dobričević *et al.* (2019) found pigment content lower than in our research. It can be explained by the fact that pigment content is dependent on plant genotype and environmental factors. The chlorophyll content is influenced by various factors, such as the place where the plant is grown, leaf maturity, and position (Schwartz *et al.*, 2008). Total chlorophyll content was significantly lower during the drying process, whereas there was no significant difference in total chlorophyll content between oven-dried and air-dried samples. The influence of temperature on chlorophyll degradation during the drying process has been widely studied. Various authors showed that degradation kinetics followed pseudo-first order with a high impact of temperature. Kathirvel *et al.* (2006) reported a decrease of total chlorophyll in oven-dried (45°C) samples of coriander, parsley, and dill for 1.66, 1.86, and 2.41 times, respectively. Similar trends were observed in the present study. The chlorophyll content in oven-dried parsley samples decreased 1.6 times, in oven-dried dill samples 1.33 times, and in coriander samples the chlorophyll content was 1.22 times lower than in fresh samples. Oven-dried basil samples showed a chlorophyll content approximately 50% lower than that of fresh samples. These results, which correlate with previous studies (Mafakheri *et al.*, 2010; Ghorbanli *et al*., 2013; Giannakoula and Ilias, 2013; Al Hassan *et al*., 2015), could be an indicator for the rapid decrease of photosynthetic pigment synthesis in the stress conditions. During the thermal processing of herbs, chlorophylls have been converted to pheophytins with a change of color from light green to olive green, which has been recognized as unpleasant by consumers. Hence, preventive procedures, like blanching or microwave drying, which can minimize degradation, have been developed (Alibas, 2006; Shaw *et al.*, 2007).

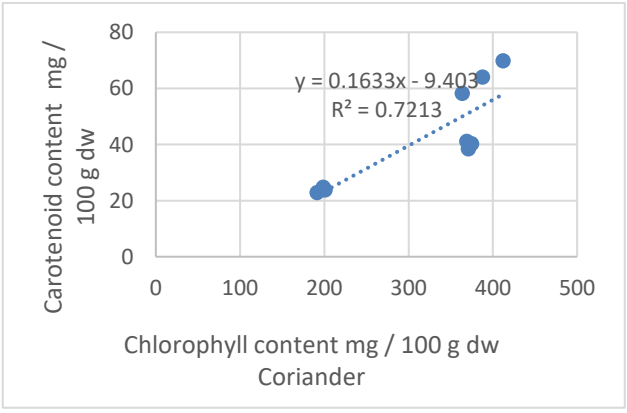
Levels of total carotenoids found in selected herbs are given in Table 1. The results ranged from 47.60 to 114.99 mg/100 g in fresh samples, and 23.85 to 48.57 mg/100 g in dried samples. The highest total carotenoid content was found in fresh parsley leaves (114.99 ± 2.04 mg/100 g dw), whilst the lowest total carotenoid content was detected in air-dried basil leaves (23.85±0.95 mg/100 g dw). Carotenoids are ubiquitous in all plants, mostly in reproductive organs in high concentrations. Beta-carotene, the most abundant, is known for its role as a radical scavenger in photosynthesis (Speek *et al*., 1988). Recent studies have highlighted the bioactivity and bioavailability of carotenoids, including β-carotene, emphasizing technological and innovative approaches for their application in human health (Bas, 2024). In addition, dietary intake of provitamin A carotenoids, such as β-carotene, has been associated with cognitive function in adults, suggesting potential neurobiological benefits (Hailili *et al*., 2025). Furthermore, microalgae have been explored as an alternative source of carotenoids, including β-carotene, with study focusing on challenges and strategies associated with obtaining stable compounds from these emerging sources (Mostafa and Hashem, 2025). Statistical analysis revealed significant differences between fresh and dried samples. Carotenoid content is influenced by ecological factors, geographical and geological conditions, and the level of plant maturity at the moment of analysis, as well as treatments after harvesting (Aizawa and Inakuma, 2007). Analysis of carotenoid content

in basil grown in an open field and in a greenhouse showed different results: 1.22 mg/100 g for field samples and 0.92 mg/100 g for greenhouse samples (Kopsel *et al*., 2005). Daly *et al*. (2010) reported carotenoid content in basil, dill, coriander, and parsley as follows: 25.8 mg/100 g, 8.7 mg/100 g, 14.4 mg/100 g, and 6.6 mg/100 g dw, respectively. Divya *et al*. (2012) found statistically significant differences in carotenoid content among different varieties of coriander, from 152.79 to 159.15 mg/100g dw in fresh leaves of a young plant and from 203.55 to 217.50 mg/100 g of a mature plant. Aizawa and Inakuma (2007) reported carotenoid content in fresh basil leaves (15.56 mg/100 g) and in parsley (18.33 mg/100 g). The total carotenoid content among the analyzed fresh samples varied, with parsley exhibiting the highest levels, followed by coriander, dill, and basil, which showed the lowest content. Herbs with darker green leaves also have higher anthocyanin content, which can reduce damage to leaves, acting both as light filters and as free-radical scavengers, thereby reducing photo-oxidative damage (Gould *et al*., 2018; Oliveira *et al*., 2020). Heat treatments used for herb processing can cause a loss of bioactive compounds. The drying process of parsley, dill, coriander, and basil samples resulted in a decrease of carotenoid content. However, the total carotenoid content in oven-dried samples was higher than in air-dried samples. Oven-dried coriander leaves resulted in a loss of total carotenoids of 35% and chlorophylls of 65% (Divya *et al*., 2012). Our research showed a loss of total carotenoid content in oven-dried samples of 64.2% for parsley, dill, and basil (39.8% and 37.55%), and coriander of 12%. Air-dried samples showed a total carotenoid content loss from 14% for coriander to 70.08% for parsley. Mazzeo *et al*. (2011) studied the influence of heat treatment on carotenoid content and determined the loss of total carotenoid content from 8-10 %. El Abassy *et al*. (2010) showed that a fast and conventional drying process at high temperatures resulted in carotenoid degradation, but that was not the case with the microwave drying process.

The correlation between chlorophyll and total carotenoid content in dependence on the drying process has been calculated for all samples. A positive correlation between total chlorophyll and carotenoid content in fresh and dried samples among selected herbs has been found (r^2 ranged from 0.849 to 0.954) (Figure 1).







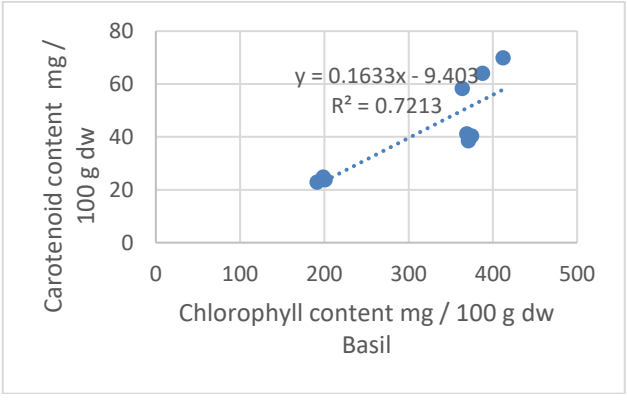


Figure 1. Linear regression between total chlorophyll and carotenoid content among selected herbs (parsley, dill, coriander, and basil)

Previous studies have demonstrated a positive correlation between chlorophyll and carotenoid content in various green plants, such as kale (Kopsell *et al*., 2004) and basil (Kopsell *et al*., 2005). Falcioni *et al*. (2023) proposed a sensor-based method for the estimation of photosynthetic pigments, which can be applied in plant research and for pigment analysis. Sumi *et al*. (2024) reported in their research that most of the investigated species exhibited a positive correlation between pigments, including chlorophylls and carotenoids, indicating that higher chlorophyll content is often associated with higher carotenoid levels. Such strong correlations may serve as a useful indicator for estimating carotenoid levels based on chlorophyll content.

CONCLUSIONS

This research showed that selected herbs, including parsley, dill, coriander, and basil, which are rich in chlorophyll and carotenoids, represent valuable sources of plant pigments and may contribute to improved nutritional quality. The drying process had a significant impact on plant pigment content, with a general trend toward degradation, whereas the specific drying method exerted only a minor effect on the overall pigment levels.

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UTICAJ PROCESA SUŠENJA NA SADRŽAJ BILJNIH PIGMENATA U ODABRANIM ZAČINSKIM BILJKAMA

Sažetak

Biljni pigmenti važne su funkcionalne molekule u fotosintetskim organizmima i prepoznati su kao fotoprotektivni spojevi. Ovaj rad je imao za cilj kvantifikaciju biljnih pigmenata u odabranim začinskim biljkama te procjeniti utjecaj procesa sušenja na stabilnost hlorofila i karotenoida. Za analizu su odabrani korijander (*Coriandrum sativum*), peršin (*Petroselinum crispum*), kopar (*Anethum graveolens*) i bosiljak (*Ocimum basilicum*). Svježe biljke (0,5 g) analizirane su na sadržaj biljnih pigmenata (ukupni hlorofil, hlorofil a, b i ukupni karotenoidi) nakon čega su uzorci sušeni na zraku i u sušnici (45°C). Biljni pigmenti ekstrahirani su 80% acetonom iz svježeg i osušenog bilja i određeni spektrofotometrijskom metodom (mjerenje apsorbancije na 470 nm, 648,6 nm, odnosno 663,2 nm). Svježi peršun pokazao je najveći ukupni sadržaj hlorofila (524,38±7,13mg/100 g), a zatim najveći sadržaj hlorofila a (Chl a) i hlorofila b (Chl b), s odnosom Chl a/Chl b 1:2. Najniži ukupni sadržaj hlorofila zabilježen je kod bosiljka sušenog u sušnici (196,83±4,95 mg/100g suhe tvari). Svježi peršun pokazao je najveći sadržaj karotenoida (114,99±2,04 mg/100 g), a uzorci bosiljka osušeni na zraku imali su najmanji sadržaj karotenoida (23,85±0,95mg/100 g t.v.). Proces sušenja pokazao je značajan utjecaj na biljne pigmente s tendencijom njihove razgradnje tokom sušenja, iako je način sušenja pokazao minoran utjecaj na sadržaj biljnih pigmenata.

Ključne riječi: *biljni pigmenti, hlorofil, karotenoidi, sušenje, začinske biljke*

MASOVNA POJAVA CIGARAŠA (*Bycticus betulae* L.) U VINOGRADIMA NA PODRUČJU GRADA LJUBUŠKI U 2025. GODINI

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Izvorni znanstveni rad – *Original scientific paper*

Sažetak

Cigaraš (*Bycticus betulae* L.) je kornjaš iz porodice *Rhynchitidae*, široko rasprostranjen na području Europe, te dijelova Azije. Najčešće nastanjuje staništa bogata listopadnim drvećem i grmljem, a u vinogradima se povremeno javlja kao sekundarni štetnik. Odrasle se jedinke pojavljuju početkom proljeća i hrane pupovima, a kasnije i lišćem, praveći crtičave grizotine. Kada se pupovi otvore i vinova loza prolista, odrasli kukci počinju nagrizati peteljke listova, što uzrokuje njihovo venuće. Ženke motaju uvelo lišće u tuljce („cigare“) unutar kojih odlažu nekoliko jaja. Jedna ženka može smotati približno 20 tuljaca. Tijekom svibnja i lipnja 2025. godine proveden je vizualni pregled trsova vinove loze na lokalitetima: Grabovo vrelo, Bijača, Lisice, Radišići, Veljaci, Ljubuški centar i Ljubuški – Plantaža. Štete od cigaraša utvrđene su na lokalitetima Grabovo vrelo, Bijača, Lisice i Ljubuški centar. Svi lokaliteti na kojima su zabilježene štete nalazili su se u neposrednoj blizini većih šumskih sastojina. Najveći intenzitet šteta zabilježen je na lokalitetu Grabovo vrelo, gdje je prosječan broj tuljaca po trsu iznosio od 4 do 10. Ovisno o lokalitetu, prosječna dužina tuljaca bila je od 7 do 9 cm, a prosječan broj jaja po tuljcu od 2 do 5.

Ključne riječi: *cigaraš, Bycticus betulae L., vinova loza, Ljubuški*

UVOD

Cigaraš (*Byctiscus betulae*) je polifagna vrsta kornjaša iz porodice *Rhynchitidae.* Široko je rasprostranjen u Europi, a prisutan je i u Maloj Aziji i na Kavkazu. Prezimi kao odrasli oblik u zemljištu, koji se aktivira u proljeće, najčešće u travnju i svibnju. Odrasle jedinke duge su od 6 do 9 mm, a odlikuju se izrazito metalik sjajnom bojom tijela, koja može varirati od zelenih i plavih do zlatnih tonova (Maceljski, 2002). Istraživanjem provedenim u Sloveniji utvrđeno je da u populaciji cigaraša dominiraju jedinke metalnozelene boje, dok su metalnoplavi primjerci znatno rjeđi, a jedinke metalno bakrene boje vrlo rijetke (Trdan i Valič, 2004). Nakon kopulacije, ženke u uvijene listove polažu jaja. Iz jaja se razvijaju apodne ličinke bijele boje sa smeđom glavom, dužine do 6 mm. Ličinke se razvijaju unutar tuljaca hraneći se tkivom lista, a po završetku razvoja napuštaju list, te se spuštaju u tlo gdje se kukulje. Antonie i sur. (2006)

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navode da se prelazak ličinke u kukuljicu odvija pri relativnoj vlažnosti od 50–55%, dok odstupanja izvan tog raspona u značajnoj mjeri utječu na proces kukuljenja. Prema Milleru (1956), vrlo teška (glinovita) i izrazito pjeskovita tla nepovoljno utječu na proces kukuljenja. Cjelokupan razvojni ciklus odvija se tijekom jedne vegetacijske sezone, pri čemu vrsta prezimi u stadiju kukuljice ili imaga unutar tla. Ženke prosječno odlažu 4–5 jaja u jedan tuljac, iako su zabilježeni slučajevi i s većim brojem jaja po tuljcu (Urban, 2015). Najvažnija biljka domaćin cigaraša je vinova loza (*Vitis vinifera* L.), a zabilježene su štete i na listovima kruške (*Pyrus communis* L.). Kao biljke domaćini navode se i obična bukva (*Fagus sylvatica* L.), lipa (*Tilia* spp.), vrba (*Salix* spp.), topola (*Populus* spp.) i druge vrste listopadnog drveća (Urban, 2015). Odrasle jedinke početkom vegetacije oštećuju nabubrele pupove, arazvojem listova, one se počinju hraniti lisnim tkivom, praveći karakteristične crtičave grizotine. Najkarakterističnija oštećenja ženke cigaraša prave na listovima vinove loze. One nagrizaju peteljke listova, te takvi listovi gube turgor i počinju venuti. Savijanjem i rolanjem listova, ženke formiraju tuljce nalik „cigarama“ u koje odlažu jaja. Za pravljenje jednog tuljca ženka upotrijebi jedan list vinove loze i to najčešće list koji se nalazi u blizini grozda. Štetnost cigaraša posebno dolazi do izražaja pri masovnoj pojavi, kada istodobno hranidba odraslih jedinki i formiranje tuljaca dovode do značajnih oštećenja lisne mase na mladim trsovima, što može utjecati na prinos i kvalitetu grožđa. Štete su obično veće ukoliko su vinogradi podignuti u blizini šumskih sastojina, gdje se cigaraš može pojaviti u velikoj brojnosti (Nazarenko i Petrenko, 2008). Isti autori navode da je pojava cigaraša usko povezana s biotipom u kojem dominiraju listopadne drvenaste biljke. Zabilježena je sklonost vrste prema staništima umjerene vlažnosti i temperature, gdje prevladavaju listopadne i mješovite šume, ali i kulturni krajobrazi poput voćnjaka, urbanih parkova, te vegetacijskih pojaseva drvenastih biljaka uz cestovne i poljske rubove (Mazur, 2002; 2011). Povremene masovne pojave u takvim agroekološkim uvjetima zahtijevaju praćenje dinamike populacije, posebno ukoliko se u blizini nalaze nasadi vinove loze. Ukoliko postoji potreba, cigaraš se može suzbijati primjenom mehaničkih, agrotehničkih i kemijskih mjera (Ostojić i sur., 2006). Smanjenje brojnosti populacije cigaraša postiže se uklanjanjem i mehaničkim uništavanjem tuljaca s jajima i ličinkama. Odrasli oblici su dobro uočljivi, pa se također mogu skupljati i uništavati. Plitkom obradom tla oko trsova uništavaju se kukuljice u tlu. Odrasle jedinke mogu se suzbijati primjenom insekticda želučanog djelovanja, od početka pojave kornjaša, prije nego ženke naprave tuljce i u njih odlože jaja.

Cilj istraživanja bio je utvrditi vrijeme pojave, brojnost populacije, te intenzitet šteta od cigaraša u vinogradima na području grada Ljubuški. Rezultati će poslužiti kao temelj za izradu preporuka vezanih uz integrirane mjere zaštite vinove loze i održivo upravljanje populacijama ovog štetnika.

MATERIJAL I METODE RADA

Praćenje pojave cigaraša provedeno je tijekom vegetacijske sezone 2025. godine na području grada Ljubuški. U istraživanju je bilo uključeno sedam vinogradarskih lokaliteta. Odabrane lokacije razlikovale su se u pogledu položaja, udaljenosti od šumskih ekosustava, sortimenta, te starosti nasada, što je omogućilo usporedbu intenziteta napada u različitim uvjetima uzgoja.

Tablica 1. Opis lokaliteta na kojima je provedeno istraživanje
Table 1. Description of the sites where the research was conducted

Lokalitet	Koordinate	Površina (ha)	Starost vinogarada	Sortiment	Tip vegetacije koji okružuje vinograd
Grabovo vrelo	43°15.2147'S 17°27.5318'I	0,1	6 godina	Blatina Trnjak Žilavka	Listopadna šuma
Bijača	43°81.0501'S 17°34.2000'I	0,15	12 godina	Žilavka Smederevka Bena	Listopadna šuma
Lisice	43°11.6700'S 17°29.7190'I	0,05	30 godina	Smederevka Žilavka	Listopadna šuma
Radišići	43°12.7940'S 17°31.3660'I	0,05	10 godina	Žilavka Bena Smederevka	Poljoprivredne površine
Veljaci	43°16.4890'S 17°27.1000'I	0,1	13 godina	Žilavka Bena Cabernet Sauvignon	Poljoprivredne površine
Ljubuški - centar	43°11.6290'S 17°33.4390'I	0,1	22 godine	Žilavka Smederevka	Listopadna šuma
Ljubuški – Plantaža	43°12.1492'S 17°31.9523'I	2,5	4 godine	Žilavka Blatina Trnjak Vranac Merlot	Livada

Metodologija istraživanja temeljila se na sustavnom vizualnom pregledu trsova vinove loze. Pregledi su obavljani jednom tjedno, tijekom svibnja i lipnja, što se prema dosadašnjim istraživanjima smatra najkritičnijim razdobljem za pojavu imaga u vinogradu, te odlaganje jaja i formiranje karakterističnih tuljaca. Prilikom svakog pregleda bilježen je broj odraslih jedinki po trsu, broj djelomično formiranih i već zatvorenih tuljaca. Poseban naglasak stavljen je na vinograde smještene u neposrednoj blizini šumskih ekosustava, budući da takvi lokaliteti osiguravaju stabilnije

mikroklimatske uvjete i veću dostupnost alternativnih domaćina, što može pogodovati održavanju i širenju populacija ovog štetnika. U svakom vinogradu, slučajnim odabirom, odabrano je po deset trsova vinove loze. S odabranih trsova prikupljena su po tri formirana tuljca, što je činilo ukupni uzorak od 30 tuljaca po vinogradu. Prikupljeni uzorci dopremljeni su u Laboratorij za zaštitu bilja na Agronomskom i prehrambeno-tehnološkom fakultetu Sveučilišta u Mostaru. U laboratoriju je izmjerena dužina prikupljenih tuljaca. Kako bi utvrdili prosječan broj jaja/ličinki po tuljcu, isti su pažljivo otvarani, te detaljno pregledani pod stereolupom (Leica EZ4D). Bilježen je broj jaja odloženih unutar pojedinog tuljca, kao i razvojni stadij ličinki. Dobiveni podaci poslužili su za procjenu intenziteta napada cigaraša na istraživanim lokalitetima.

a) b) c)

Slika 1. Cigaraš (*B. betulae*): a. imago, b. jaje i c. ličinka (foto: Zovko, M.)

Fig. 1. Leaf-rolling weevil (B. betulae L.*): a. adult (imago), b. egg, and c. larva (photo: Zovko, M.)*

REZULTATI I DISKUSIJA

Tijekom istraživanja provedenog 2025. godine, štete od cigaraša zabilježene su na lokalitetima Grabovo vrelo, Bijača, Lisice i Ljubuški – centar, dok na lokalitetima Radišići, Veljaci i Ljubuški – Plantaža prisutnost štetnika nije uočena.

U tablici 2. prikazana je brojnost populacije, te intenzitet šteta od cigaraša po lokalitetima.

Tablica 2. Lokaliteti na području grada Ljubuški na kojima su obavljeni pregledi vinove loze

Table 2. Locations in the Ljubuški area where grapevine inspections were conducted

Lokalitet	Datum pregleda	Broj odraslih jedinki po trsu	Broj oštećenih listova po trsu od imaga	Prosječan broj tuljaca po trsu	Prosječna dužina tuljca (cm)	Prosječan broj odloženih jaja po tuljcu	Prosječan broj ličinki po tuljcu
Grabovo vrelo	9.5.2025.	1	8	4	7	2	1
	15.5.2025.	1	15	10	9	5	2
	22.5.2025.	3	14	10	9	3	3
	30.5.2025.	2	8	9	9	3	2
	7.6.2025.	2	9	7	8	3	2
	11.6.2025.	1	5	4	8	2	2
Bijača	12.5.2025.	1	4	4	7	2	1
	16.5.2025.	2	10	8	9	4	2
	21.5.2025.	2	12	9	9	3	3
	28.5.2025.	1	8	8	9	3	2
	4.6.2025.	1	3	5	8	2	2
	9.6.2025.	0	4	3	8	2	1
Lisice	12.5.2025.	1	5	5	7	2	1
	16.5.2025.	2	6	9	9	4	2
	21.5.2025.	3	10	8	9	3	3
	28.5.2025.	3	11	8	9	3	2
	4.6.2025.	2	9	5	8	2	2
	9.6.2025.	1	1	3	8	2	1
Radišići	9.5.2025.	-	-	-	-	-	-
	15.5.2025.	-	-	-	-	-	-
	22.5.2025.	-	-	-	-	-	-
	30.5.2025.	-	-	-	-	-	-
	7.6.2025.	-	-	-	-	-	-
	11.6.2025.	-	-	-	-	-	-
Veljaci	9.5.2025.	-	-	-	-	-	-
	15.5.2025.	-	-	-	-	-	-
	22.5.2025.	-	-	-	-	-	-
	30.5.2025.	-	-	-	-	-	-
	7.6.2025.	-	-	-	-	-	-
	11.6.2025.	-	-	-	-	-	-
Ljubuški - centar	13.5.2025.	1	4	5	7	2	1
	17.5.2025.	2	9	8	9	3	2
	23.5.2025.	3	12	8	9	3	3
	29.5.2025.	2	8	8	9	3	2
	6.6.2025.	2	5	6	8	2	2
	14.6.2025.	1	3	2	8	2	1
Ljubuški – Plantaža	13.5.2025.	-	-	-	-	-	-
	17.5.2025.	-	-	-	-	-	-
	23.5.2025.	-	-	-	-	-	-
	29.5.2025.	-	-	-	-	-	-
	6.6.2025.	-	-	-	-	-	-
	14.6.2025.	-	-	-	-	-	-

Provedenim istraživanjem, štete od cigaraša zabilježene su na lokalitetima Grabovo vrelo, Bijača, Lisice i Ljubuški centar. Prosječan broj formiranih tuljaca po trsu kretao

se od 2 do 10, a najčešća duljina tuljaca bila je 7–9 cm. U tuljcima duljine 7–9 cm prosječno je pronađeno 2–5 jaja, dok su u kraćim tuljcima (<7 cm) najčešće pronađena 1–2 jaja. Broj ličinki prvog i drugog razvojnog stupnja (L_1 i $L_{2)}$ po tuljcu kretao se između 1 i 3, dok vizualnim pregledom ličinke trećeg razvojnog stupnja ($L_{3)}$ nisu pronađene unutar tuljca, što potvrđuje da ličinke ovog stupnja napuštaju tuljac, odlaze u tlo gdje se kukulje (Urban, 2015). Broj oštećenih listova po trsu kretao se od 1 do 15, s najvećim vrijednostima zabilježenim sredinom svibnja. Najveći intenzitet šteta, s najviše vizualnim pregledom utvrđenih tuljaca po trsu, zabilježen je sredinom svibnja (od 15.5. do 22.5.). Ovi rezultati su u skladu s ranijim istraživanjem provedenim na području grada Ljubuški. Herceg (2016) navodi da je tijekom istraživanja provedenih 2016. godine, najveće štete od cigaraša zabilježio sredinom mjeseca svibnja. Provedenim istraživanjem utvrđeno je da ženke cigaraša za formiranje tuljaca i odlaganje jaja, preferiraju listove srednje veličine, izbjegavajući vrlo mlade i starije listove. Aktivnost odraslih jedinki uveliko ovisi o meteorološkim uvjetima u vinogradu. Za vrijeme vizualnih pregleda prosječno su po trsu zabilježene 1–2 odrasle jedinke , pri čemu je najveći broj jedinki opažen za toplih i suhih dana, kada su one aktivne u kopulaciji, formiranju tuljaca i odlaganju jaja. Urban (2015), navodi da su odrasle jedinke najaktivnije pri toplom, sunčanom vremenu bez vjetra, dok u hladnim, oblačnim ili vjetrovitim uvjetima miruju skriveni ispod trsa. Evidentirana imaga imala su duljinu tijela 5–7 mm, te karakterističnu sjajno tamnoplavu boju, dok su u populacijama promatranim u Sloveniji prevladavale odrasle jedinke metalnozelene boje (Trdan i Valič, 2004). Vizualnim pregledom čokota vinove loze uočeno je da su vinogradi smješteni u neposrednoj blizini šumskih ekosustava pokazivali izraženije simptome napada od cigaraša, uključujući veći intenzitet oštećenja listova i pupova, u usporedbi s vinogradima koji nisu graničili sa šumom. Dobiveni podatci ukazuju da blizina šumskih površina pogoduje opstanku i razmnožavanju populacije štetnika. Ovakvi rezultati su u skladu s istraživanjem Nazarenko i Petrenko (2008), koji ističu povezanost masovnije pojave cigaraša s biotipovima u kojima prevladavaju listopadne i mješovite šume. Uspoređujući intenzitet napada ovisno o sorti vinove loze, najveći broj tuljaca pronađen je na sortama Žilavka, Smederevka i Blatina. Povećana osjetljivost ovih sorata može se objasniti njihovim specifičnim morfološkim karakteristikama listova, koji su tanji i mekši u usporedbi s ostalim sortama, što ih čini pogodnijima za savijanje i formiranje tuljaka.

ZAKLJUČAK

Istraživanjem provedenim na području grada Ljubuški zabilježena je masovnija pojava cigaraša (*Byctiscus betulae*) u vinogradima podignutim u neposrednoj blizini većih šumskih sastojina. Najveći intenzitet šteta zabilježen je sredinom svibnja, što se podudara s povećanom aktivnošću odraslih jedinki. Prosječan broj formiranih tuljaca po trsu kretao se ovisno o lokalitetu od 2 do 10. Prosječna dužina tuljaca bila je 7–9 cm, a u njima se prosječno nalazilo 2–5 jaja. Istraživanjem je utvrđeno da ženke za odlaganje jaja preferiraju listove srednje veličine, a izbjegavaju potpuno mlade, kao i stare listove.

Veći intenzitet šteta zabilježen je na sortama Žilavka, Smederevka i Blatina, što se može povezati s morfološkim odlikama listova ovih sorti. Glavne štete od cigaraša nastaju od uništenja listova od kojih ženka pred odlaganje jaja pravi karakteristične tuljce u obliku „cigare". S obzirom na to da jedna ženka formira i do dvadesetak tuljaca, veća brojnost ovog štetnika dovodi do ozbiljnijeg gubitka lisne mase na trsovima. Takva oštećenja posebno dolaze do izražaja u mladim nasadima, gdje je ukupna lisna površina znatno manja. Na osnovu dobivenih rezultata, možemo zaključiti da je neophodno pratiti brojnost populacije cigaraša u mladim vinogradima, posebno u onima podignutim uz šumske ekosustave. Na osnovu utvrđene brojnosti populacije vrste, kao i same fenofaze razvoja i kondicije vinove loze, potrebno je procijeniti potrebu za provedbom mjera suzbijanja.

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MASS OCCURRENCE OF LEAF-ROLLING WEEVIL (*Byctiscus betulae* L.) IN VINEYARDS IN THE LJUBUŠKI AREA IN 2025

Abstract

The leaf-rolling weevil (*Byctiscus betulae* L.) is a beetle belonging to the family *Rhynchitidae*, widely distributed across Europe and parts of Asia. It typically inhabits environments rich in deciduous trees and shrubs, while in vineyards it occasionally occurs as a secondary pest. Adults emerge in early spring and feed on buds, later also on leaves, producing characteristic notch-like feeding damage. Once the buds open and grapevines develop foliage, adults begin gnawing on leaf petioles, which leads to leaf wilting. Females roll wilted leaves into cylindrical structures ("cigars"), inside which they deposit several eggs. A single female may roll approximately 20 such cigars. During May and June 2025, visual inspections of grapevine plants were carried out at the following sites: Grabovo Vrelo, Bijača, Lisice, Radišići, Veljaci, Ljubuški Center, and Ljubuški – Plantaža. Damage caused by the leaf-rolling weevil was recorded at Grabovo Vrelo, Bijača, Lisice, and Ljubuški Center. All sites where damage was observed were located in close proximity to larger forest stands. The highest intensity of damage was recorded at Grabovo Vrelo, where the average number of cigars per vine ranged from 4 to 10. Depending on the site, the average cigar length ranged from 7 to 9 cm, while the average number of eggs per cigar varied between 2 and 5.

Keywords: *leaf-rolling weevil, Byctiscus betulae L., grapevine, Ljubuški*

TRENUTNO STANJE ZLATNOŽUTE KRUMPIROVE CISTOLIKE NEMATODE (*Globodera rostochiensis* Woll., 1923) NA PODRUČJU HERCEGOVINE - PETNAEST GODINA NAKON PRVOG NALAZA

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Izvorni znanstveni rad – *Original scientific paper*

Sažetak

Prvi nalaz zlatnožute krumpirove cistolike nematode (*Globodera rostochiensis* Wollenweber, 1923) u Bosni i Hercegovini zabilježen je 2009. godine na lokalitetu Zaside – Tihaljina. U BiH se već duži niz godina provodi poseban nadzor s ciljem utvrđivanja prisustva i odsustva karantenskih štetnih organizama na krumpiru na mjestima uvoza i proizvodnje krumpira u BiH, distributivnim centrima i skladištima. Kroz dvogodišnje istraživanje utvrđivana je prisutnost i brojnost cista zlatnožute krumpirove cistolike nematode *G. rostochiensis* u uzorcima tla prikupljenima na području Hercegovačko-neretvanske i Zapadnohercegovačke županije. Tijekom 2022. i 2023. godine prikupljeno je 200 uzoraka tla sa 100 parcela na većem broju lokaliteta. Uzorci tla uzimani su sondom s 50 pojedinačnih mjesta po parceli s dubine do 5 cm. Osim uzoraka tla sa proizvodnih parcela, uzorkovanje je obavljeno i u dorađivačkom centru gdje su sa stroja za doradu sjemenskog krumpira uzeti ostaci tla. Tijekom vegetacije (vrijeme cvatnje) obavljeni su i vizualni pregledi u polju te uzeti uzorci „sumnjivih" biljaka na pregled korijenja. Ispiranje prikupljenih uzoraka tla kao i uzoraka iz dorađivačkog centra, obavljeno je u laboratoriju za zaštitu bilja na Agronomskom i prehrambeno-tehnološkom fakultetu Sveučilišta u Mostaru na Spearsovim flotacionom uređaju. Isto tako, u laboratoriju Agronomskog i prehrambeno-tehnološkog fakulteta obavljeno je ispiranje korijenja „sumnjivih" biljaka iz polja, te obavljen pregled pod stereo lupom. Analizom prikupljenih uzoraka tla, te vizualnim pregledom korijena krumpira nije utvrđena prisutnost cista vrste *G. rostochiensis* na istraživanom području.

Ključne riječi: *krumpir, Globodera rostochiensis, uzorkovanje tla, Hercegovina*

UVOD

Kao najznačajniji zemljišni štetnici krumpira širom svijeta posebno se izdvajaju zlatnožuta krumpirova cistolika nematoda *Globodera rostochiensis* (Wollenweber, 1923) i blijedožuta krumpirova cistolika nematoda *Globodera pallida* (Stone, 1973) (Turner i Evans, 1998).

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Ove nematode mogu uzrokovati velike gubitke u prinosu krumpira. Imaju sposobnost održavanja u latentnom obliku dugi niz godina, bez prisutnosti biljaka domaćina, te su stoga u mnogim zemljama predmet strogih karantenskih propisa. Zlatnožuta krumpirova cistolika nematoda, *G. rostochiensis* potječe iz područja Anda u Južnoj Americi, odakle je u 19. stoljeću unesena u Europu zaraženim gomoljima. Zlatna krumpirova nematoda *G. rostochiensis* potječe s područja Anda, južni Peru, odakle se antropogenim djelovanjem proširila širom svijeta (Grenier i sur., 2010). Gomoljima na kojima su se nalazile čestice tla inficiranog nematodama, vrsta je unijeta u Europu u 17. stoljeću. Danas je raširena širom Europe, Južne Amerike, dijelovima Azije, prisutna je i u Sjevernoj Americi, Australiji, te dijelovima Afrike gdje se krumpir uzgaja (EPPO, 2023). Vrsta se razmnožava samo na korijenju biljaka, a glavni domaćin je krumpir (*Solanum tuberosum* L.). Ostali potencijalni domaćini su rajčica, paprika, patlidžan, te korovi iz porodice pomoćnica (*Solanaceae*), a to su bijeli kužnjak (*Datura stramonium* L.) i crna pomoćnica (*Solanum nigrum* L.) (Ivezić i sur., 2005). Ovisno o klimatskim uvjetima, *G. rostochiensis* razvije jednu ili dvije generacije tijekom godine (Greco i sur., 1988). Prvi nalaz vrste *G. rostochiensis* u Bosni i Hercegovini zabilježen je 2009. godine u lokalitetu Zaside – Tihaljina (Ostojić i sur. 2011). Monitoringom provedenim 2010. godine, vrsta je utvrđena i na području općine Čapljina, na lokalitetu Opličići. Budući da se radi o karantenskoj vrsti nematode, u Bosni i Hercegovini se već duži niz godina provodi poseban nadzor s ciljem utvrđivanja prisustva, odnosno odsustva karantenskih štetnih organizama na krumpiru na mjestima ulaska pošiljki krumpira koje se uvoze u BiH, te na mjestima proizvodnje sjemenskog i merkantilnog krumpira, distributivnim centrima i mjestima skladištenja.

PREGLED LITERATURE

Krumpir napada velik broj uzročnika biljnih bolesti i štetnika koji u pojedinim godinama znaju pričiniti velike štete. Kao najznačajni štetnici krumpira u svijetu navode se zlatnožuta krumpirova cistolika nematoda, *Globodera rostochiensis* (Woll.) i blijedožuta krumpirova cistolika nematoda *Globodera pallida* (Stone) (Šubić i Bićak, 2001; Sedlak i sur., 2004). Zlatnožuta krumpirova cistolika nematoda, *G. rostochiensis* potječe iz područja Anda u Južnoj Americi, odakle je u 19. stoljeću unesena u Europu zaraženim gomoljima. Prvi nalaz *G. rostochiensis* u Bosni i Hercegovini zabilježen je 2009. godine na lokalitetu Zaside – Tihaljina, gdje su pronađene dvije vitalne ciste u jednom od 17 uzoraka (Ostojić i sur., 2011). Tijekom 2010. godine na području Hercegovine obavljena su detaljnija istraživanja prisutnosti krumpirovih cistolikih nematoda kod proizvođača konzumnog krumpira. Istraživanja su provedena na području Zapadnohercegovačke (Ljubuški, Grude, Široki Brijeg) i Hercegovačko-neretvanske županije (Stolac, Čapljina, Mostar), a uključila su najvažnije lokalitete na kojima se krumpir godinama uzgaja u monokulturi. U jednom uzorku tla uzetom iz Čapljine, Opličići – Turajlovina otkriveno je pet vitalnih cista *G. rostochiensis* (Ostojić i sur., 2011). Na temelju rezultata istraživanja zaključeno je da *G. rostochiensis* nije široko rasprostranjena, ali da se ciste mogu otkriti, što ukazuje da je zaraza relativno

nova i da postoji opasnost od daljnjeg širenja ove karantenske vrste. Najznačajniji domaćin *G. rostochiensis* je krumpir *Solanum tuberosum* L., no međutim i rajčica, patlidžan i neki korovi mogu biti pogodni domaćini. Brojne druge vrste iz roda *Solanum*, njih oko 90 i njihovi hibridi, također mogu biti domaćini ovoj nematodi. Uzgojem potpuno otpornih sorti kroz 3 do 4 godine zaraza tla bi se mogla smanjiti za 99 % (Grubišić, 2006). U Bosni i Hercegovini uzgaja se nekoliko sorti krumpira koje su tolerantne na napad nematoda, a neke od njih su: Adora, Agria, Arnova, Carrera, Liseta i Marabel (Kolarić, 2020). Zlatnožuta krumpirova cistolika nematoda, *G. rostochiensis* snižava prinos uzgajane kulture. Ovisno o visini populacije nematoda, na pojedinim parcelama štete mogu biti neznatne do potpune. Čimbenici o kojima ovisi intenzitet zaraze, preživljavanje i reprodukcija ove vrste nematode su agroekološki uvjeti poput temperature, izloženosti svjetlosti, vlažnosti tla i drugi. Nematode se hrane citoplazmom biljne stanice, potpuno prodiru u korijen biljke, te se zbog toga nazivaju endoparazitima. Prepoznatljiv simptom napada na biljci su zastoj u rastu, venuće i sušenje, a u konačnici i manji urod. Prvi simptomi napada teško se mogu uočiti. Na nadzemnom dijelu biljaka simptomi se najprije uočavaju lokalizirano u kružnim i ovalnim „oazama" u nasadu gdje se pojavljuju plješine koje se s vremenom šire. Na biljkama su vidljivi simptomi žućenja i uvijanja listova. Korijenski sustav postaje slabije razvijen i biljke razvijaju veću količinu bočnog korijenja što dovodi do ukupnog smanjenog rasta biljke i preranog uvenuća. Biljke s oštećenim korijenjem uvenu, osobito pri višim temperaturama tijekom dana, a mogu ostati uvenule čak i uz navodnjavanje. Prilikom pregleda korijena biljke potrebno je obratiti pažnju na prisustvo cista, njihovu brojnost, boju i veličinu. Biljke mogu preživjeti, ali je umanjena njihova rodnost. Prinosi krumpira u svijetu posljednjih godina su naglo pali na oko 9-10 tona/ha (Kiptoo i sur., 2016), što je znatno ispod potencijala prinosa ove kulture. Takvi gubici prinosa vjerojatno se mogu barem djelomično pripisati krumpirovim nematodama roda *Globodera*. Samo laboratorijskom analizom biljnog materijala (korijena) ili uzoraka tla može se sa sigurnošću potvrditi prisutnost nematoda. Krumpirove cistolike nematode prenose se zaraženim sadnim materijalom ili presadnicama, zaraženim supstratom, vjetrom, vodom, životinjama, ali najzaslužniji za prenošenje nematoda je čovjek jer se njegovom aktivnošću zaraženo tlo može prenositi na kotačima vozila, na mehanizaciji, oruđu, opremi, obući, te zaraženim biljnim materijalom i presadnicama povrća. Tamo gdje se ne poduzimaju mjere zaštite zabilježene su totalne štete. U suzbijanju krumpirovih cistolikih nematoda najvažnije su preventivne mjere i pravovremeno otkrivanje zaraze. Preventivne mjere podrazumijevaju sadnju krumpira u poljima koja nisu zaražena nematodama i upotrebu certificiranog sjemena. U slučaju da se štetnik pojavi potrebno je preduzeti odgovarajuće mjere jer je njegovo suzbijanje dosta zahtjevno. Uspjeh u smanjenju razine populacije štetnika je promjenjiv i ovisi o početnoj gustoći populacije, vrsti tla i genotipu biljke. Potpuno otporne sorte krumpira „ne dopuštaju" umnožavanje nematoda na korijenju, stolonima i gomoljima. Dobri rezultati se postižu kombinacijom različitih metoda suzbijanja koje nisu u potpunosti učinkovite kada se koriste pojedinačno. Stoga se u većem broju zemalja primjenjuje program integriranog upravljanja štetnicima (IPM) zbog suzbijanja i sprječavanja širenja štetnih organizama.

Integrirana zaštita uključuje agrotehničke mjere, biološke mjere (pripravci na osnovi bakterija i entomopatogenih nematoda), fizikalne mjere (sterilizacija i solarizacija), te u konačnici i kemijsko suzbijanje dopuštenim sredstvima. Kao najbolja kombinacija u integriranoj zaštiti je korištenje najmanje trogodišnjeg plodoreda i fumigacije tla (Grubišić, 2006).

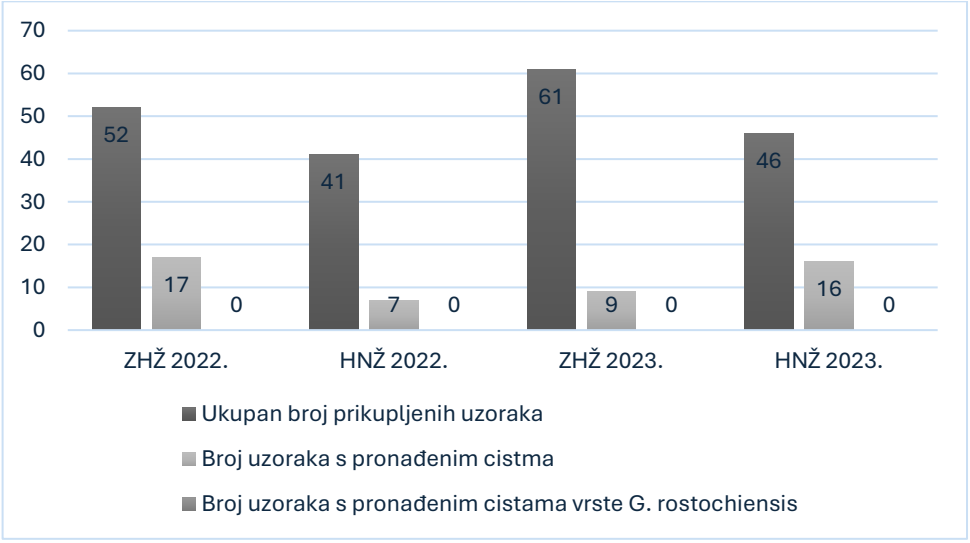
MATERIJAL I METODE

Istraživanje prisutnosti cista zlatnožute krumpirove cistolike nematode *Globodera rostochiensis* provedeno je tijekom vegetacijske sezone 2022. i 2023. godine. Istraživanje je provedeno na području Zapadnohercegovačke i Hercegovačko-neretvanske županije. Uzorci tla s proizvodnih parcela uzimani su prije sadnje, tijekom vegetacije i nakon vađenja krumpira. Osim s proizvodnih parcela, uzorci tla uzimani su i iz doradivačkih centara (pakirnice sjemenskog krumpira). Tijekom dvije godine s područja Zapadnohercegovačke županije ukupno je prikupljeno 113 uzoraka tla. Uzorci su prikupljeni sa sljedećih lokaliteta: Vojnići, Šipovača, Lisice, Vašarovići, Radišići, Klobuk, Bijača, ul. Zvonimira Remete (općina Ljubuški), Turčinovići, Ružići (općina Široki Brijeg), Drinovci, Sovići (općina Grude). Na području Hercegovačko-neretvanske županije ukupno je prikupljeno 87 uzoraka tla. Uzorci su prikupljeni s lokaliteta: Trijebanj, Poplat (općina Stolac), Hotanj, Stanojevići, Bivolje brdo, Gabela (općina Čapljina), Gubavica (općina Mostar). Uzorci tla su uzimani nematološkom sondom cjevastog oblika, promjera 2 cm. Uzorci su prikupljeni ravnomjerno s 50 pojedinačnih mjesta po parceli s dubine do 5 cm. Miješanjem uzoraka dobiven je jedan homogeni uzorak iz koje je izdvojeno oko 1 kilogram zajedničkog uzorka. Uzorak je spremljen u vrećicu koja je obilježena podatcima o datumu, mjestu uzorkovanja i koordinatama lokaliteta. Uzorci tla su dopremljeni u Laboratorij za zaštitu bilja na Agronomskom i prehrambeno-tehnološkom fakultetu Sveučilišta u Mostaru, te su ostavljeni na sušenju u laboratorijskim uvjetima. Nakon sušenja uzoroka izvršeno je usitnjavanje i miješanje tla. Uzorci tla su izmiješani, a za postupak izdvajanja uzeto je 100 ml tla po uzorku. Postupak izdvajanja cista iz uzoraka tla proveden je Spearsovim flotaciskim uređajem čiji se rad temelji na principu flotacije (Grubišić, 2006). Pregled uzoraka rađen je pomoću binokularne lupe Leica EZ4D, a izdvojene ciste su spremljene u epruvete. Izrada mikroskopskih preparata rađena je prema Van Bezooijen (2006), a identifikacija vrsta prema Brzecki (1988). Potvrda determinacije obavljena je na Poljoprivrednom fakultetu, Univerziteta u Banja Luci. Tijekom vegetacije obavljen je vizualni pregled nasada krumpira za vrijeme cvatnje na prisutnost simptoma koji upućuju na zarazu nematodama (zastoji u rastu biljaka, žućenje biljaka, pojava plješina). Otkrivanje cista na biljkama moguće je samo kratko vrijeme kada ženke sazriju u ciste. Kad one potpuno sazriju, ciste lako mogu otpasti s korijena prilikom čupanja biljke. Kasnim pregledavanjem ciste mogu lako otpasti prilikom čupanja biljaka iz tla, a preranim pregledavanjem ne može se ništa uočiti na korijenju, što rezultira negativnim rezultatom (Nijs i sur., 2018). Biljke koje su pokazivale navedene simptome vađene su iz tla, stavljene u posebne vrećice, te dopremljene u laboratorij na Agronomskom i

prehrambeno-tehnološkom fakultetu, gdje je obavljeno ispiranje korijenja i pregled pod binokularom.

REZULTATI I DISKUSIJA

Tijekom 2022. i 2023. godine prikupljeno je 200 uzoraka tla s 100 parcela na području šest različitih općina u Zapadnohercegovačkoj (ZHŽ) i Hercegovačko-neretvanskoj županiji (HNŽ). Determinacija pronađenih cista obavljena je na osnovu morfoloških karakteristika vrste *G. rostochiensis*, a potvrda identifikacije urađena je u laboratoriju za nematologiju na Poljoprivrednom fakultetu Univerziteta u Banjoj Luci. Tijekom obje istraživačke godine uzorci su uzimani tijekom veljače, prije sadnje krumpira i tijekom svibnja i lipnja nakon vađenja krumpira. Tako je u 2022. godini s područja ZHŽ ukupno uzeto 52 uzorka tla za analizu na prisutnost cista *G. rostochiensis* Laboratorijskom analizom uzoraka nije utvrđena prisutnost cista ove vrste, ali je u uzorcima prikupljenim s lokaliteta Vojnići (Pršura, Župnice, Prigrada i Ajdarovina), Šipovača, Klobuk, Vašarovići, Lisice i Radišići, utvrđena prisutnost cisti iz roda *Heterodera*. Tijekom 2022. godine s područja HNŽ ukupno je uzet 41 uzorak tla za analizu na prisutnost cista *G. Rostochiensis*. Laboratorijskom analizom uzoraka također nije utvrđena prisutnost cista *G. rostochiensis,* ali je u uzorcima prikupljenim s lokaliteta Trijebanj, Hotanj, Poplat i Stanojevići utvrđena prisutnost cista iz roda *Heterodera* i *Punctodera*. Tijekom 2023. godine s područja ZHŽ ukupno je uzet 61 uzorak tla za analizu na prisutnost cista *G. rostochiensis*. Nakon urađene laboratorijske analize nije utvrđena prisutnost cista *G. rostochiensis*. U uzorcima prikupljenim s lokaliteta Vojnići (Pršura, Župnice, Prigrada i Šamatorje), Šipovača, Klobuk i Lisice utvrđena prisutnost cista iz roda *Heterodera*. Tijekom 2023. godine s područja HNŽ ukupno je uzeto 46 uzorka tla za analizu na prisutnost cista *G. rostochiensis*. Laboratorijskom analizom uzoraka nije utvrđena prisutnost cista *G. rostochiensis,* ali je u uzorcima prikupljenim s lokaliteta Trijebanj, Hotanj, Poplat i Stanojevići utvrđena prisutnost cista iz roda *Heterodera* i *Punctodera*. Rezultati o broju uzetih uzoraka u 2022. i 2023. godini sa područja Zapadnohercegovačke i Hercegovačko-neretvanske županije prikazani su u grafikonu br. 1., a detaljni podaci o lokalitetima i koordinatama u prilogu 1, 2, 3 i 4.



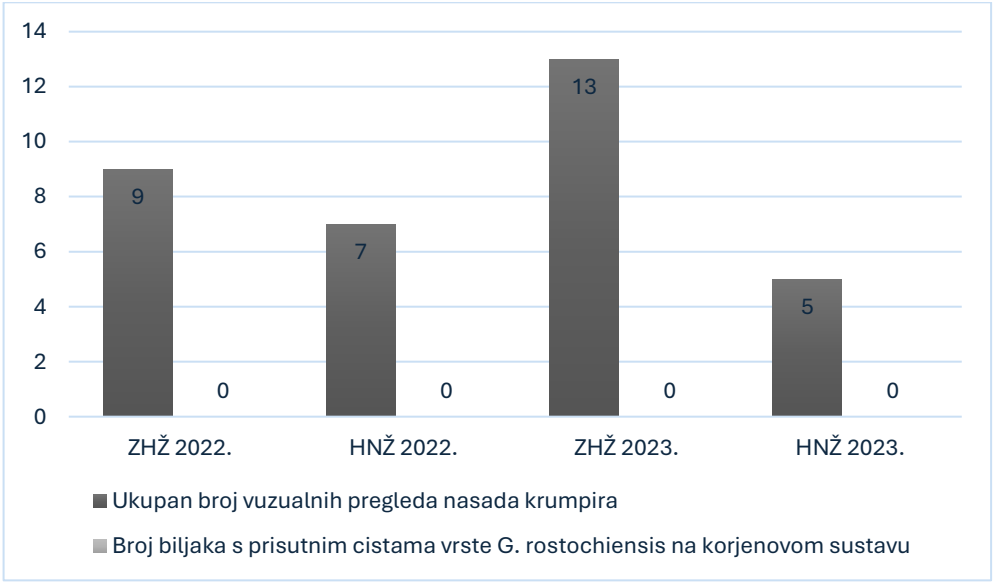
Grafikon 1. Ukupan broj prikupljenih uzoraka tla za analizu
Chart 1. Total number of soil samples collected for analysis

Tijekom 2022. i 2023. godine u doređivačkom centru Sjemenarna d.o.o prikupljeno je ukupno 25 uzoraka. Uzorci su prikupljeni od početka do kraja veljače. U tablici br.1 prikazani su podaci o datumu uzorkovanja i rezultatima analize.

Tablica 1. Rezultati analize uzoraka tla prikupljenih u doređivačkom centru Sjemenarne d.o.o. u 2022. i 2023. godini na prisutnost cista *G. rostochiensis.*
Table 1. Results of soil sample analyses collected at the Sjemenarna d.o.o. processing center in 2022 and 2023 for the presence of G. rostochiensis cysts

Redni broj uzorka	Datum uzorkovanja	Datum uzorkovanja	Broj pronađenih cista	Broj pronađenih cista vrste *G. rostochiensis*
1.	09.02.2022.	01.02.2023.	0	0
2.	10.02.2022.	02.02.2023.	0	0
3.	11.02.2022.	03.02.2023.	0	0
4.	16.02.2022.	06.02.2023.	0	0
5.	17.02.2022.	07.02.2023.	0	0
6.	18.02.2022.	08.02.2023.	0	0
7.	19.02.2022.	09.02.2023.	0	0
8.	22.02.2022.	10.02.2023.	0	0
9.	23.02.2022.	13.02.2023.	0	0
10.	24.02.2022.	14.02.2023.	0	0
11.		15.02.2023.	0	0
12.		16.02.2023.	0	0
13.		20.02.2023.	0	0
14.		20.02.2023.	0	0
15.		23.02.2023.	0	0

Analizom uzoraka tla (otpad i prašina sa gomolja krumpira) nisu pronađene ciste nematode *G. rostochiensis.* Tijekom vegetacije u 2022. i 2023. godini obavljen je vizualni pregled nasada krumpira na prisutnost simptoma koji upućuju na zarazu nematodama (zastoji u rastu biljaka, žućenje biljaka, pojava plješina). Pregled je obavljen u vrijeme cvatnje krumpira. Pregledane su 34 parcele na području šest različitih općina u Zapadnohercegovačkoj i Hercegovačko-neretvanskoj županiji. Biljke koje su ispoljavale simptome zaraze nematodama, kompletno su čupane iz tla, te donošene u laboratorij. Korijenje tih biljaka isprano je pod mlazom vode i detaljno pregledano uz pomoć stereolupe. Rezultati vizualnih pregleda korijenja krumpira obavljenih tijekom vegetacije u 2022 i 2023. godine sa područja Zapadnohercegovačke i Hercegovačko-neretvanske županije, na prisutnost cisti, prikazani su u grafikonu br. 2, te detaljnije u tablicama br. 2, 3, 4 i 5.



Grafikon 2. Rezultati vizualnih pregleda korijena krumpira tijekom vegetacije
Chart 2. Results of visual inspections of potato roots during the vegetation period

Tablica 2. Rezultati vizualnog pregleda korijena krumpira na prisutnost cista *G. rostochiensis* s područja Zapadnohercegovačke županije u 2022. godini.
Table 2. Results of visual inspection of potato roots for the presence of the G. rostochiensis from the West Herzegovina Canton in 2022.

Redni broj uzoraka	Datum vizualnog pregleda	Mjesto	Lokalitet	Koordinate	Sorta krumpira	Broj pronađenih cista	Broj pronađenih cista vrste *G.rostochiensis*
1.	30.05.2022.	Ljubuški	ul.Zvonimira Remeta	43°11.6520'S 17°33.4080'I	Carrera	0	0
2.	30.05.2022.			43°11.5380'S 17°33.4010'I	Liseta	0	0
3.	30.05.2022.			43°11.6290'S 17°33.4390'I	Liseta	0	0
4.	30.05.2022.		Lisice	43°11.6710'S 17°29.7180'I	Carrera	0	0
5.	30.05.2022.		Vojnići, Župnice	43°15.5730'S 17°24.9880'I	Carrera	0	0
6.	30.05.2022.		Vojnići, Donji gaj	43°15.5240'S 17°25.0640'I	Carrera	0	0
7.	30.05.2022.		Vojnići, Ajdarovina	43°15.5560'S 17°25.0830'I	Carrera	0	0
8.	31.05.2022.	Široki Brijeg	Kočerin	43°23.2450'S 17°29.2451'I	Monalisa	0	0
9.	01.06.2022.	Ljubuški	Šipovača	43°15.3510'S 17°23.5590'I	Esma	0	0

Tablica 3. Rezultati vizualnog pregleda korijena krumpira na prisutnost cista *G. rostochiensis* prikupljenih s područja Hercegovačko- neretvanske županije u 2022. godini.
Table 3. Results of visual inspection of potato roots for the presence of the G. rostochiensis cysts collected in the Herzegovina-Neretva Canton in 2022.

Redni broj uzorka	Datum vizualnog pregleda	Mjesto	Lokalitet	Koordinate	Sorta krumpira	Broj pronađenih cista	Broj pronađenih cista vrste *G.rostochiensis*
1.	25.05.2022.	Stolac	Trijebanj	43°90.8800'S 17°52.1330'I	Monalisa	0	0
2.	25.05.2022.			43°90.9000'S 17°52.1400'I	Monalisa	0	0
3.	25.05.2022.			43°09.9670'S 17°51.9510'I	Monalisa	0	0
4.	25.05.2022.	Čapljina	Hotanj	43°06.5750'S 17°45.3610'I	Liseta	0	0
5.	25.05.2022.			43°06.6420'S 17°45.2250'I	Liseta	0	0
6.	25.05.2022.			43°06.7000'S 17°45.2250'I	Liseta	0	0
7.	25.05.2022.			43°07.0230'S 17°44.7590'I	Monalisa	0	0

Tablica 4. Rezultati vizualnog pregleda korijena krumpira na prisutnost cista *G. rostochiensis* s područja Zapadnohercegovačke županije u 2023. godini.
Table 4. Results of visual inspection of potato roots for the presence of the G. rostochiensis cysts from the West Herzegovina Canton in 2023.

Redni broj uzoraka	Datum vizualnog pregleda	Mjesto	Lokalitet	Koordinate	Sorta krumpira	Broj pronađenih cista	Broj pronađenih cista vrste *G.rostochiensis*
1.	01.05.2023.	Ljubuški	ul. Zvonimira Remeta	43°11.6520'S 17°33.4080'I	Carrera	0	0
2.	01.05.2023.		Vojnići, Pršura	43°15.5720'S 17°24.9510'I	Carrera	0	0
3.	01.05.2023.		Vojnići, brdo 2	43°15.7430'S 17°25.2580'I	Anais i Carrera	0	0
4.	01.05.2023		Vojnići, Gračina	43°15.5860'S 17°24.4470'I	Carrera	0	0
5.	01.05.2023.		Vojnići, Šamatorje 1	43°15.5070'S 17°24.3390'I	Carrera	0	0
6.	01.05.2023.		Klobuk	43°16.4890'S 17°27.1000'I	Liseta	0	0
7.	01.05.2023.		Bijača	43°80.5000'S 17°34.2000'I	Liseta	0	0
8.	05.05.2023.	Grude	Drinovci	43°21.3600'S 17°21.0000'I	Monalisa	0	0
9.	10.05.2023.	Ljubuški	Lisice	43°11.6710'S 17°29.7180'I	Liseta	0	0
10.	10.05.2023.		Lisice	43°11.6720'S 17°29.7180'I	Monalisa	0	0
11.	10.05.2023.		Vašarovići	43°12.3600'S 17°28.1210'I	Anais	0	0
12.	15.05.2023.		Radišići	43°12.7940'S 17°31.3660'I	Liseta	0	0
13.	15.05.2023.		ul. Zvonimira Remeta	43°11.5690'S 17°33.2930'I	Monalisa	0	0

Tablica 5. Rezultati vizualnog pregleda korijena krumpira na prisutnost cista *G. rostochiensis* prikupljenih s područja Hercegovačko-neretvanske županije u 2023. godini.
Table 5. Results of visual inspection of potato roots for the presence of the G. rostochiensis cysts collected in the Herzegovina-Neretva Canton in 2023.

Redni broj uzorka	Datum vizualnog pregleda	Mjesto	Lokalitet	Koordinate	Sorta krumpira	Broj pronađenih cista	Broj pronađenih cista vrste *G.rostochiensis*
1.	06.05.2023.	Stolac	Trijebanj	43°90.8800'S 17°52.1330'I	Monalisa	0	0
2.	06.05.2023.			43°90.9000'S 17°52.1400'I	Monalisa	0	0
3.	06.05.2023.	Čapljina	Hotanj	43°06.5750'S 17°45.3610'I	Liseta	0	0
4.	07.05.2023.	Mostar	Gubavica	43°12.4290'S 17°49.7550'I	Monalisa	0	0
5.	08.05.2023.	Čapljina	Stanojevići	43°10.7620'S 17°50.0070'I	Carrera	0	0

Zlatnožuta krumpirova cistolika nematoda (*G. rostochiensis)* jedna je od najvažnijih parazitskih nematoda širom svijeta i nalazi se na karantenskim listama velikog broja zemalja (Bélair i sur., 2016). Štete uzrokovane krumpirovim cistolikim nematodama, mogu biti izuzetno velike, veće od 70% (CABI, 2015). Ovisno o populaciji nematoda, štete variraju od malih gubitaka do potpunih propadanja nasada (Lima i sur., 2018). U Europi se godišnji gubitci u prinosu uzrokovani krumpirovim nematodama, procjenjuju na 220 milijuna eura (Viaene, 2016). U Bosni i Hercegovini se već duži niz godina provodi poseban nadzor s ciljem utvrđivanja prisustva, odnosno odsustva karantenskih štetnih organizama na krumpiru, među kojima je i zlatnožuta krumpirova cistolika nematoda. Detaljnija istraživanja prisutnosti zlatnožute krumpirove cistolike nematode su provedena tijekom 2022. i 2023. godine na području Zapadnohercegovačke i Hercegovačko-neretvanske županije na proizvodnim parcelama, i u dorađivačkom centru. Rezultati istraživanja ukazuju da vrsta *G. rostochiensis* nije prisutna na istraživanom području ili je njena populacija veoma niska i jako ograničena, što uveliko otežava pozitivan nalaz. Rezultate ovih istraživanja potvrđuju i istraživanja koja su obavljena na području BiH gdje je potvrđena prisutnost obje vrste krumpirovih nematoda na tri parcele što ukazuje na veoma ograničenu rasprostranjenost (Nježić i sur., 2025). Isto tako, rezultate ovih istraživanja možemo usporediti s rezultatima istraživanja provedenim u Sloveniji. Na području Slovenije, *G. rostochiensis* prvi put je zabilježena 1971. godine kada je samo jedna cista izolirana iz tla. Na istom području vrsta je ponovo utvrđena 1975. godine. Međutim, unatoč provedenim opsežnim istraživanjima, vrsta je ponovo pronađena tek 1999. godine (Urek i Lapajne, 2011). U Republici Hrvatskoj vrsta je prvi put zabilježena 2001. godine na području Međimurske županije, točnije na lokalitetu Belica. Naknadno provedenim istraživanjima utvrđena je velika brojnost populacije ove nematode na navedenom području. Istraživanje provedenim na području Međimurja 2002. godine u uzorcima tla s površine gdje je krumpir bio u monokulturi, utvrđeno je 458 cista/100 ccm tla, a s površine pod pšenicom, gdje je krumpir bio predkultura, utvrđeno je 368 cista/100 ccm tla (Ivezić i sur., 2005). U uzorcima tla koji su prikupljeni 2003. godine na lokalitetu Belica, prosječan broj cista iznosio je 434 ciste/100 ml tla što upućuje na zarazu jakog intenziteta, a vitalnost je iznosila prosječno 93,41 jaja i ličinki/g tla čime je prekoračen ekonomski prag štetnosti od 20 jaja i ličinki/g tla (Pinturić, 2016). Istraživanjem provedenim na području Belice 2019. godine, prosječan broj cista bio je 169 cista/100 ml tla. Ciste su bile vitalne, a broj jaja i ličinki/g tla prosječno je iznosio 14,80 jaja i ličinki/g tla (Herak, 2019). U Bugarskoj, vrsta je prvi put utvrđena 1978. godine (Stoyanov, 1980). Veoma brzo se proširila dijelovima zemlje gdje se krumpir uzgaja, te predstavlja jednog od najvažnijih štetnika krumpira (Samaliev, 2011; Trayanov i sur., 2020). Širenje ovog štetnika primarno se odvija putem gomolja na kojima su ostale čestice tla u kojima se nalaze ciste štetnika (Nijs i sur., 2018). Zbog dugog održavanja u zaraženom tlu, preživljavanja jaja unutar cista, velikih ekonomskih šteta koje može uzrokovati i teških mjera kontrole, navedeni štetnik se nalazi u karantenskim propisima u više od 100 zemalja (Niere i Karuri, 2018). Porast populacije i širenje štetnika u tlu pridonosi najvećim dijelom uzgoj krumpira u monokulturi.

Budući da se u zaraženom tlu održavaju i do 20 godina bez prisutnosti biljke domaćina, izuzetne otpornosti na visoke temperature, izuzetno je teško trajno iskorijeniti krumpirove nematode iz zaraženog tla (Chandel i sur., 2020). U zadnjih 30 godina, širom svijeta provode se različita istraživanja učinkovitosti različitih mjera suzbijanja kao što je fumigacija tla, primjena nematocida, rotacija s kulturama koje nisu domaćini i uzgoj otpornih sorti (Bélair i sur., 2016). Budući da je danas malo nematocida dostupno na tržištu čija je primjena dosta skupa, a uz to imaju i negativan učinak na okoliš (Douda i sur., 2021), biološko suzbijanje nematoda danas je u fokusu brojnih istraživača (Ngala i sur., 2015; Ochola i sur., 2022; Pulavarty i sur., 2022). Kako bi se spriječio porast populacije, potrebno je provoditi integriranu zaštitu krumpira koja podrazumijeva primjenu šireg plodoreda, sadnju otpornih kultivara krumpira, prema potrebi primjenu nematocida, te redovito provođenje monitoringa. Obavezno je provođenje redovite kontrole brojnosti i vitalnosti cista u tlu. Ranim otkrivanjem i provođenjem mjera suzbijanja može se spriječiti širenje štetnika na širem području.

ZAKLJUČAK

Tijekom 2022. i 2023. godine proveden je monitoring prisutnosti zlatnožute krumpirove nematode (*G. rostochiensis)* kod proizvođača merkantilnog krumpira na području Zapadnohercegovačke i Hercegovačko- neretvanske županije. Ukupno je prikupljeno 200 uzoraka tla s 100 parcela na području šest različitih općina. Laboratorijskom analizom uzoraka tla prikupljenih prije sadnje i nakon vađenja krumpira na području Zapadnohercegovačke županije u 2022. i 2023. godini nije utvrđena prisutnost cisti *G. rostochiensis*. Laboratorijskom analizom uzoraka tla (otpad prilokom dorade krumpira) prikupljenih iz dorađivačkog centra Sjemenarna d.o.o. Široki Brijeg tijekom veljače 2022. i 2023. godine nije utvrđena prisutnost cisti *G. rostochiensis*. Isto tako, analizom korijenja krumpira tijekom vegetacije nisu pronađene ciste ove vrste.Ova istraživanja potvrđuju izostanak prisutnost ove nematode na istraživanom području ili je njena populacije vrlo mala. Također, potrebno je neophodno provoditi kontrolu sjemenskog krumpira ili drugih biljaka domaćina kod uvoza, posebno ukoliko krumpir dolazi iz zemalja gdje je nematoda prisutna. Osim toga, potrebno je nastaviti ova istraživanja i obuhvatiti i druga područja gdje se uzgaja krumpir kako bi se na vrijeme otkrila prisutnost ove, ali i drugih vrsta nematoda, te blagovremeno poduzele adekvatne mjere zaštite.

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CURRENT STATUS OF THE GOLDEN POTATO CYST NEMATODE (*Globodera rostochiensis* Woll., 1923) IN THE HERZEGOVINA REGION – FIFTEEN YEARS AFTER THE FIRST DETECTION

Abstract

The first detection of the golden potato cyst nematode (*Globodera rostochiensis* Wollenweber, 1923) in Bosnia and Herzegovina was recorded in 2009 at the locality Zaside – Tihaljina. In Bosnia and Herzegovina, a special monitoring programme has been implemented for many years with the aim of determining the presence or absence of quarantine harmful organisms on potatoes at points of import and potato production sites, as well as in distribution centres and storage facilities. Within a two-year study, the presence and abundance of cysts of the golden potato cyst nematode, *G. rostochiensis* were assessed in soil samples collected in the areas of the Herzegovina-Neretva and West Herzegovina Cantons. During 2022 and 2023, a total of 200 soil samples were collected from 100 fields across numerous localities. Soil samples were taken using a probe, with 50 individual sampling points per field at a depth of up to 5 cm. In addition to soil samples from production fields, sampling was also carried out in a processing centre, where soil residues were collected from a seed potato processing machine. During the vegetation period (flowering stage), visual field inspections were performed, and samples of "suspect" plants were collected for root examination. Washing of the collected soil samples, as well as samples from the processing centre, was performed in the Plant Protection Laboratory of the Faculty of Agriculture and Food Technology, University of Mostar, using a Spears flotation apparatus. Likewise, in the same laboratory, the roots of "suspect" plants from the field were washed and examined under a stereo microscope. Analysis of the collected soil samples, together with the visual inspection of potato roots, confirmed no presence of *G. rostochiensis* cysts in the investigated area.

Keywords: *potato, Globodera rostochiensis, soil sampling, Herzegovina*

SEEDLING RESISTANCE OF SOME WHEAT LINES AND CULTIVARS TO ROOT AND CROWN ROT CAUSED BY *Fusarium pseudograminearum* O'Donnell & T. Aoki

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Original scientific paper

Abstract

Wheat (*Triticum* spp.), one of the most important crops in human nutrition, is cultivated in large areas around the world. *Fusarium pseudograminearum* O'Donnell & T. Aoki is one of the most destructive pathogens of wheat causing root and crown rot. For soilborne plant pathogens, it is difficult to find resistant genotypes. Finding resistant germplasm is an important goal in plant breeding studies. In this study, 104 bread and durum wheat genotypes were tested for resistance to root and crown rot under greenhouse conditions using a virulent *F. pseudograminearum* isolate. No resistant cultivars or lines were observed among the tested durum wheat cultivars and durum wheat lines. Three of the genotypes used in the bread wheat yield trial exhibited resistant reactions, while 15 exhibited moderately resistant reactions. Three bread wheat advanced lines were classified as moderately resistant. No resistant cultivars were found among the tested bread wheat cultivars, with Ahsen, Dinçer, Altınbaşak, Yakamoz, and Karatopak exhibiting moderately resistant reactions.

Keywords*:* *Fusarium pseudograminearum, wheat, disease resistance*

INTRODUCTION

Wheat (*Triticum* spp.), one of the most important crops in human nutrition, is cultivated in large areas around the world. An important carbohydrate source, wheat is used in bread, pasta, and bulgur, while its stems and straw are used in animal nutrition. Post-harvest residues enrich the soil's organic matter content (Bockus *et al*., 2010; Geçit, 2016). There are important diseases that affect wheat yield and quality. Of these, *Fusarium* species cause significant yield losses, with *Fusarium pseudograminearum* O'Donnell & T. Aoki standing out as one of the most destructive species (Bockus *et al*., 2010, Kazan and Gardiner, 2018).

Fusarium species and other fungal diseases with a necrotrophic phase of their infection cycle causes billions of dollars of losses in cereal crops every year (Savary *et al*., 2012).

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In many arid and semi-arid cropping regions of the world, such as Australia, the Pacific Northwest of the United States, Canada, New Zealand, South Africa, the Middle East, North Africa, and South America, Fusarium crown rot caused by the fungal pathogen *F. pseudograminearum* is an important disease agent lowering both quality and quantity (Kazan and Gardiner, 2018). There is a wide variety of responses to *Fusarium* crown rot in bread wheat, but among cool-season cereals, bread wheat and especially durum wheat are vulnerable to *F. pseudograminearum* (Liu and Ogbonnaya, 2015, Yazıcı Kuzu *et al.*, 2022; Yılmaz *et al*., 2023). Due to its modest yield losses upon infection, barley is regarded as tolerant. Oats can also be infected by *F. pseudograminearum*, which causes the development of very few or no disease symptoms (Percy *et al*., 2012). Seedlings infected with *F. pseudograminearum* may suffer from damping-off both before and after emergence (Kazan and Gardiner, 2018). Plants that survive damping-off may show unfulfilled kernels and stunted growth as a result of nutrient and water transfer being blocked. Infected seedlings have dark brown to black crowns as a result of the rot (Boamah *et al.*, 2021). The accumulation of deoxynivalenol (DON), an internationally regulated mycotoxin, is frequently the caused by *F. pseudograminearum* (Bolanos-Carriel *et al.*, 2020).

Balmas (1994) isolated *F. pseudograminearum* in Southern Italy. The pathogen was discovered in a wheat (*Triticum aestivum*) crop in Cordoba, Spain, in 2016 by Agustí-Brisach *et al*. (2018). The crown and basal stems of the affected plants displayed dry rot and necrosis. It appears that in central-southern Spain, Fusarium crown rot is a prevalent wheat disease that significantly reduces yield.

The distribution and species of *Fusarium* spp. found in wheat samples taken from 12 areas of Anhui Province, China, in 2020, 2022, and 2024 were examined by He et al., (2025). Based on molecular and morphological identification, nine species of *Fusarium* were found. Over time and in different parts of Anhui Province, the predominant pathogen of Fusarium crown rot shifted from *F. graminearum* Schwabe to *F. pseudograminearum*. Pathogenicity tests reveaşed that all *Fusarium* species caused crown rot in wheat seedlings. He et al (2025) also found that *F. culmorum* was the most harmful species followed by *F. pseudograminearum* and *F. graminearum*. Disease control by the application of pyraclostrobin and prothioconazole was also assessed. The results showed that *F. pseudograminearum* was sensitive to prothioconazole and pyraclostrobin, the co-formulation (1:1) was more effective than prothioconazole alone.

Gebremariam et al. (2018) conducted a comprehensive survey in the summer of 2013 to collect *Fusarium* species that were colonizing the lower stems (crowns) of durum wheat (*Triticum durum*) and bread wheat (*Triticum aestivum*) from various wheat-growing districts of Türkiye. Fungi were identified from symptomatic crowns after samples were taken from 200 fields that represented Türkiye's main wheat-growing regions. Using morpholgical and molecular methods, the isolates were identified to the species level. A total of seventeen species of *Fusarium* were isolated. With 36% of all isolated *Fusarium* species, *F. equiseti* (Corda) Saccardo was the most frequently isolated species. The most common of the harmful species, *F. culmorum* (W. G. Smith) Saccardo, was recovered from 13.6% of the sites examined, but *F. pseudograminearum*

O'Donnell & T. Aoki and *F. graminearum* were also isolated from 1% and 0.5% of the sites, respectively. Crown rot of varying degrees was produced by six of the seventeen *Fusarium* species that were examined for pathogenicity. On durum wheat, *F. culmorum* , *F. pseudograminearum*, and *F. graminearum* induced severe crown rot disease. Both *F. hostae* Geiser & Juba and *F. avenaceum* (Fr.:Fr.) Sacc. exhibited weak to moderate virulence. The virulence of *F. redolens* Wollenweber was weak. The following, however, were not harmful: *F. oxysporum* Schlechtendahl emend. Synder & Hansen, *F. equiseti* (Corda (Saccardo), *F. solani* (Martius) Appel & Wollenweber emend. Synder & Hansen, *F. incarnatum* Berkeley & Ravene (syn.: *F. semitectum* Berkeley & Ravenel) (Leslie & Summerell, 2006), *F. reticulatum* Montagne (syn.: *F. heterosporium* Nees *ex* Fries) (Leslie & Summerell, 2006), *F. flocciferum* Corda, *F. tricinctum* (Corda) Saccardo, *F. brachygibbosum* Padwick, *F. torulosum* (Berkeley & Curtis) Nirenberg, *F. acuminatum* Ellis & Everhart, and *F. proliferatum* (Matsushima) Nirenberg.

Fusarium pseudograminearum was found in Türkiye as a destructive species also by Ölmez and Tunalı (2019). In their study, researchers obtained 143 *Fusarium* isolates from wheat-producing areas in Adıyaman, Diyarbakır, Mardin, and Şanlıurfa provinces of Türkiye. The most isolated species was *F. proliferatum* (17.4%). *Fusarium pseudograminearum* and *F. culmorum* were the most important crown rot pathogens with a 13% isolation rate.

Chemical control is one of the most essential approaches for managing plant diseases. According to Moya-Elizondo and Jacobsen (2016) and Alahmad *et al.* (2018), fungicidal control of *F. pseudograminearum* in wheat is insufficient and does not offer year-round protection against the pathogen, and it may even be harmful to human health (Boamah *et al*., 2021). It is not well known what causes host resistance to *F. pseudograminearum*. No genotype of wheat has been shown to be completely resistant to this disease. Near maturity, the majority of wheat cultivars infected with Fusarium root rot develop similar lesions at the base of the stem, a condition that is aided by drought. However, some wheat cultivars exhibit less yield loss under Fusarium root rot infection, suggesting they are tolerant to this disease (Powell *et al*., 2017).

Identifying sources of resistance to *F. pseudograminearum* is crucial in disease control. In this study, 104 wheat genotypes obtained from the Eastern Mediterranean Agricultural Research Institute, Adana, Türkiye were tested for resistance to root and crown rot under greenhouse conditions using a virulent *F. pseudograminearum* isolate.

MATERIALS AND METHODS

Fifty-five wheat genotypes used in bread wheat yield trials, 6 durum wheat advanced lines, 15 bread wheat advanced lines, 7 durum wheat cultivars and 21 bread wheat cultivars obtained from the Eastern Mediterranean Agricultural Research Institute located in Adana, Türkiye were tested for resistance to root and crown rot under greenhouse conditions using a virulent *F. pseudograminearum* isolate maintained at the Mycology Laboratory of the Ankara University, Türkiye.

Inoculum preparation was carried out by infecting wheat bran with *F. pseudograminearum*, as described in Yılmaz *et al*. (2023). Wheat genotypes were germinated in 9-cm-diameter Petri dishes containing moistened sterile blotting paper for 3-4 days and then placed in 7-cm-diameter pots containing a mixture of sterilized sand: soil: manure (50:40:10 v/v/v) and approximately 1 g of bran-soaked inoculum. These pots were then covered with this mixture. After eight weeks, the roots were washed and the results were evaluated. A 1-5 scale was used to evaluate the results (1: 1-9% (Resistant), 2: 10-29% (Moderately Resistant), 3: 30-69% (Moderately Susceptible), 4: 70-89% (Susceptible) and 5: 90-99% (Very Susceptible) (Wildermuth and McNamara, 1994; Nicol *et al*., 2001).

RESULTS AND DISCUSSION

In the bread wheat yield trial (EVD) genotypes, out of 55 genotypes tested, 3 genotypes showed resistant reactions, and 15 genotypes exhibited moderately resistant reactions. On the other hand, 20 genotypes were classified as moderately susceptible, while 13 genotypes were classified as susceptible. Four genotypes were classified as very susceptible. (Table 1). In the testing of six durum wheat advanced lines (M-İ-H), no lines were found to be resistant or moderately resistant. Two genotypes exhibited moderate susceptibility, three were susceptible, and one genotype was very susceptible.Out of the 15 advanced bread wheat lines (E-İ-H) tested, three genotypes were classified as moderately resistant. Nine lines were deemed moderately susceptible, while three were categorized as susceptible. Notably, none of the genotypes were identified as either resistant or highly susceptible among the tested lines.

All durum wheat cultivars tested in the experiment exhibited reactions ranging from susceptible to very susceptible. Durum wheat cultivars Sarıbaşak, Fuatbey, and Sham 1 were susceptible to the virulent *F. pseudograminearum* isolate used, while Eker, Günberi, Ayzer, and Avanos 97 showed very susceptible reactions. Bread wheat cultivars Ahsen, Dinçer, Altınbaşak, Yakamoz, and Karatopak showed moderately resistant reactions, while Altınöz, Candaş, Gemini, Ekinoks, Pandas, Osmaniyem, Doğankent, Gökkan, Ceyhan 99, Şahika, and Karmen showed moderately susceptible reactions. Yüreğir 89, Simge, Adana 99, Alkım, and Seyhan 99 showed susceptible reactions (Table 1).

In a study conducted in Türkiye, the reactions of 199 durum wheat genotypes obtained from International Maize and Wheat Improvement Center (CIMMYT) to *F. pseudograminearum* were determined under growth chamber and greenhouse conditions. Under growth chamber conditions, 15 genotypes were resistant, 20 genotypes were moderately resistant, 134 genotypes were moderately susceptible, and 30 genotypes showed susceptible reactions. Under greenhouse conditions, 19 genotypes were resistant, 16 genotypes were moderately resistant, 121 genotypes were moderately susceptible, and 43 genotypes showed susceptible reactions. In both seedling resistance trials in the growth chamber and mature plant resistance trials in the greenhouse, 2 genotypes were resistant, 2 genotypes were moderately resistant, 85 genotypes were

moderately susceptible, and 7 genotypes showed susceptible reactions (Yılmaz *et al*., 2023).

In another study conducted in Türkiye, it was found that of 200 bread wheat lines supplied by CIMMYT, 1 (0.5%) was resistant to *F. pseudograminearum*, 35 (17.5%) were moderately resistant, 112 (56%) were moderately susceptible, 45 (22.5%) were susceptible and 7 (3.5%) were very susceptible (Yazıcı Kuzu *et al*., 2022).

Table 1. Seedling resistance status of some wheat lines and cultivars obtained from Eastern Mediterranean Agricultural Research Institute, Adana, Türkiye to *F. pseudograminearum*

Lines and cultivars	**Scale values**			**Mean**	**Resistance status**
EVD 101	2	2	3	2,33	MR
EVD 103	4	4	4	4	S
EVD 104	3	3	2	2,66	MS
EVD 106	2	2	1	1,66	MR
EVD 107	3	3	2	2,66	MS
EVD 108	2	2	2	2	MR
EVD 111	3	3	3	3	MS
EVD 112	5	5	5	5	HS
EVD 113	4	4	4	4	S
EVD 114	4	4	3	3,66	S
EVD 116	4	4	5	4,33	S
EVD 117	2	2	3	2,33	MR
EVD 118	2	2	3	2,33	MR
EVD 119	5	5	5	5	HS
EVD 121	2	2	3	2,33	MR

EVD 122	4	4	4	4	S
EVD 123	3	3	3	3	MS
EVD 124	2	2	1	1,66	MR
EVD 125	5	5	5	5	HS
EVD 128	4	4	4	4	S
EVD 129	3	3	2	2,66	MS
EVD 131	4	3	3	3,33	MS
EVD 132	3	3	2	2,66	MS
EVD 133	4	4	4	4	S
EVD 134	3	3	2	2,66	MS
EVD 136	3	3	2	2,66	MS
EVD 137	1	1	2	1,33	R
EVD 138	2	2	3	2,33	MR
EVD 139	3	3	4	3,33	MS
EVD 141	2	2	2	2	MR
EVD 142	2	2	3	2,33	MR
EVD 143	3	3	2	2,66	MS
EVD 144	5	5	4	4,66	HS
EVD 146	3	3	3	3	MS
EVD 147	3	3	3	3	MS
EVD 148	3	3	2	2,66	MS
EVD 149	1	1	2	1,33	R

Scale values: 1: % 1-9 (R: Resistant), 2: % 10-29 (MR: Moderately Resistant), 3: % 30-69 (MS: Moderately Susceptible), 4: % 70-89 (S: Susceptible) ve 5: % 90-99 (VS: Very Susceptible) (Wildermuth and McNamara,1994; Nicol *et al*., 2001)

Table 1. Seedling resistance status of some wheat lines and cultivars obtained from Eastern Mediterranean Agricultural Research Institute, Adana, Türkiye to *F. pseudograminearum* (continued)

Lines and cultivars	**Scale values**			**Mean**	**Resistance status**
EVD 150	3	3	2	2,66	MS
EVD 151	2	2	3	2,33	MR
EVD 152	3	3	3	3	MS
EVD 153	3	3	4	3,33	MS
EVD 154	4	4	4	4	S
EVD 156	4	4	3	3,66	S

EVD 157	4	4	3	3,66	S
EVD 158	1	1	2	1,33	R
EVD 159	2	2	3	2,33	MR
EVD 163	2	2	3	2,33	MR
EVD 166	4	4	3	3,66	S
EVD 167	3	3	2	2,66	MS
EVD 168	3	3	4	3,33	MS
EVD 169	3	3	3	3	MS
EVD 172	2	2	3	2,33	MR
EVD 173	4	4	3	3,66	S
EVD 174	2	2	2	2	MR
EVD 175	4	4	4	4	S
M-İ-H 1	5	5	5	5	HS
M-İ-H 3	3	3	4	3,33	MS
M-İ-H 4	4	4	5	4,33	S
M-İ-H 5	4	4	4	4	S
M-İ-H 6	3	3	4	3,33	MS
M-İ-H 7	4	4	3	3,66	S
E-İ-H5	4	4	4	4	S
E-İ-H 1	3	3	4	3,33	MS
E-İ-H 2	3	3	3	3	MS
E-İ-H 4	3	3	2	2,66	MS
E-İ-H 6	3	3	3	3	MS
E-İ-H 7	4	4	3	3,66	S
E-İ-H 8	2	2	3	2,33	MR
E-İ-H 9	4	4	4	4	S
E-İ-H 10	3	3	2	2,66	MS
E-İ-H 11	2	2	2	2	MR
E-İ-H 12	3	3	3	3	MS
E-İ-H 13	3	3	3	3	MS
E-İ-H 14	3	3	4	3,33	MS
E-İ-H 15	2	2	2	2	MR
E-İ-H 16	3	3	4	3,33	MS

Scale values: 1: % 1-9 (R: Resistant), 2: % 10-29 (MR: Moderately Resistant), 3: % 30-69 (MS: Moderately Susceptible), 4: % 70-89 (S: Susceptible) ve 5: % 90-99 (VS: Very Susceptible) (Wildermuth and McNamara, 1994; Nicol *et al*., 2001)

Table 1. Seedling resistance status of some wheat lines and cultivars obtained from Eastern Mediterranean Agricultural Research Institute, Adana, Türkiye to *F. pseudograminearum* (continued)

Lines and cultivars	Scale values			Mean	Resistance status
Sarıbaşak	4	4	5	4,33	S
Eker	5	5	4	4,66	HS
Günberi	5	5	4	4,66	HS
Ayzer	5	5	4	4,66	HS
Fuatbey	4	4	4	4	S
Sham 1	4	4	5	4,33	S
Avanos 97	5	5	5	5	HS
Ahsen	2	2	2	2	MR
Altınöz	3	3	3	3	MS
Dinçer	2	2	1	1,66	MR
Yüreğir 89	4	4	4	4	S
Simge	4	4	5	4,33	S
Candaş	3	3	2	2,66	MS
Gemini	3	3	2	2,66	MS
Ekinoks	3	3	3	3	MS
Altınbaşak	2	2	3	2,33	MR
Yakamoz	2	2	2	2	MR
Adana 99	4	4	4	4	S
Pandas	3	3	2	2,66	MS
Osmaniyem	3	3	2	2,66	MS
Doğankent	3	3	3	3	MS
Alkım	4	4	4	4	S
Karatopak	2	2	3	2,33	MR
Seyhan 95	4	4	5	4,33	S
Gökkan	3	3	3	3	MS
Ceyhan 99	3	3	2	2,66	MS
Şahika	3	3	4	3,33	MS
Karmen	3	3	2	2,66	MS

Scale values: 1: % 1-9 (R: Resistant), 2: % 10-29 (MR: Moderately Resistant), 3: % 30-69 (MS: Moderately Susceptible), 4: % 70-89 (S: Susceptible) ve 5: % 90-99 (VS: Very Susceptible) (Wildermuth and McNamara, 1994; Nicol *et al*., 2001)

Although a limited number of durum genotypes and varieties were tested in this study, durum genotypes were found to exhibit reactions ranging from moderately susceptible to very susceptible. Other genotypes exhibited a wide range of reactions, ranging from resistant to very susceptible. Genotypes in the resistantand moderately resistant groups can be used in breeding studies, and it would be appropriate to use varieties in these groups in regions where *F. pseudograminearum* is prevalent.

CONCLUSIONS

Finding resistant germplasm is an important goal in plant breeding studies. Managing soilborne plant pathogens, particularly *Fusarium* species, poses significant challenges. While cultural methods and chemical control measures have yielded some success, losses continue to occur. To achieve sustainable control, it is essential to identify disease-resistant genotypes. However, resistance to *F. pseudograminearum* has been limited. Therefore, discovering resistant germplasm is of utmost importance for enhancing disease resistance (Bockus *et al*., 2010; Kazan and Gardiner 2018). In this study, 104 bread and durum wheat genotypes were tested for resistance to root and crown rot under greenhouse conditions using a virulent *F. pseudograminearum* isolate. Three of the genotypes used in the bread wheat yield trial exhibited resistant reactions, while 15 wheat genotypes exhibited moderately resistant reactions. Three bread wheat advanced lines were classified as moderately resistant. Bread wheat cultivars Ahsen, Dinçer, Altınbaşak, Yakamoz, and Karatopak exhibited moderately resistant reactions.

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OTPORNOST KLIJANACA ODREĐENIH LINIJA I KULTIVARA PŠENICE NA *Fusarium pseudograminearum* O'Donnell & T. Aoki UZROČNIKA TRULEŽI KORIJENA I KORJENOVOG VRATA

Sažetak

Pšenica (*Triticum* spp.), jedna od najvažnijih kultura u ljudskoj ishrani, se uzgaja na velikim površinama širom svijeta. *Fusarium pseudograminearum* O'Donnell & T. Aoki se smatra za najznačajnijeg patogena pšenica, budući da uvjetuje trulež korijena i korjenovog vrata. Za patogene koji se održavaju u zemljištu, poput *F. pseudograminearum*, je iznimno teško pronaći rezistentne genotipove. Budući da je osnovni cilj oplemenjivačkog rada pronalazak rezistentne germplazme odabranih kultura, u sklopu ovog rada su ispitivana 104 genotipa obične i durum pšenice na otpornost na trulež korijena i korjenovog vrata. Genotipovi su uzgajani u zaštićenom prostoru i inokulisane virulentnim izolatom *F. pseudograminearum*. Među testiranim kultivarima i linijama durum pšenice nisu uočene rezistentne sorte ili linije. Tri genotipa koja su korištena u ispitivanju prinosa obične pšenice pokazala su rezistentne reakcije, dok je 15 pokazalo umjereno rezistentne reakcije. Tri napredne linije obične pšenice su klasifikovane kao umjereno rezistentne. Među testiranim kultivarima obične pšenice nisu pronađene rezistentne sorte, a Ahsen, Dinçer, Altınbaşak, Yakamoz i Karatopak pokazali su umjereno rezistentne reakcije.

Ključne riječi: *Fusarium pseudograminearum, pšenica, otpornost na bolesti*

RAD PRVE ERGELE ZA SELEKTIVNI UZGOJ BOSANSKOG BRDSKOG KONJA "Goražda" 1907-1916.

Enver Žiga[1]

Pregledni rad - *Review paper*

Sažetak

Postojanje bosanskog brdskog konja kao autohtone bosanskohercegovačke pasmine registrovano je u dokumentima još u dalekoj prošlosti, a davni preci ove pasmine bili su hiljadugodišnji saputnici naroda u Bosni i Hercegovini pomažući ljudima u obavljanju svih vrsta poslova kako na seoskim domaćinstvima tako i u gradovima. Bili su poznati još u srednjem vijeku i kao izvanredni tovarni konji koji su prenosili rudu i proizvode od željeza i drugih metala iz Bosne do velikih svjetskih trgovačkih centara. Organizovani selektivni uzgoj ove pasmine po prvi put počinje u Goraždu 1907. godine u ergeli u kojoj su se već uzgajali arapski konji. Ergela se zvala "Goražda", a svi konji za početak uzgoja nabavljeni su u okolnim mjestima. Gojidbena izgradnja u ergeli prikazana je na nekoliko karakterističnih primjera. Osnovu gojidbene izgradnje činile su domaće kobile iz narodnog uzgoja koje su u prvim godinama rada ergele parene sa originalnim arapskim pastusima, da bi u drugoj fazi za rasplod bili korišteni križanci iz vlastitog uzgoja. Ergela je egzistirala do početka Prvog svjetskog rata tj. do 1916. godine kada je većina konja odvedena na front. Manji dio konja odveden je u Austriju u mjesto Brück am Leita gdje je bila osnovana manja ergela za uzgoj bosanskih brdskih konja, ali nije nigdje zabilježeno šta je dalje bilo sa ovom ergelom. Iako je ergela bila aktivna jedan kratak vremenski period njezino osnivanje je vrlo značajno za konjogojstvo Bosne i Hercegovine jer se po prvi put u historiji bosanski brdski konj počeo organizovano uzgajati, a uz to u ergeli je utvrdjen pravac u kojem treba u budućnosti da ide uzgoj ovo značajne bosanskohercegovačke autohtone pasmine.

Ključne riječi: *Bosanski brdski konj, ergela "Goražda", linije pastuha, rodovi kobila*

UVOD

Bosanski brdski konj kao autohtona bosanskohercegovačka pasmina ima vrlo dug i interesantan historijat. Pasmina, prema raspoloživim pisanim dokumentima, vodi porijeklo od izvornih pasmina divljih konja Tarpan i Przewalskog. Tarpana su sobom doveli Slaveni prilikom naseljavanja ovih područja, dok se pojava Przewalskog može vezati za doseljavanje azijskih plemena mongolskog govornog korijena. Naučnici nisu dali odgovor na pitanje da li su u prvom oblikovanju pasmine bosanski brdski konj učestvovali još neke vrste osim Tarpana i Pševalskog.

[1] Ergela „ Žiga"

Vjerovatno su na tlu Bosne i Hercegovine postojali konji i prije dolaska Slovena, koji su se kasnije križani sa potomcima Tarpana i Pševalskog i polako započeli proces formiranja današnje pasmine. Sa okupacijom Bosne i Hercegovine od strane Osmanske imperije počelo je dodavanje krvi orijentalnih pasmina među kojima je preovladavao Arapski konj. Oplemenjivanje domaćih konja na području Bosne i Hercegovine dodavanjem orijentalne krvi u početku se je odvijalo spontano da bi pri kraju turske vladavine dobilo organizovanu formu. Medjutim, sa sigurnošću možemo konstatovati da je oplemenjivanje bosanskog brdskog konja dodavanjem krvi Arapskog konja, u pravom smislu, počeo sa austrougarskom okupacijom.
Križanje sa arapskim konjima imalo je prvenstveno za cilj popravljanje eksterijera (posebno visine) i temperamenta domaćih konja. Uz to trebalo je zadržati sve one dobre karakteristike bosanskog brdskog konja zbog kojih je bio na velikoj cijeni, naročito kod vojnih jedinica. U tu svrhu okupacione vlasti su već 1880. godine osnovale u Sarajevu depo sa 70 arapskih pastuha koji su stavljeni na raspolaganje domaćem stanovništvu preko pastuhskih stanica. Zemaljska vlada je zadužila majora Tilija (Tilly) da u pogodnim mjestima osnuje pastuhske stanice na način kako je to bilo uradjeno u drugim dijelovima Austro–Ugarske monarhije. Pastusi su za vrijeme sezone parenja iz Sarajeva odvodjeni u pastuhske stanice, da bi se nakon završetka sezone parenja ponovo vraćali u glavni depo. U prvo vrijeme pastusi su nabavljani iz mađarske ergele u Babolni, da bi se ubrzo prešlo na nabavku originalnih arapskih pastuha iz Sirije, Jemena i Mezopotanije. Ova aktivnost odvijala se sve do 1914. godine. U međuvremenu je u Sarajevu 1895. osnovana ergela za vlastiti uzgoj arapskih konja koja je trebalo da obezbjedjuje dovoljan broj pastuha za potrebe pastuhskih stanica. Ergela je između 1898. i 1900. godine premještena u Goražde.

OSNIVANJE ERGELE

Krajem 1906. godine ministarstvo poljoprivrede Austrije, na prijedlog nadležne komisije, dalo je saglasnost Zemaljskoj vladi u Sarajevu da u Goraždu uz ergelu Arapskih konja osnuje i ergelu za uzgoj bosanskog brdskog konja. Cjelokupan posao na organizaciji nove ergele organizirao je pukovnik Sigmund Fessl koji je poslat u Bosnu iz Kraljevske mađarske ergele, upravnik ergele bio je Eduard von Melecki postavljen od strane Zemaljske vlade u Sarajevu ali po direktivi iz Beča. Od domaćih radnika bio je angažovan Sijerčić Abdulkadir iz Goražda čiji je glavni zadatak bio da obilazi seoska područja u okolini i predlaže kobile koje bi mogle doći u obzir za otkup kako bi imali kobile traženih karakteristika. (Sijerčić je poticao iz bogate begovske porodice iz Goražda, studirao je u Beču gdje je stekao veliki broj prijatelja zahvaljujući svojoj veseloj naravi i velikoj količini novca koji je sa društvom nemilice trošio. Upravo su ga ti prijatelji preporučili za ovaj posao jer je bio briljantan jahač i poznavalac konja). Uprava ergele bila je smještena u Sarajevu.

Osnivanje ove ergele je vrlo značajno za cjelokupno bosanskohercegovačko konjogojstvo jer se radi o prvom slučaju sistematskog selektivnog uzgojnog rada na bosanskom brdskom konju. Tim radom išlo se ka tome da se infiltriranje arapske krvi u pasminu bosanskog brdskog konja vrši na indirektan način tj. preko uzgoja iz novoosnovane ergele. Ustaljena praksa je bila da se oplemenjivanje bosanskog brdskog konja vrši križanje domaćih kobila sa originalnim arapskim pastusima nabavljenim u Jemenu, Siriji, Mezopotaniji i Saudijskoj Arabiji. Čitav plan pripusta se organizovao i realizovao preko pripusnih stanica u koje su se iz depoa u Sarajevu, za vrijeme sezone pripusta, slali pastusi. Za svaku godinu se pravio poseban plan i utvrdjivao broj pastuha koji će biti poslan u pojedinu stanicu. Dobijena ždrijebad (F1) ostajala su u vlasništvu vlasnika kobila pa je praktično bilo nemoguće pratiti njihov dalji uticaj na uzgoj, ali je sigurno da se priliv arapske krvi širio u narodnom uzgoju. Takodje je bilo teško pratiti kvalitet ždrijebadi F1 generacije i koliko ta ždrijebad zadovoljavaju unaprijed postavljene ciljeve križanja. Kvalitet ždrijebadi nije bio jednak, što je razumljivo kad se zna da kod pripusta nije bilo sistema u radu, već su križanja vršena nasumično. To je i bio jedan od razloga osnivanja ergele bosanskog brdskog konja u Goraždu, ali je i dalje nastavljeno križanje domaćih kobila sa originalnim arapskim pastusima u planiranom obimu.

Drž. ergela Goražde kod Sarajeva. Konjušnica. (Vidi članak i „Naše Konjarstvo" na strani 7.)

Ergela bosanskog brdskog konja u Goraždu trebalo je da obezbijedi u prvom redu pastuhe koji bi zadovoljavali tražene kriterije u pogledu visine, eksterijera i temperamenta, a ti pastusi bi se dalje koristili i za potrebe same ergele i za potrebe narodnog uzgoja gdje su vremenom trebali da zamijene arapske pastuhe. Na taj način bi se arapska krv indirektnim putem ubacivala u pasminu preko uzgoja u novoosnovanoj ergeli od koje se je mnogo očekivalo.

GOJIDBENA IZGRADNJA U ERGELI "GORAŽDA"

S obzirom da je krv arapskog konja dugo vremena, nešto stihijski, a nešto i organizovano, dodavana pasmini bosanskog brdskog konja, u narodnom uzgoju vidno se osjećao taj uticaj, a i uzgajivaču su već znali razlikovati originalna domaća grla od onih kod kojih je uticaj arapa bio veći. Medjutim, čitav taj proces se odvijao na relaciji pripusna pastuhska stanica – privatno domaćinstvo koje je u ovom slučaju bilo uzgajivač, ali preferirajući svoj način uzgoja. Uvodjenje selekcije u uzgoj kod njih je išao dosta sporo i sa velikom dozom nepovjerenja, kao što je uostalom bilo u kod uvodjenja bilo kakvih novina kod seoskog stanovništva naviknutog na svoje standarde, svoje običaje i uopšte svoj način života. Prva križanja pokazivala su veliku šarolikost kod F1 generacije koja se odlikovala većom visinom, ali okvir nije bio uvijek zadovoljavajući jer nije bio u skladu sa visinom. Dalja križanja F1 potomaka mogla su ići u dva pravca. Prvo, povratno križanje sa arapskim konjem i to tako da bi se kobile F1 generacije ponovo parile sa arapskim pastusima, što se vrlo rijetko događalo. Drugi pravac je bio da se pastusi F1 generacije pare ili sa čistim domaćim kobilama ili sa kobilama F1 generacije. U oba slučaja krv arapskog konja se širila u domaćem uzgoju. Vlasnici seoskih domaćinstava, koji su i inače bili dobri poznavaoci i uzgoja i vrijednosti svakog konja pojedinačno, ubrzo su otkrili da dobra grla F1 generacije, i muška i ženska, u povratnom križanju daju puno bolje konje pa su ta grla dobijala na svojoj vrijednosti i teško su se nabavljala jer su ih vlasnici zadržavali za sebe. Upravo taj vid konsolidacije uzgoja na pastuhe F1 i F2 generacije bio je inicijalna ideja austrijskim vlastima za formiranje posebne ergele bosanskog brdskog konja. Ovdje treba istaći veliki uticaj konjičkog kapetana Veselija i konjičkog kapetana Krčmara, koji su više puta pisali pisma zemaljskoj vladi u Sarajevu da se osnuje ergela i ubrza unošenje arapske krvi u pasminu bosanskog brdskog konja. U zemaljskoj vladi u Sarajevu radio je Jakob fon Mikuly koji je bio zaljubljenik u bosanskog brdskog konja, često odlazeći u okolinu Sarajeva kod domaćina koji su imali te konje i provodeći dugo vremena sa njima, analizirajući ih i praveći zabilješke. On je na osnovu zahtjeva pomenuta dva konjička kapetana u dva puta slao opširne izvještaje u Beč sa prijedlogom da se osnuje ergela bosanskog brdskog konja. Punu podršku mu je davao Sigmund Fessl, tako da je konačno pri kraju 1906. godine odobreno formiranje ergele, ali i budžet koji je bio relativno skroman. Nabavka kobila za potrebe nove ergele nije išla predvidjenom dinamikom pa je 1907. godine u ergelu nabavljeno samo 7 od planiranih 14 kobila. Rezultat rada Sijerčića bio je više nego skroman, našao je samo jednu kobilu, pet kobila je povučeno iz vojnih jedinica a jednu kobilu je vlasnik sam doveo na osnovu raspisanog natječaja. Veliki broj kobila koje su vlasnici doveli u ergelu nisu eksterijerno odgovarale traženim karakteristikama, a sve kobile koje su odabrane eksterijerno su bile odlične, pa je bilo očito da u sebi već imaju arapske krvi. Gojidbenu izgradnju u ergeli u Goraždu možemo vidjeti preko rodovnica br. 2, 4, 5, 6 i 7.

Rodovnica br, 2. Belsta I, 1908.

Belsta I			
Belsta		13 Gazal	
Domaća kobila	Državni pastuh	Ox - Sirija	Ox - Sirija

Kako prva naredba da svi okruzi odaberu najbolje kobile za novu ergelu nije dala nikakav rezultat, da bi se udovoljilo vojnim vlastima, te da bi imali dobar prvi zapat, pregledane su sve kobile koje su se našle pri artiljerijskim baterijama i najboljih 5 je odabrano za priplod. Jedna od njih je i kobila Belsta koju je konjički kapetan Vesely lično doveo u ergelu. Kobilu su ocjenjivali Fessel i Melecki i zaključili da je idealna, a naknadno je utvrdjeno da joj je otac bio državni pastuh, originalni pastuh arapske pasmine. Iste godine su je parili sa originalnim pustinjskim pastuhom 13 Gazal kupljenim u Siriji i dobili žensko ždrijebe sa kojim je rod nastavljen.

Fig. 13b. Bosnische Gestütsstute „Belsta".

Rodovnica br. 4 17 Ljuba I

17 Ljuba I, 1908.			
9 Ljuba		13 Gazal	
Domaća kobila	Državni pastuh	Ox – Sirija	Ox – Sirija

I kobila Ljuba je dovedena iz artiljerijske baterije koja je bila locirana na Metaljci. Ispitivanjem porijekla ustanovljeno je da i ona potiče od državnog pastuha i domaće kobile, a eksterijerom je potpuno odgovarala traženim karakteristikama. Parena je 1907. godine sa originalnim pustinjskim pastuhom 13 Gazal, a 1908. godine oždrijebila je žensko ždrijebe 17 Ljuba I pa je tako i ovaj rod nastavljen.

Rodovnica br. 5 52 Zora I

52 Zora I, 1914.			
41 Zora		Vezir	
Domaća kobila	Domaći pastuh	Domaća kobila	OX Massud -Sirija

Rodovnica kobile 52 Zora I je interesantna iz dva razloga, njezina majka 41 Zora je nabavljena od vojske, tj. dovedena je je iz jedne od artiljerijskih baterija uz granicu. Medjutim, ovdje se već vidi kojem pravcu je išla gojidbena izgradlja na ergeli u Goraždu. Ova kobila je parena sa bosanskim brdskim pastuhom pastuhom Vezir koji je bio križanac F1 generacije izmedju originalnog arapskog pastuha i bosanske brdske kobile. To je ustvari bio putokaz kako treba u budućnosti raditi, a to je da se postepeno u rasplod uvode pastusi koji su križanci a iz rasploda izbacuju arapski pastusi.

Rodovnica br. 6 Alajbeg I

Alajbeg - I, dorat, 1913.			
41 Zora		14 Alajbeg	
Domaća kobila	Domaći pastuh	Domaća kobila	Arapski pastuh - Dilaver

Rodovnica od Alajbeg – I nam pokazuje način formiranja linija pastuha u ergeli u Goraždu. Ovdje vidimo da je domaća kobila Zora parena sa pastuhom 14 Alajbeg koji je križanac F1 generacije. Otac arapski pastuh, majka domaća kobila. Nije bilo mnoguće pronaći karakteristike niti fotografiju pastuha 14 Alajbeg, ali s obzirom na činjenicu da je odmah po navrešene 3 godine uključen u rasplod može se zaključiti da je zadovoljavao sve tražene karakteristike, jer je uprava ergele strogo vodila računa o striktnoj primjeni tada važećih selekcijskih uzusa.
Kobila Ljuba (koja je u matičnim knjigama dobila broj 9), značajna je i po tome što je dala vrlo kvalitetno muško ždrijebe 447 Vezir – 4, dorat 1914. čiju rodovnicu prilažemo.

Rodovnica br. 7

447 Vezir – 4, dorat, 1914.			
9 Ljuba		Vezir	
Domaća kobila	Dežavni pastuh	Domaća kobila	Massud o.x.

Linija Vezir ustanovljena je 1912. godine uvodjenjem u rasplod pastuha Vezir koji je kupljen od Stanka Duvnjaka iz sela Malovana kod Kupresa. Majka mu je bila domaća kobila a otac originalni pustinjski pastuh Massud, takodje iz Sirije, koji je jedne godine bio dodijeljen stanici Kupres po planu pripusta. Na ovome pastuhu se odlično može analizirati plan koji se u konjogojstvu Bosne i Hercegovine dosljedno realizovao. Taj plan je predvidjao da se što više kobila bosanske brdske pasmine pari sa originalnim arapskim pastusima, a da se onda tako dobijeni pastusi koji zadovoljavaju postavljene kriterije koriste dalje u rasplodu, sa željom da se pastusi bosanske pasmine postepeno izbaciju iz rasploda da bi jednoga dana potpuno bili zamijenjeni ovim križancima

oplemenjenim krvlju arapskog konja. Takav jedan križanac je bio i pastuh Vezir koji je nabavljen za potrebe ergele u Goraždu. Vezir je ocijenjen vrlo visokom ocjenom i po svojim eksterijernim karakteristikama u potpunosti je zadovoljavao tražene kriterije. Mjere su mu bile: visina do grebena 147 cm. (mjereno vrpcom), obim grudi 166 cm., obim cjevanice 19,5 cm. Uporedjivanjem vanjskog izgleda pastuha Vezir, zatim njegovih mjera sa današnjim pastusima bosanskog brdskog konja da se uočiti velika sličnost, ustvari značajnih razlika i nema.


VEZIR

Vezir je bio u rasplodu sve do 1914. godine, a u rasplod je bio uveden i njegov sin 447 Vezir – 4 koji je od oca naslijedio sve dobre karakteristike. Već za nekoliko godina rada na ergeli su zasnovane dvije kvalitetne linije pastuha: Alajbeg I Vezir, što je bio veliki uspjeh jer su time stvorene mogućnosti za brži i kvalitetan uzgoj na bazi ciljeva utvrdjenih gojidbenom izgradnjom. U literature je zabilježen i podatak da je u rasplodu bio i pastuh Dečko, ali nigdje nije bilo moguće pronaći podatke od kojeg pastuha potiče niti da li je imao potomke. Ergela za uzgoj bosanskog brdskog konja u Goraždu nije bila dugog vijeka, a razlog je početak Prvog svjetskog rata. Već početkom 1915. godine počela je masovnija mobilizacija konja u svim dijelovima Bosne i Hercegovine pa su vremenom i konji ergele došli na red. Prvo su 11 rasplodnih kobila i dva rasplodna pastuha odvedeni u malo mjesto Brück an der Leitha na austrijsko – mađarskoj granici. Tu je bila osnovana mala ergela za uzgoj bosanskog brdskog konja o kojoj se malo zna. Ko je donio odluku o formiranju te ergele nije poznato, takodje nije poznata dalja sudbina ergele poslije osnivanja, koliko dugo je bila aktivna, koje je rezultate ostvarila i sl. Sve su to pitanja na koja nema odgovora. Ostalo je samo zapisano da je to prvi put u historiji da je organizovan uzgoj bosanskog brdskog konja van Bosne i Hercegovine. Ostali konji iz ergele odvedeni su na različite frontove pa im se skupa sa još cca. 100.000 bosanskih brdskih konja gubi svaki trag.

ZAKLJUČAK

Iako je selektivni uzgoj bosanskog brdskog konja praktikovan i ranije, ali samo sporadično i u pojedinačnim slučajevima, selektivni uzgoj u pravom smislu te riječi počeo je sa osnivanjem ergele u Goraždu. Velike zasluge za osnivanje jedne ovakve ergele pripadaju pukovniku Sigmundu Fesslu iz mađarske kraljevske ergele i Jakobu fon Mikuliju zaposleniku Zemaljske vlade u Sarajevu, dok je od domaćih jedino bio angažovan Abdulkadir Sijerčić i to na manje važnim poslovima. Ergela je bila skromnog kapaciteta, ali je imala vrlo ambiciozne planove prema kojima je trebalo da obezbjedjuje rasplodne pastuhe kojima bi se u narodnom uzgoju popravljale karakteristike pasmine, U svom radu ergela se u početku oslanjala na korištenje originalnih arapskih pustinjskih pastuha, da bi u kratkom roku arapski pastusi bili zamijenjeni sa pastusima iz vlastitog uzgoja koju su bili križanci F1 generacije dobijeni ukrstanjem domaćih kobila sa arapskim pastusima. Uzgoj na egeli Goražde odvijao se uz primjenu, tada važećih, najsavremenijih svjetskih uzgojnih metoda. Ergela je aktivno radila svega 8 godina, ali je i u tom kratkom roku uspjela zasnovati tri linije pastuha i desetak rodova kobila što je bilo više od svih očekivanja. Izbijanjem Prvog svjetskog rata, rad ove ergele krenuo je prema svome kraju jer je prvo 1915. godine dio konja odveden u mjesto Brück an der Leitha na mađarsko-austrijskoj granici. Ti konji su predstavljali bazu novoosnovane ergele za uzgoj bosanskog brdskog konja. Ostali konji odvedeni su na brojne frontove odakle se nikada nisu vratili.

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THE WORK OF THE FIRST STABLE FOR SELECTIVE BREEDING OF THE BOSNIAN MOUNTAIN HORSE "Goražda" 1907-1916.

Abstract

The existence of the Bosnian Mountain Horse as an indigenous Bosnian and Herzegovinian breed has been documented in documents since the distant past, and the ancient ancestors of this breed have been companions of the people of Bosnia and Herzegovina for thousands of years, helping people in performing all kinds of tasks both in rural households and in cities. They were also known in the Middle Ages as extraordinary pack horses that transported ore and iron and other metal products from Bosnia to major world trade centers. Organized selective breeding of this breed began for the first time in Goražde in 1907 in a stud farm where Arabian horses were already bred. The stud farm was called "Goražda", and all the horses for the beginning of breeding were purchased in surrounding towns. The breeding construction in the stud farm is shown in several characteristic examples. The basis of the stud farm was domestic mares from folk breeding, which in the first years of the stud farm were mated with original Arab stallions, and in the second phase, crossbreeds from their own breeding were used for breeding. The stable existed until the beginning of the First World War, i.e. until 1916 when most of the horses were taken to the front. A small part of the horses was taken to Austria to Brück am Leita, where a small stud farm was established for the breeding of Bosnian mountain horses, but it is not recorded anywhere what happened to this stud farm. Although the stud farm was active for a short period of time, its establishment is very significant for the horse breeding of Bosnia and Herzegovina, because for the first time in history, the Bosnian mountain horse began to be bred in an organized manner, and in addition, the stud farm established the direction in which the breeding of this important indigenous breed of Bosnia and Herzegovina should go in the future.

Keywords: *Bosnian mountain horse, stud farm "Goražda", stallion lines, mare lines*

RAZVOJ I SENZORSKA EVALUACIJA FUNKCIONALNOG I SPECIJALNIH VRSTA KRUHA

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Izvorni znanstveni rad – *Original scientific paper*

Sažetak

Kruh je kroz ljudsku povijest jedan od glavnih prehrambenih proizvoda. Nutritivno je bogat energijom, vitaminima i prehrambenim vlaknima te primjenjivanjem kiselog tijesta povećava biodostupnost fitokemikalija. Sastavani dio kruha je gluten. Gluten je odgovoran za stabilnost, izgled i okus kruha. Danas je moguće proizvoditi kruh bez glutena, te na taj način omogućiti konzumaciju kruha potrošačima intolerantnim na gluten. Provedeno istraživanje ispituje senzorsku prihvatljivost 4 uzorka kruha priređena na bazi kiselog tijesta. Uzorci kruha su rađeni prema vlastitim recepturama koje su imale za cilj povisiti nutritivnu vrijednost kruha. Jedna od receptura bila je za bezglutenski kruh.
Provedena je senzorska analiza uzoraka kruha u kojoj je sudjelovalo sveukupno 17 senzoričara. Senzoričari su najniže ocjene dali bezglutenskom kruhu, a najviše veganskom kruhu. Na temelju dobivenih rezultata zaključuje se kako je potrebna promjena u svim recepturama osim u veganskom kruhu. U recepturi za bezglutenski i vinski kruh trebalo bi se promijeniti brašno korišteno u tijestu, dok kod integralnog kruha trebalo bi napraviti izmjenu recepture u svrhu postizanja poboljšanja teksture sredine kruha. Senzoričari su procijenili financijsku vrijednost ocjenjivanih kruhova, te su se njihove procjene uklopile u tržišnu vrijednost sličnih kruhova.

Ključne riječi*: kruh, kiselo tijesto, senzorska analiza, nutritivna vrijednost*

UVOD

Kruh je jedna od osnovnih namirnica u prehrani čovjeka. Sadrži velik udio ugljikohidrata te je dobar izvor energije i ujedno olakšava održavanje poželjne razine glukoze u krvi (Kourkouta i Monios, 2017). Federation of Bakers Ltd (URL) u svojoj sekciji o nutricionizmu i zdravlju ističe zdravstvene vrijednosti kruha poput niske količine dodanih šećera (najviše 1%), uz iznimke integralnih kruhova koji nemaju dodanih šećera. Kruh sadrži male koncentracije masnoće pri čemu u njegovom sastavu prevladavaju nezasićene masnoće. Različiti kruhovi imaju raznolike udjele masnoća u svojem sastavu te se tako u prosječnoj kriški kruha nalazi 2,1 g masnoće, u integralnom

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kruhu 2,5 g, dok se u crnom kruhu nalazi 2,0 g. Kruh sadrži vitamine B skupine s najvećim udjelom B1, B3 i B9. Tiacin i niacin važni su za oslobođenje energije iz konzumirane hrane, povoljno utječu na zdravlje kože, noktiju i očiju. Folna kiselina igra ključnu ulogu u zdravlju trudnica. Željezo prisutno u kruhu doprinosi jačanju imunološkiog sustava, a ima ga više u integralnom kruhu. Naposlijetku, s tri prosječne kriške kruha zadovoljeno je 30% dnevne potrebe za kalcijem, koji igra važnu ulogu u zdravlju kostiju i zubi (Aghalari i sur., 2022). Miješanjem ječmenog i pšeničnog brašna dobiva se proizvod dobrih nutritivnih i senzorskih svojstava. Ječmeno brašno prema istraživanju Gupta i sur. (2009) značajno povećava količinu mineralnih tvari u pšeničnom dvopeku. Prema navedenom istraživanju u 100 g kruha, dodatak od 40 % ječmenog brašna povećao je udio kalcija od 7,99 mg do 10,73 mg, cinka od 4,13 mg do 22,4 mg, kalija od 285,9 mg do 431,6 mg, natrija od 99,2 mg do 205,4 mg i željeza od 15,77 mg do 45 mg. Ipak, preporučuju korištenje do 20% ječmenog brašna, jer pri povećanju udjela do 40% dolazi do znatnog pada glutena. Nadalje ječam je bogat izvor β-glukana, povoljnih za ljudsko zdravlje. Kourkouta i Monios (2017) i El Khoury i sur. (2016) ističu β-glukane kao najvrijednije složene ugljikohidrate za stimulaciju imunološkog sustava te izvrsnim u borbi protiv raka i infektivnih bolesti. Navode kako je kod pretilih muškarca koji su imali povećan kolesterol u krvi, zamijećeno da je konzumiranje prehrambenih proizvoda s kvasacem koji sadrže β-(1,3;1,6)-D-glukane zabilježen pad razine kolesterola i povećanje razine HDL kolesterola. Kombiniranjem kokosovog brašna ili brašna kukuruznih mekinja moguće je povećati sadržaj vlakana u kruhu. U svom istraživanju Olubumni i sur. (2015) utvrdili su da su najviši udio prehrambenih vlakna sadržavali kruhovi s dodatkom 10% kokosovog brašna i 5 % brašna od kukuruznih mekinja. Konzumacijom takvog kruha u dnevno preporučenim količinama može se zadovoljiti čak 21,12% dnevnih potreba za vlaknima.

Smjesa brašna i vode koju fermentiraju bakterije mliječne kiseline naziva se kiselo tijesto (De Vuyst i Neysens, 2005). Kisela tijesta sadrže niz ugljikohidrata pogodnih za fermentaciju te uz pH vrijednost od 5,0 - 6,2 omogućuju razvoj bakterija mliječne kiseline. Decock i Capelle (2005) navode kako se kisela tijesta razlikuju prema svojoj konzistenciji, te navode dvije vrste fermentiranog kiselog tijesta: tradicionalni oblik tvrdog tijesta i tekuću suspenziju brašna u vodi. Omjer vode i brašna, to jest prinos tijesta (dough yield - DY), matematički se izražava kao suma ukupnog brašna i vode, pomnoženog sa 100 i podijeljeno s ukupnom količinom brašna. Nadalje, u slučaju pšeničnog kiselog tijesta, iznos prinosa tijesta 160 označava tvrdo tijesto, a iznos od 200 tekući oblik kiselog tijesta. Niska razina DY u tijestu znak je da tijesto sadrži veće količine octene kiseline u odnosu na mliječnu kiselinu čime se postiže neželjeni okus jer je octena kiselina izraženijeg okusa i neugodno oštrog mirisa u odnosu na blagu mliječnu. Prema tehnologiji proizvodnje kisela tijesta dijele se u tri skupine: tradicionalna kisela tijesta (tip I), ubrzana kisela tijesta (tip II) i suha kisela tijesta (tip III). Tradicionalna kisela tijesta imaju visoku metaboličku aktivnost, odnosno proizvode puno plinova čime dolazi do izraženog dizanja tijesta. Njihova metabolička aktivnost rezultat je svakodnevnog hranjenja kvasaca pri temperaturi 20 - 30 °C. Čista kultura tradicionalnog kiselog tijesta koja je nastala prirodnom fermentacijom (u trajanju

između 3 i 48 h) naziva se tip Ia. Ovakav tip kiselog tijesta sadrži veliku količinu kiseline, a mikroflora je prilagodljiva i otporna na mikrobiološku kontaminaciju. Za visoku razinu kiseline odgovoran je *Fructilactobacillus sanfrancicensis* koji iz maltoze proizvodi velike količine mliječne i octene kiseline te dodatno pomaže pri dizanju tijesta i proizvodnji plinova. Korištenje raži i pšenice ili njihovom kombinacijom nastaje miješana kultura kiselog tijesta koja prolazi višestruki proces fermentacije. Takva kisela tijesta nazivaju se Ib. Oslanjaju se na starter ili majčinsko tijesto koje djeluje kao cjepivo koje se umješava u tijesto. Starter održava konstantnu mikrofloru indirektnom fermentacijom (back slopping). Posljednji tip Ic su kisela tijesta koja fermentiraju na visokim temperaturama poput Afričkog sirak tijesta. Tip II kiselog tijesta nastao je zbog potrebe industrije za brzim i efektivnim procesom fermentacije. Nadalje, ovakva tijesta ostaju svježa sve do uporabe. Fermentacija ovakvog kiselog tijesta traje od 2 do 5 dana te se može ubrzati ukoliko se provodi na višoj temperaturi od 30 °C. Fermentacija stvara okruženje u kojem *Fructilactobacillus sanfranciscensis* nije dominantan. Neke od bakterija prisutnih u mikroflori su *Lactobacillus acidophilus, Lactobacillus amylovorus i Lactobacillus farciminis*. Posljednji tip III kiselog tijesta je u obliku praha te mu je glavna uloga kiseljenje različitih proizvoda. Odlikuje se stvaranjem poželjnih aroma tijekom pečenja kruha, otpornošću na sušenje i dugim rokom trajanja (De Vuyst i Neysens, 2005). Tip III, najčešće se koristi u industrijskoj proizvodnji s DY vrijednošću višom od 200, primjenom jedne od tehnika sušenja (prskanjem i bubnjevima) (Decock i Capelle, 2005). Jedna od prednosti korištenja fermentiranog kiselog tijesta je sniženje glikemijskog indeksa. Glikemijski indeks pšeničnog kruha od kiselog tijesta iznosi 54 dok u standardnom pšeničnom kruhu iznosi 71. Fermentacijom dolazi do sinteze aminokiselina i FAA (free amino acids) čime se smanjuje razina soli, pod uvjetom postojanja određenih bakterija mliječne kiseline u tijestu, čime također nastaje prividan efekt smanjenja soli. Nadalje, dodatkom raženog slada u kiselo tijesto koje sadrži *Limosilactobacillus Reuteri* snižava se razina soli s 1,5 % na 1 % bez gubitka senzorskih svojstava. Kiselo tijesto ima značajan utjecaj na biodostupnost fitokemikalija. Veći udio antioksidansa se postiže kod kruhova u čijoj izradi je korištena mješaavina raženog brašna i pšeničnih mekinja te kod raženih kruhova (Gobbetti i sur., 2018).

MATERIJAL I METODE

Priprema uzoraka kruha

Postupak pripreme startera za kruh odvijao se tijekom pet dana. Osnovni sastojci startera u svim uzorcima su voda i brašno. Za svaki uzorak startera korištena je drugačija vrsta brašna (Tablica 1). Na početku pripreme uzoraka u staklenku je stavljeno 50 g brašna i 50 g vode, a potom su sastojci promiješani. Zatim je staklenka prekrivena prozirnom folijom s rupicama i vezana gumicom. Idućeg dana dodano je 50 g vode i 50 g brašna (prema recepturi za pojedini uzorak) i promiješano, te je staklenka ponovno zatvorena.

Trećeg dana odvojena je polovica startera iz staklenke te je u nju dodano po 50 g vode i brašna. Četvrtog dana postupak je ponovljen. Nakon petog dana starter je bio spreman za daljnji postupak pripreme kvasa ambijentalnom metodom (25 g startera, 90 g vode i 100 g odgovarajućeg brašna za svaku pojedinu vrstu kruha). Proces fermentacije provodio se na sobnoj temperaturi u trajanju od 8 h. Nakon toga priređeni su uzorci kruha:

- bezglutenski kruh (uzorak 1)
- vinski kruh (uzorak 2)
- kruh za smanjenje kolesterola, funkcionalni kruh (uzorak 3)
- veganski kruh (uzorak 4)

Sastojci svakog pojedinog uzorka prikazani su Tablicom 1. Sve sirovine kupljene su u trgovačkom lancu Kaufland.

Priprema tijesta započela je miješanjem vode i odgovarajućeg brašna, nakon čega je slijedilo odležavanje pokrivenog tijesta u trajanju od trideset minuta. Nakon toga u tijesto je dodan kvas i svi ostali sastojci. Tijesto je ručno oblikovano 5 minuta, razvlačeno podizanjem uvis i oblikovano u oblik kugle. Potom je pokriveno pamučnom krpom i ostavljeno da se odmara 30 minuta. Proces razvlačenja ponovljen je još dva puta. Potom je tijesto premješteno na podlogu posutu brašnom i oblikovano. Oblikovano tijesto je zarezano po gornjoj površini i pečeno u pećnici na 200 °C oko trideset minuta.

Tablica 1. Sirovinski sastav pojedinih uzoraka kruha
Table 1. Ingredient composition of individual bread samples

Sastojak (na 500 g brašna)	Uzorak 1 (bezglutenski kruh)	Uzorak 2 (vinski kruh)	Uzorak 3 (funkcionalni kruh)	Uzorak 4 (veganski kruh)
Bezglutenski pšenični starter (g)	150	-	-	-
Raženi starter	-	150	-	-
Integralni pšenični starter	-	-	150	-
Pšenični bijeli starter	-	-	-	150
Bezglutensko brašno	500	-	-	
Sol	10	10	10	10
Voda	350	200	350	100
Šećer	10	10	10	10
Sušene šljive	50	-	-	-
Pire od bundeve	50	-	-	-
Raženo brašno	-	400	-	-
Pšenično bijelo brašno	-	100	100	500
Maslinovo ulje	-	15	10	-
Crno vino	-	20	-	-
Integralno pšenično brašno	-	-	400	-
Nesoljeni prženi kikiriki	-	-	50	-
češnjak	-	-	5	-
Mješavina chia, sezamovih i lanenih sjemenki	-	-	50	-
Sojino mlijeko	-	-	-	250
Suncokretovo ulje	-	-	-	20
Chia sjemenke	-	-	-	50

Legenda: - (ne sadrži)

Slike 1 i 2 prikazuju pripremljene uzorke kruha neposredno nakon pečenja**.**

Slika 1. Pečeni kruh, uzorak 1
Figure 1. Baked bread, sample 1

Slika 2. Pečeni kruh, uzorak 2, 3 i 4
Figure 2. Baked bread, sample 2,3,4

Senzorsko ocjenjivanje kruha

Za provođenje senzorskog ocjenjivanja sačinjen je obrazac s pitanjima koji je činio kombinaciju hedonističkog testa, deskriptivne analize i testa potrošačke preferencije. Senzorsko ocjenjivanje kruha provedeno je s ciljem procjene kvalitete različitih uzoraka iz perspektive potrošača, odnosno krajnjih korisnika. Ocjenjivanje je omogućilo prikupljanje ocjena o osnovnim organoleptičkim svojstvima (izgled, tekstura, miris, okus), kao i informaciju o preferencijama ispitanika u pogledu prihvatljivosti i spremnosti za kupnju kušanih uzoraka. Takva analiza pružila je uvid u potencijal tržišne konkurentnosti proizvoda, ali i mogućnosti za unaprjeđenje receptura i procesa proizvodnje. Tijekom ispitivanja, svaki sudionik je dobio obrazac za senzorsko ocjenjivanje te po jedan komadić svakog od četiri uzorka kruha (Slika 3).

Slika 3. Uzorci za senzorsko ocjenjivanje
Figure 3. Samples for sensory evaluation

Ocjenjivački panel sastojao se od 17 obučenih senzoričara. Panel su sačinjavali senzoričari u dobi od 21 do 45 godina, od čega su bila 4 muškarca i 13 žena. Ocjenjivački listić je sadržavao 12 pitanja, podijeljenih u nekoliko tematskih cjelina.

Pitanja 1 – 6 odnosila su se na ocjenjivanje senzorskih svojstava: vanjskog izgleda, izgleda sredine, teksture, mirisa, okusa i ukupnog dojma. Svako svojstvo ocjenjivalo se za svaki uzorak zasebno. Pri ocjenjivanju svojstava 1 do 6. Senzorska procjena provedena je primjenom ordinalne skale od 1 do 5. Niže vrijednosti ukazivale su na slabiju, a više na bolju ocjenu analiziranog atributa. Pitanje 7 tražilo je od ocjenjivača da prepoznaju i navedu koji okus prevladava u svakom uzorku. Pitanje 8 odnosilo se na spremnost ispitanika da uvrste kušani kruh u svoju svakodnevnu prehranu, odgovorom "da" ili "ne". Pitanje 9 omogućilo je slobodne primjedbe, dok su pitanja 10 i 11 bila usmjerena na isticanje jednog pozitivnog svojstva i jednog uočenog nedostatka za svaki kruh. Pitanje 12 odnosilo se na procjenu tržišne vrijednosti ocjenjivanog uzorka kruha. Sudionici su trebali navesti koliku bi cijenu (u eurima) bili spremni platiti za 500 g pojedinog kruha. Cilj ovakvog pristupa senzorskoj analizi bio je identificiranje najprihvatljivijeg uzorka prema preferencijama senzoričara i procjena potencijala proizvoda na tržištu s obzirom na očekivanu cijenu i percepciju kvalitete.

Statistička obrada podataka

Kako bi se utvrdilo postoje li statistički značajne razlike u svojstvima različitih uzoraka, korištena je najprije jednostruka ANOVA na razini od 95 %, pomoću programa Microsoft Excel (Microsoft Corporation, SAD). Nakon toga proveden je LSD test kojim su identificirane parne razlike između uzoraka. U slučajevima kada jednofaktorijalnom analizom varijance nije utvrđena statistički značajna razlika među uzorcima, također je pristupljeno LSD testu u eksplorativne svrhe kako bi se utvrdile moguće razlike između pojedinih parova.

REZULTATI I DISKUSIJA

Prikazani rezultati predstavljaju srednje vrijednosti ocjena dobivenih od svih sudionika, čime se osigurava reprezentativnost i pouzdanost evaluacije. Rezultati senzorskog ocjenjivanja na prvih 6 postavljenih pitanja prikazani u tablici 2. Iz rezultata je vidljivo da su među ispitivanim uzorcima kruha postojale izražene razlike u svim ocjenjivanim svojstvima.

Tablica 2. Prosječne ocjene svojstva (1-6)
Table 2. Average scores for properties (1–6)

Kruh	Vanjski izgled	Izgled sredine	Tekstura	Miris	Okus	Ukupni dojam
uzorak 1	$4,41^{a}\pm0,71$	$4,24^{a}\pm0,83$	$3,88^{a}\pm0,78$	$3,76^{a}\pm0,83$	$3,47^{a}\pm0,72$	$3,82^{a}\pm0,64$
uzorak 2	$4,53^{ab}\pm0,62$	$4,53^{ab}\pm0,62$	$4,77^{b}\pm0,72$	$3,94^{a}\pm1,09$	$4,18^{b}\pm0,88$	$4,29^{b}\pm0,69$
uzorak 3	$4,65^{ab}\pm0,61$	$4,64^{ab}\pm0,61$	$4,41^{b}\pm0,71$	$4,06^{a}\pm0,66$	$3,88^{ab}\pm0,86$	$4,35^{b}\pm0,79$
uzorak 4	$4,88^{b}\pm0,33$	$4,82^{b}\pm0,39$	$4,71^{b}\pm0,59$	$4,24^{a}\pm0,83$	$4,41^{b}\pm0,71$	$4,71^{b}\pm0,47$

Rezultati su izraženi kao srednja vrijednost ± standardna devijacija
Srednje vrijednosti označene istim slovom unutar iste kolone nisu statistički značajno različite pri razini značajnosti od 5 %

Najviše ukupne ocjene u gotovo svim analiziranim kategorijama (vanjski izgled, izgled sredine, tekstura, miris, okus, ukupni dojam) postigao je uzorak 4 (veganski kruh), dok je uzorak 1 (bezglutenski kruh) sustavno ocjenjivan najniže. Ovi rezultati potvrđuju visoku senzorsku prihvatljivost veganskog kruha te ukazuju na izazove povezane s formulacijom bezglutenskih proizvoda. S obzirom na ocjenjivana senzorska svojstva, dominantna je prihvaćenost veganskog kruha. Veganski kruh (uzorak 4) ostvario je najviše ocjene u svim kategorijama senzorskog ocjenjivanja. Ocjena vanjskog izgleda (4,88) i izgleda sredine (4,82) sugerira dobar vizualni dojam, ujednačen oblik i atraktivan izgled kore. Slično, tekstura je ocijenjena vrlo visoko (4,71), što ukazuje na uspješnu formulaciju recepture kojom je postignuta dobra mekoća i elastičnost, bez gubitka strukture. Ovi rezultati su u skladu su s istraživanjem Iwamura i sur. (2022), koji su dokazali da kombinacije biljnih brašna i biljnih mlijeka doprinose boljoj teksturi i vizualnoj privlačnosti kruhova bez sastojaka životinjskog podrijetla. Autori naglašavaju da upravo sinergija alternativnih sastojaka može dovesti do proizvoda s uravnoteženim senzorskim profilom, što potvrđuju i rezultati ovoga istraživanja. Neutralan aromatski profil uzorka 4, u kojem nisu prepoznate specifične arome sojinog mlijeka, dodatno je povećao njegovu prihvatljivost među ispitanicima. Ova neutralnost, prema Irigoytia i sur. (2023), često doprinosi univerzalnoj prihvaćenosti proizvoda, osobito među potrošačima bez specifičnih prehrambenih ograničenja. Samo kreiranje recepture za bezglutenski kruh predstavlja izazov u postizanju zadovoljavajuće teksture i prihvatljivosti okusa. Iz rezultata je vidljivo da je bezglutenski kruh (uzorak 1) postigao najniže ocjene u svim kategorijama, osobito za teksturu (3,88), miris i ukupni dojam (3,82). Ovi rezultati ukazuju na nepovoljnu strukturu kruha, što je čest problem u bezglutenskim formulacijama. Kao što navode Breshears i Crowe (2013), proizvodi bez glutena često imaju smanjenu elastičnosti, povećanu mrvljivost sredine kruha i slabije prihvaćene arome, ako sastav i tehnološki postupci nisu precizno optimizirani. U ovom slučaju korištena je gotova bezglutenska mješavina, vjerojatno na bazi rižinog i sojinog brašna, no bez poznatih omjera. Prema Sciarini i sur. (2010) i Dennis i sur. (2025), dodatak do 10% sojinog brašna u rižino brašno poboljšava volumen, teksturu i okus, dok veći udjeli narušavaju senzorska svojstva. Moguće je da je korištena mješavina sadržavala nepovoljan omjer, što je rezultiralo lošijom ocjenom teksture i izraženijim okusom soli, unatoč identičnoj količini soli u svim recepturama. Dodatni čimbenici, poput dodatka sušenih šljiva i pirea od bundeve, mogli su neočekivano pojačati slanost i kiselost. Funkcionalni kruh (uzorak 3), formuliran za snižavanje kolesterola, postigao je srednje do visoke ocjene u većini kategorija, s izraženim aromama češnjaka i kikirikija. Iako je bilo planirano da aroma kikirikija bude dominantna, većina ispitanika nije ju prepoznala, niti je navela češnjak kao smetnju okusu. Međutim, određena neskladnost aroma može biti razlog zašto ukupna prihvatljivost nije bila jednaka onoj za veganski kruh. Prema Gillespie i sur. (2021), ravnoteža funkcionalnosti i senzorske privlačnosti ključna je za prihvaćanje funkcionalnih proizvoda. Stoga bi buduće recepture trebale uključiti strategije usklađivanja aromatskog profila, bez gubitka nutritivne vrijednosti. Uzorak 2 (vinski kruh) također je dobio relativno dobre ocjene, dok aroma vina nije bila prepoznata.

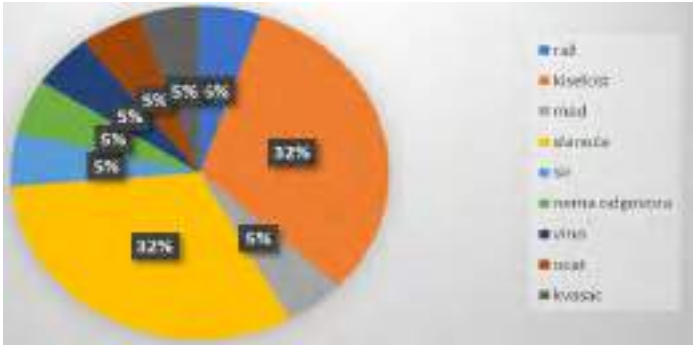
To ukazuje na potrebu za optimizacijom količine i vrste vina ili drugih sastojaka u recepturi. S obzirom na rezultate Yu i sur. (2021) i El Khoury i sur. (2011), koji ističu da dodatak određenih brašna (npr. ječmenog) može poboljšati senzorska svojstva i nutritivni profil, moguće je dodatno unaprijediti ovaj kruh bez gubitka prihvatljivosti.
Statistički značajna razlika među uzorcima utvrđena je za slijedeća svojstva: tekstura ($p=0,0028$), okus ($p=0,0070$) i ukupni dojam ($p=0,0094$). Iako je u vanjskom izgledu i izgledu sredine LSD testom utvrđena određena razlika između uzorka 1 i uzorka 4, dobiveni rezultati se ne mogu smatrati statistički značajnima već ih se tumači samo kao analizu trenda pri čemu uzorak 4 ima bolje ocjenjena navedena svojstva od uzorka 1. Rezultati pokazuju da se ocjene vanjskog izgleda kreću između 4,41 i 4,88. Uzorak 4 ostvario je statistički značajno višu ocjenu u usporedbi s uzorkom 1, dok su uzorci 2 i 3 zauzeli međupoložaje te nisu pokazali jasne razlike ni u odnosu na najniže ni u odnosu na najviše ocijenjeni uzorak. Ovakav rezultat upućuje na to da se većina uzoraka ne razlikuje bitno prema vizualnoj prihvatljivosti, s izuzetkom najnižeg i najvišeg ocijenjenog uzorka. Svojstvo izgleda sredine pokazalo je sličan obrazac kao i vanjski izgled. Uzorak 4 imao je najvišu prosječnu ocjenu, dok je uzorak 1 ostvario najslabiji rezultat. Uzorci 2 i 3 podijelili su međupoložaje te nisu pokazali statistički značajne razlike ni prema uzorku 1 ni prema uzorku 4. Ovi nalazi sugeriraju da je upravo formulacija ili tehnološka obrada primijenjena u uzorku 4 dovela do najpovoljnijih svojstava presjeka kruha.
Svojstvo teksture istaknulo se kao jedno od parametara s najizraženijim razlikama. Uzorak 1 imao je statistički značajno niže ocjene teksture u odnosu na ostale uzorke, dok se između uzoraka 2, 3 i 4 nije utvrdila značajna razlika. Visoke ocjene teksture kod uzoraka 2 i 4 ukazuju na to da primijenjene formulacije ili tehnike izrade doprinose boljim mehaničkim svojstvima kruha, poput mekoće, elastičnosti i homogenosti. Za svojstvo mirisa ANOVA nije utvrdila statistički značajne razlike među uzorcima. Prosječne ocjene kretale su se od 3,76 do 4,24, što upućuje na relativno ujednačenu aromatsku kvalitetu ispitivanih uzoraka. Iako su rezultati LSD testa korišteni u eksplorativne svrhe ukazali na numerički nešto višu ocjenu uzorka 4, takve razlike nisu statistički pouzdane i stoga se ne mogu interpretirati kao relevantne. Kod svojstva okusa uočene su jasnije razlike. Uzorci 2 i 4 imali su statistički značajno više ocjene u odnosu na uzorak 1, dok je uzorak 3 zauzeo međupoložaj te se nije značajno razlikovao ni od jedne skupine. Rezultati sugeriraju da formulacije primijenjene u uzorcima 2 i 4 doprinose povoljnijim okusnim svojstvima kruha, što se odrazilo i na njihove više senzorničke ocjene. Ukupni dojam slijedio je obrazac sličan teksturi i okusu. Uzorak 1 imao je najnižu ocjenu, dok su uzorci 2, 3 i 4 ostvarili statistički značajno više vrijednosti. Najvišu ocjenu ukupnog dojma postigao je uzorak 4, što dodatno potvrđuje njegovu generalno najveću senzorsku prihvatljivost unutar ispitivanog seta uzoraka.
Analiza spremnosti na uključivanje u prehranu (Tablica 3) pokazuje jasnu preferenciju za uzorak 4. Veganski kruh (uzorak 4) čak 94,12 % ispitanika bilo bi spremno uključiti u svoju prehranu. Suprotno tome, samo 29,41 % ispitanika izjavilo je isto za bezglutenski kruh. Ovaj rezultat dodatno potvrđuje lošu senzorsku prihvaćenost uzorka 1 te njegovu nižu procijenjenu tržišnu vrijednost (0,97 €) (Tablica 4).

Tablica 3. Interes uvođenje uzorka kruha u prehranu
Table 3. Interest in introducing the bread sample into the diet

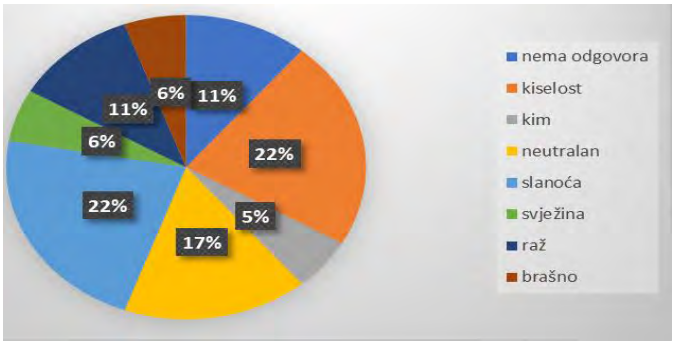
Uzorak	Odgovor: Da (%)
1	29,41
2	76,47
3	70,59
4	94,12

Slično zapažanje iznosi Irigoytia i sur. (2023), u kom navode da potrošači često percipiraju bezglutenske proizvode kao manje vrijedne, osobito ako nisu informirani o njihovim zdravstvenim prednostima. U tom smislu, rezultati ovog istraživanja također ukazuju na važnost edukacije potrošača, jer je poznato da informiranost o funkcionalnim svojstvima prehrambenih proizvoda može pozitivno utjecati na prihvatljivost (Gillespie i sur. 2021). Analiza komentara ispitanika potvrđuje kvantitativno dobivene rezultate. Bezglutenski kruh (uzorak 1) dobio je najviše negativnih primjedbi, što upućuje na potrebu za izmjenom recepture. Uzorak 4 nije imao značajnijih nedostataka, dok su uzorci 2 i 3 prepoznati kao proizvodi s potencijalom za daljnji razvoj, posebice u pogledu nutritivne optimizacije i poboljšanja aromatskog profila.

Prema rezultatima istraživanja (slika 4) na okuse koji prevladavaju, utvrđeno je da uzorak 1 ima najintezivniji okus soli. Dodatak soli je bio jednak u svim recepturama pojedinačnih uzoraka. Razlog tome je najvjerojatnije dodatak sušenih šljiva i pirea od bundeve koji su pojačali okus slanoće i kiselosti. Pri tome intenzitet slanosti je prikrio aromu bundeve i šljive.

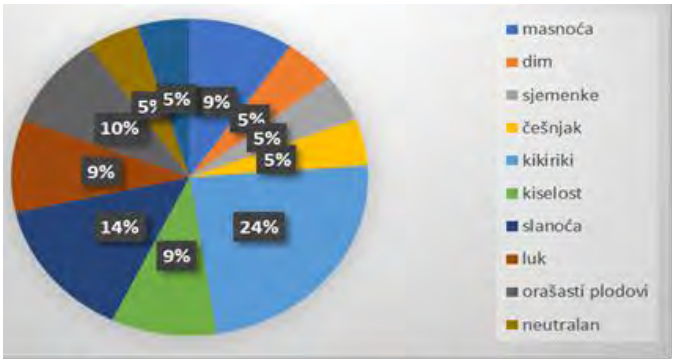


Slika 4. Okusi koji prevladavaju u uzorku 1 (bezglutenski kruh)
Figure 4. Dominant flavours detected in sample 1 (gluten-free bread)



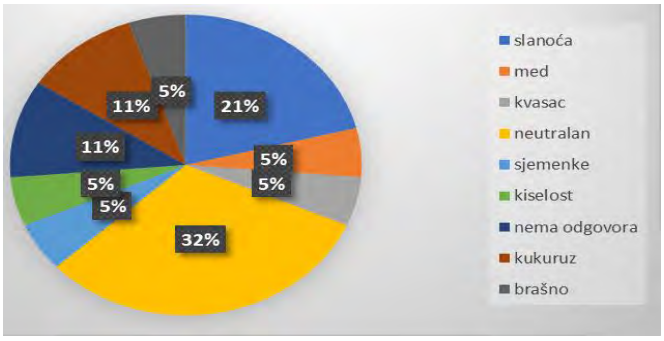
Slika 5. Okusi koji prevladavaju u uzorku 2 (vinski kruh)
Figure 5. Dominant flavours detected in sample 2 (wine bread)

Iz rezultata (slika 5) vidljivo je da je slanost najizraženiji okus, dok ključna aroma vina nije prepoznata. Povećanje udjela vina zahtijevalo bi promjenu omjera raženog i pšeničnog brašna. Ukoliko bi se povećao udio crnog vina, trebala bi se povećati i količina pšeničnog brašana. Moguće je zamijeniti raženo brašno s ječmenim, kokosovim ili brašnom od kukuruznih mekinja, te time poboljšati okus i nutritivna svojstva kruha (Yo i sur., 2021).
U uzorku 3 senzoričari su prepoznali ključne arome češnjaka i kikirikija (slika 6). Prema planu u originalnoj recepturi aroma češnjaka je trebala biti prikrivena aromom kikirikija. Usprkos visokoj količini kikirikija, 5% ispitanika još uvijek prepoznaje češnjak. Ovaj problem ne može se riješiti povećanjem udjela kikirikija zbog njegove visoke energetske vrijednosti. Bilo bi bolje uvrstiti novi sastojak u recepturu koji bi prekrio aromu češnjaka. Svi korišteni sastojci spuštaju razinu kolesterola. Resveratrol sadržan u kikirikiju povoljno utječe na bolesti kardiovaskularnog sustava (Poliklinika analiza, url). Češnjak stimulira imunološki sustav, ima antikancerogeno djelovanje te čisti krvne žile (Rahman i Lowe, 2006). Maslinovo ulje sadrži oleinske masne kiseline koje smanjuju razinu LDL kolesterola u krvi (Harvard Health Publishing, url). Korišteno je integralno pšenično brašno i mješavina chia, sezamovih i lanenih sjemenki zbog povećanja nutritivne vrijednosti. Naime, prema navodima Bourre i sur. (2008) samo kruh od žitarica i sjemenki osigurava značajne količine lipida (3,9 g/100 g), što se pripisuje udjelu lipida u pojedinim sastojcima, a posebnu prehrambenu vrijednost doprinosi prisutnost omega-3 masnih kiselina (0,44 g/100 g), čime bi se ispunio uvjet za navođenje tvrdnje 'izvor omega-3 masnih kiselina' za kruh.



Slika 6. Okusi koji prevladavaju u uzorku 3 (kruh za smanjenje kolesterola)
Figure 6. Dominant flavours detected in sample 3 (cholesterol-lowering bread)

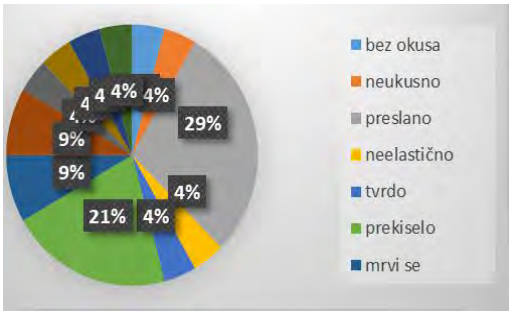
U uzorku 4 (veganski kruh) senzoričari nisu prepoznali ključne arome sojinog mlijeka (slika 7). Ključni dio recepture veganskog kruha je nekorištenje sastojaka životinjskog podrijetla. Prema smjernicama za jednostavan kruh po uzoru na mliječne kruhove, korišteno je sojino mlijeko umjesto kravljeg mlijeka. Još jedna prednost korištenja sojinog mlijeka je izbacivanje laktoze iz kruha što ga čini pogodnim intolerantnim osobama.
Senzoričari pokazuju interes za uvrštavanjem uzoraka 2, 3 i 4 (tablica 3) u svakodnevnu prehranu. Najzadovoljniji su veganskim kruhom (uzorak 4) usprkos nedostatka aroma što vodi do zaključka kako aromatična neutralnost igra veliku ulogu u kvaliteti kruha. Važno je istaknuti kako senzoričari nisu informirani o funkcionalnim ulogama uzoraka što bi inače moglo utjecati na ocjene.



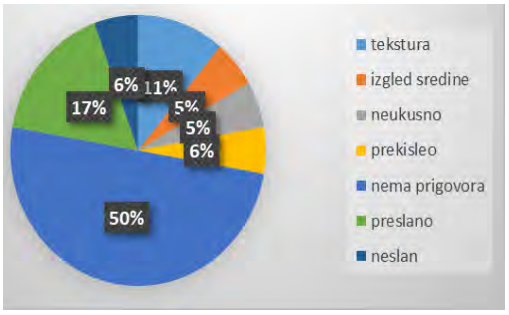
Slika 7. Okusi koji prevladavaju u uzorku 4
Figure 7. Dominant flavours detected in sample 4 (vegan bread)

Na slikama 8 - 11 prikazane su primjedbe senzoričara na ocjenjivane uzorke. Za bezglutenski kruh (uzorak 1) senzoričari navode loš okus i lošiji (unutarnji i vanjski) izgled u usporedbi s drugim uzorcima. Na temelju primjedbi za uzorak 3, smanjenjem udjela nekih sastojaka iz recepture kao što su mješavine sjemenki i maslinovo ulje umanjio bi se i okus masnoće kruha.

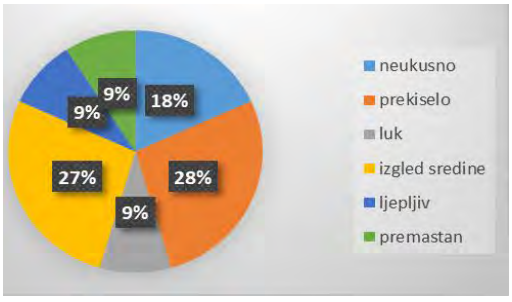
Također, mijenjanje vrste brašna ili omjera korištenih brašna mogla bi se poboljšati iz tekstura kruha. Uzorci 2 i 4 ne bilježe prigovore dovoljno značajne za promjenu recepture.



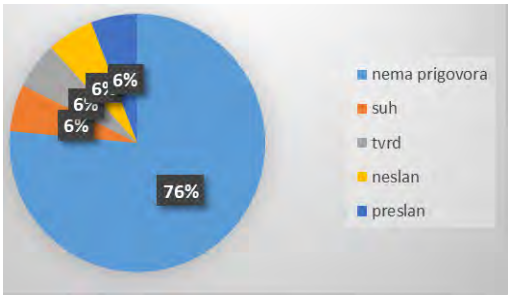
Slika 8. Primjedbe na uzorak 1
Figure 8. Comments on sample 1



Slika 9. Primjedbe na uzorak 2
Figure 9. Comments on sample 2

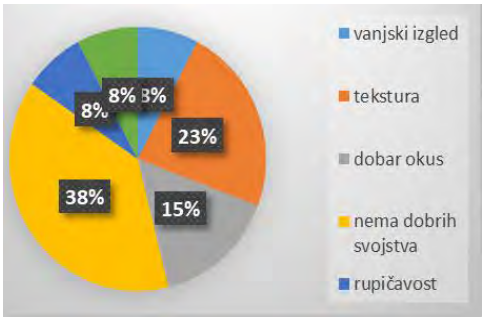


Slika 10. Primjedbe na uzorak 3
Figure 10. Comments on sample 3

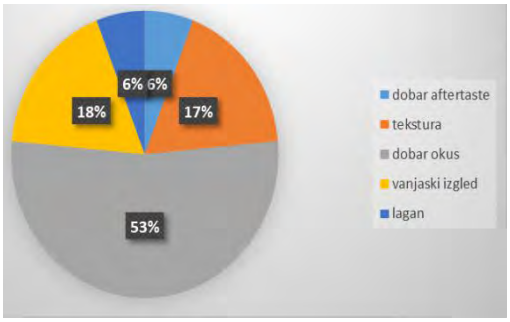


Slika 11. Primjedbe na uzorak 4
Figure 11. Comments on sample 4

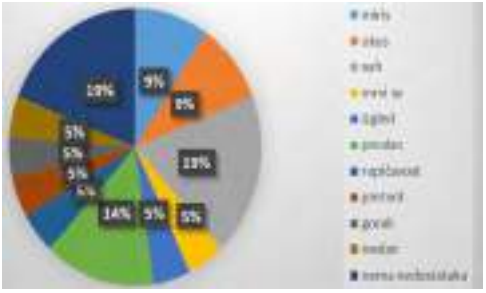
Slike 12 - 15 prikazuju rezultate dobrih svojstva za svaki uzorak. Prema dobivenim rezultatima, bezglutenskom kruhu (uzorak 1) bilo bi poželjno izmijeniti recepturu zbog velike zastupljenosti negativnih mišljenja senzoričara pri čemu bi trebalo zadržati poželjna svojstva kruha. Za uzorak 3, izgled sredine i rupičavost nisu prepoznati kao dobra svojstva, ali senzoričari su zadovoljni okusom kruha zbog čega se smatra kako prekrivanje ili uklanjanje arome češnjaka nije nužno. Fokus treba biti na popravku izgleda sredine s obzirom na procjenu senzoričara i već utvrđenu potrebu za zamjenu izabranih sastojaka čime se također može unaprijediti izgled sredine. Uzorak 2 sadrži specifična svojstva poput mekoće i elastičnosti čime se dovodi u pitanje poboljšanje svojstava kruha eliminiranjem raženog brašna. Izjednačavanje omjera raženog i pšeničnog brašna omogućilo bi i povećanje udjela crnog vina u recepturi. Ugodan „aftertaste“ je svojstvo prepoznato u uzorku 4. S obzirom na procjene senzoričara smatra se da se receptura uzorka ne treba mijenjati.



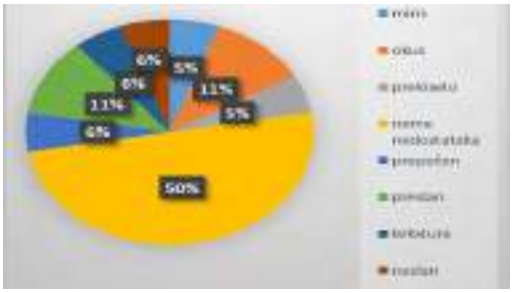
Slika 12. Dobra svojstva uzorka 1
Figure 12. Positive attributes of sample 1



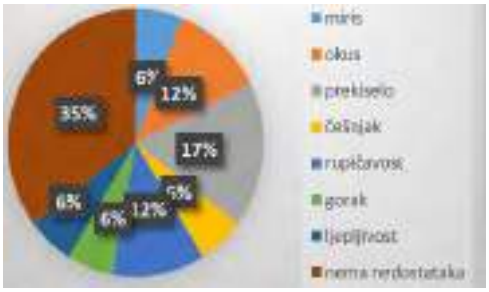
Slika13. Dobra svojstva uzorka 2
Figure 13. Positive attributes of sample 2



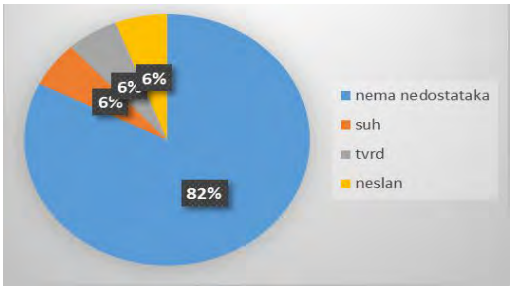
Slika 16. Nedostatci uzorka 1
Figure 16. Negative attributes of sample 1



Slika 17. Nedostatci uzorka 2
Figure 17. Negative attributes of sample 2



Slika 18. Nedostatci uzorka 3
Figure 18. Negative attributes of sample 3



Slika 19. Nedostatci uzorka 4
Figure 19. Negative attributes of sample 4

Slikama 16 - 19 prikazuju se rezultati koji se odnose na nedostatke ocjenjivanih uzoraka. Uočeni nedostaci su bitan podatak za daljnji rad na razvoju pojedine vrste kruha, naročito lošije ocijenjenih. Kao što je prethodno utvrđeno, uzorak 1 lošije je ocijenjen u odnosu na ostale uzorke. Navedeni nedostatci ne daju dovoljno novih informacija koje bi ukazivale na potrebnu izmjenu recepture. Kod uzorka 3 uočljiv je nedostatak vezan uz izgled i svojstva sredine kruha.

Na kraju ocjenjivačkog obrasca od ocjenjivača se tražilo da procijene koliko bi bili spremni platiti za 500 g svakog od ocjenjivanih uzorka kruha (tablica 4). Njihovi odgovori uspoređeni s cijenama kruhova od kiselog tijesta na tržištu.

Tržišni kruhovi prodaju se u trgovačkom centru, a riječ je o tržišnoj cijeni 1 - Kruh Sourdough Foca maslinovo ulje, 1,10 euro i tržišnoj cijeni 2 - Medit. pšenič. polub., a tržišna cijena mu je 1 euro. Cijene kruhova na tržištu nisu pokazane senzoričarima tijekom rješavanja navedenog zadatka. Najniža prosječna cijena za koju bi senzoričari kupili kruh od 500 g dodijeljena je uzorku 1, a iznosila je 0.97 eura, a najviša uzorku 3 od 1,28 eura. Uspoređujući ponuđene cijene za uzorke kruha s tržišnim cijenama, može se reći da senzoričari procjenjuju financijsku vrijednost uzorka 1 nižom od ostalih uzoraka i tržišne ponude. Cijene ostalih uzoraka kruha su podjednake s onima na tržištu.

Tablica 4. Usporedba cijena kušanih uzoraka sa dva kruha na tržištu
Table 4. Price comparison between the tasted samples and two commercially available breads

	prosječna cijena (euro)	odstupanje od tržišne cijene 1, (1,10 euro)	odstupanje od tržišne cijene 2 (1,00 euro)
uzorak 1	0,97 (min. 0,5; max.1,1)	- 0,13	- 0,03
uzorak 2	1,14 (min. 0,8; max.1,2)	0,04	0,14
uzorak 3	1,28 (min. 1,0; max.1,3)	0,18	0,28
uzorak 4	1,19 (min. 0,9; max.1,3)	0,09	0,19

ZAKLJUČAK

Razvijene recepture za četiri vrste kruha ocijenjene su s posebnim naglaskom na senzorsku prihvatljivost krajnjih proizvoda. Senzorska evaluacija pokazala se kao ključna metoda za identifikaciju prednosti i ograničenja pojedinih formulacija, omogućujući sustavnu procjenu uspješnosti razvoja proizvoda. Provedena senzorska analiza omogućila je cjelovit uvid u prihvatljivost različitih uzoraka kruha te je pokazala da se pojedina senzorska svojstva statistički značajno razlikuju među uzorcima. Najbolje ocijenjen bio je uzorak 4, koji je u većini ispitivanih parametara, osobito u teksturi, okusu i ukupnom dojmu, ostvario statistički značajno više vrijednosti u odnosu na ostale uzorke, a posebno u odnosu na uzorak 1. Također rezultati procjene spremnosti na plaćanje pokazuju da senzoričari uzorak 1 vrednuju znatno niže od ostalih kruhova i od tržišnih cijena sličnih proizvoda. Veganski kruh (uzorak 4) postigao je najviše ocjene u svim analiziranim kategorijama, što ukazuje na uravnotežen sastav koji zadovoljava očekivanja potrošača u pogledu izgleda, teksture i okusa. Nasuprot tome, bezglutenski kruh (uzorak 1) ostvario je najslabije rezultate, osobito u segmentima teksture i ukupnog dojma, što upućuje na potrebu za optimizacijom recepture i mogućim prilagodbama tehnološkog procesa.Funkcionalni kruh (uzorak 3) i vinski kruh (uzorak 2) pokazali su određeni potencijal, no rezultati sugeriraju potrebu za dodatnim unaprjeđenjima, osobito u pogledu aromatskog profila i ravnoteže sastojaka, kako bi se povećala njihova

prihvatljivost. Najizraženije razlike među uzorcima zabilježene su u svojstvima teksture, okusa i ukupnog dojma, dok je miris bio najmanje diferenciran, što upućuje na to da su aromatska svojstva među uzorcima bila relativno ujednačena. Rezultati ukazuju da su određene tehnološke modifikacije ili sastojci imali značajan utjecaj na ukupnu senzorsku kvalitetu kruha, pri čemu se uzorak 4 istaknuo kao najprihvatljiviji. Te je bio najmanje diferenciran, što upućuje na to da su aromatska svojstva među uzorcima bila relativno ujednačena. Rezultati ukazuju da su određene tehnološke modifikacije ili sastojci imali značajan utjecaj na ukupnu senzorsku kvalitetu kruha, pri čemu se uzorak 4 (veganski kruh) istaknuo kao najprihvatljiviji. U cjelini, dobiveni nalazi potvrđuju da se optimizacijom formulacije i procesa proizvodnje može postići značajno poboljšanje senzorskih svojstava kruha, čime se osigurava viša razina potrošačke prihvatljivosti. Ovo istraživanje naglašava važnost holističkog pristupa u razvoju funkcionalnih i specijaliziranih kruhova, gdje se osim nutritivne vrijednosti mora voditi računa i o senzorskoj kvaliteti, kako bi proizvod bio konkurentan i prihvaćen na tržištu.

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DEVELOPMENT AND SENSORY EVALUATION OF FUNCTIONAL AND SPECIALTY BREADS

Abstract

Throughout human history, bread has been one of the main staple food products. It is nutritionally rich in energy, vitamins, and dietary fiber, and the use of sourdough enhances the bioavailability of phytochemicals. A key component of bread is gluten, which contributes to the stability, appearance, and flavor of the final product.

Today, it is possible to produce gluten-free bread, thus enabling its consumption by individuals with gluten intolerance or allergy. This study investigates the sensory acceptability of four sourdough-based bread samples. The breads were prepared according to original recipes designed to enhance their nutritional value. One of the formulations was developed specifically as a gluten-free bread. A sensory analysis was conducted involving a total of 17 trained panelists. The lowest ratings were given to the gluten-free bread, while the highest ratings were awarded to the vegan bread. Based on the results, it was concluded that recipe modifications are necessary for all bread samples except the vegan one. For the gluten-free and wine-enriched bread, the type of flour used should be reconsidered. In the case of the whole grain bread, recipe adjustments are needed to improve crumb structure.
Additionally, panelists assessed the estimated market value of the tested breads, and their evaluations aligned with the actual prices of similar commercial products.

Keywords: *bread, sourdough, sensory analysis, nutritional value*

SUDŽUKA FROM ARTISAN PRODUCERS IN BOSNIA AND HERZEGOVINA: CHEMICAL COMPOSITION, STABILITY AND SENSORY QUALITY

Sabina Operta*[1], Melisa Begić[1], Alma Džigal[1], Jasmina Tahmaz[1]

Original scientific paper

Abstract

Sudžuka is a traditional dry fermented sausage that holds a significant place in the diet and culinary tradition of Bosnia and Herzegovina. The aim of this study was to evaluate the physicochemical and sensory characteristics of domestic sudžuka samples produced in various artisan workshops and butcher shops across Bosnia and Herzegovina, and to determine the degree of their homogeneity and mutual similarity. Analysis results showed statistically significant differences between samples in all tested parameters, indicating heterogeneity in chemical composition and sensory quality of sudžuka. The greatest variations were recorded in water content (20.12–44.62%), fat content (22.18–36.37%), then in protein content (21.01–30.97%), while somewhat smaller variations were recorded in ash content (4.50–7.10%) and salt content (3.44–5.96%). Water activity varied from 0.792 to 0.886, and pH value from 4.35 to 5.03. Sensory quality analysis showed that no sample reached the extra class, only one sample belonged to class I, five samples to class II, eleven samples to class III, while four samples were below standard, i.e., unsuitable for the market. PCA analysis identified three clusters, emphasizing that quality variations arise from differences in recipes, raw materials, and technological processes of fermentation and drying. The obtained results indicate the need for standardization of recipes and production processes, control of fat and salt content, optimization of fermentation and drying, and education of producers, with the aim of improving uniformity, nutritional value, and sensory quality of sudžuka. The combination of chemical, sensory, and multivariate analyses proved effective for objective evaluation of traditional fermented products.

Keywords: *sudžuka, physicochemical parameters, sensory quality, fermented sausages, Bosnia and Herzegovina*

INTRODUCTION

Sudžuk produced in artisan workshops and butcher shops often carries the derivative name "sudžuka." It most commonly appears as a secondary product after forming (cutting) pieces of beef, which are sold as dry beef, beef roast, or beef prosciutto.

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The scraps, i.e., meat trimmings, are minced, mixed with salt, garlic, and black pepper, and after stuffing into thin beef casings, are dried and smoked in drying chambers (Operta, 2011). The production process is not controlled, which results in variations in the quality of the finished product. While in industrial production of fermented sausages in developed countries, strictly controlled fermentation, drying, and ripening procedures are applied, artisan production in the Balkans often relies only on the producer's experience.

According to the Rulebook on Minced Meat, Semi–products and Meat Products (82/2013), sudžuk belongs to the group of dry, durable fermented sausages, with clearly defined chemical parameters – maximum 40% water and minimum 16% total meat proteins in the finished product.

Previous research has indicated that "sudžuka" as an artisan variant of the "sudžuk" sausage, although widespread, is rarely the subject of systematic quality research. The physicochemical properties of similar sudžuk-type sausages have been studied by numerous authors: Čaušević *et al.* (1985), Tupajić (1991), Gajić (2000), Hadžiosmanović *et al.* (2005), Gasparik–Reichardt *et al.* (2005), Kozačinski *et al.* (2008), Operta *et al.* (2008), Operta (2008, 2018), Operta & Smajić (2012), Bešić (2013), Alić (2019), Muslić (2020), Trgo (2022), etc. Their work indicates great variability in chemical composition, especially regarding water content (22–44%), protein (18–32%), fat (23–42%), and various values of ash, NaCl, pH, and aw values, which is associated with differences in raw material composition, recipes, and duration of fermentation and drying. Operta (2018) additionally emphasizes that sudžuk can be divided into two categories, dry and semi-dry. Dry fermented Bosnian sudžuk should be produced from category I and/or II beef, with a maximum of 20% tallow, and the finished product should contain more than 22% total protein, less than 35% water, and have $pH \leq 5.2$. Semi-dry fermented sudžuk can be produced from beef, and the content of total meat proteins in this sudžuk must not be less than 16%, and the relative content of connective tissue proteins in total meat proteins must not be greater than 20%. Despite this research, there is still a need for deeper analysis of technological parameters and factors affecting the quality of sudžuka, especially regarding its nutritional and sensory properties.

The final quality of fermented meat products is very important and depends on many factors such as: quality of initial raw materials, ingredients and additives, fermentation conditions, drying, ripening, and packaging (Toldrá, 2006). Vuković (2001) states that for evaluating the quality of meat products in the regulations of most European countries, the following criteria are used: protein content, fat content, moisture content, ratio between components, carbohydrate content, calcium content, maximum allowed amount of additives, pH and Aw values. The nutritional and sensory quality of fermented sausages significantly depends on chemical composition, especially the proportion of fat and salt. Excessive fat content increases energy value and reduces nutritional balance, while too high a proportion of salt and unhealthy fats can negatively affect consumers' cardiovascular health (WHO, 2012).

Leroy & De Vuyst (2014) emphasize that traditional fermented sausages are often characterized by excessive fat and salt content, uncontrolled fermentation process, and insufficient uniformity of sensory properties. Toldrá (2015) points out that the nutritional and sensory aspects of these products depend on raw material composition, microbiological flora, and applied technological procedures. Sensory properties – appearance, smell, taste, and texture – largely determine product acceptability by consumers and its market placement. Homogeneity of cross-section, uniform distribution of fatty and muscular tissue, and absence of technological errors (e.g., fat smearing) represent important indicators of good manufacturing practice. Toldrá (2006) emphasizes that key quality parameters include temperature, microbiological load of raw materials, pH and water activity (aw), while sensory requirements (color, smell, taste, aroma, and consistency) represent an indispensable criterion of market acceptability. Optimal pH and aw values are particularly important as they determine microbiological safety, extended shelf life, and desirable sensory profile. The moisture:protein ratio, or MPR, according to USDA recommendations, is most commonly used in the USA for classifying dried sausages and other meat products. This ratio expresses the percentage of moisture divided by the percentage of protein. Stably stored sausages must have MPR $\leq$ 1.9:1, and semi-dry sausages MPR $\leq$ 3.1:1 with pH value $\leq$ 5.0, or be commercially sterilized (Sebranek, 2004). Quality control does not only include the finished product but also quality control during the production process (Toldrá, 2006). Quality control is essential for standardization of fermented meat products.

Based on these facts, the aim of this work was to:

- examine the chemical composition and selected stability parameters of sudžuka samples originating from artisan workshops and butcher shops from the area of Bosnia and Herzegovina,
- evaluate the sensory quality of products, and
- apply principal component analysis (PCA) to identify groupings and relationships between tested parameters.

MATERIALS AND METHODS

Materials

The research material consisted of 22 sudžuka samples produced in artisan workshops and butcher shops throughout Bosnia and Herzegovina. Physicochemical analyses and sensory quality evaluation of sudžuka samples were performed in the laboratories of the Faculty of Agriculture and Food Sciences, University of Sarajevo. All analyses were performed in triplicate.

Methods

Basic chemical parameters were analyzed: water content, fat, protein, ash, sodium chloride (NaCl), pH value, and water activity (aw).

Sensory evaluation was performed by a trained panel and included evaluations of appearance, cross-sectional appearance, smell, texture, taste, and aroma.

a) Testing of physicochemical parameters
Tests included determination of basic physicochemical quality parameters of sudžuka using standardized methods:
- water content – according to BAS ISO 1442:2007
- total meat protein content based on nitrogen content – according to Kjeldahl method (BAS ISO 937:2007)
- total fat content – according to Soxhlet method (BAS ISO 1443:2007)
- ash content – according to BAS ISO 936:2007
- NaCl content – by Mohr method (AOAC, 2000)
- water activity (aw) measurement – using aw-meter (LabSwift-aw, Novasina, Switzerland)
- pH value measurement – using pH-meter (FiveGo™ pH meter, Mettler Toledo, Switzerland)

b) Sensory quality evaluation
Sensory analysis was conducted using the scoring method according to Operta (2020), modified according to Anonymous (2008). The maximum number of points was 20, and six properties were evaluated: appearance (max. 2.0 points), cross-sectional appearance (max. 5.0 points), smell (max. 2.0 points), texture (max. 3.0 points), taste (max. 4.0 points), and aroma (max. 4.0 points). For evaluation purposes, samples were prepared under equal conditions, coded with randomly selected numbers, and served to evaluators on plastic plates, with bread and water as palate cleansers. Six trained evaluators participated in sensory evaluation, who, based on experience and knowledge, gave individual scores for each property. Based on the total number of points, sudžuka samples were classified into quality classes:
- Extra class (18.00 – 20.00 points)
- Class I (16.00 – 17.99 points)
- Class II (14.00 – 15.99 points)
- Class III (12.00 – 13.99 points)
- Below standard (< 12.00 points)

c) Statistical data processing
Obtained data were analyzed by analysis of variance (ANOVA) with significance threshold $p \leq 0.05$, while Tukey's test was applied to determine differences among individual samples. SPSS 26.0 software package (SPSS Inc., Chicago, IL, USA) was used for statistical processing. Principal component analysis (PCA) was conducted using Python programming language, and results were presented as biplot diagrams with marked variables and cluster groupings of samples.

RESULTS AND DISCUSSION

Results of physicochemical parameters of sudžuka

Analyses of basic physicochemical parameters (water, protein, fat, ash and NaCl content, pH and aw values) showed significant heterogeneity in the quality of 22 sudžuka samples from domestic artisan producers. Statistical tests (ANOVA and Tukey post hoc analysis, $p < 0.05$) confirmed the existence of multiple homogeneous groupings among samples, which are marked with numbers from 1 to 11 (Table 1).

Average water content was 30.46%, while individual samples had values up to 44.62%, and others were quite dry (20.12%). Twenty sudžuka samples met The Rulebook requirements (82/2013) regarding water content (≤ 40%), while two samples were above the permitted value. Higher water content indicates incomplete drying and potentially shorter shelf life, while lower values contribute to microbiological stability of the product. Variability in water content reflects different production practices, drying duration, meat moisture, and differences in recipes. The obtained values are comparable with literature data from other authors (Čaušević *et al*., 1985; Tupajić, 1991; Operta *et al*., 2012).

Fat content varied between 22.18% and 36.37%, with an average of 30.27%. A noticeable inverse negative correlation between fat and water content is evident, which is consistent with classical principles of dry fermented products. Such values indicate significant differences in the proportion of fatty tissue in applied recipes. The fat range (23–42%) confirms the findings of Tupajić (1991), Gajić (2000), Operta *et al*. (2008), Operta & Smajić (2012), and Operta (2018). High fat content can impair the nutritional value of the product but negatively affect sensory quality, as excessive fat often results in undesirable texture.

Average total meat protein content ranged from 21.01% to 30.97%, with a mean value of 25.23%, indicating that sudžuka is a valuable protein source. All samples met the minimum protein content prescribed by the Ruleboo k (≥16%). The moisture:protein ratio (M:PR) indicated that 21 sudžuka samples can be classified as dry (M:PR= 0.75:1 – 1.52:1), and one sample as semi-dry sausage (M:PR= 2.10:1). Protein content corresponded to the literature range of 18–32% (Trgo, 2022; Gajić, 2000).

Average ash content was between 4.50% and 7.10%, and salt 3.44%–5.96%. Ash content is consistent with the literature range (2.38–9.93%) cited by other authors (Gajić, 2000; Operta *et al*., 2008; Operta, 2008, 2018; Operta & Smajić, 2012; Trgo, 2022). Higher ash content in individual sudžuka samples could be associated with a higher proportion of salt or additives in recipes. Eight sudžuka samples had high salt content values (>5%), which can affect the occurrence of overly salty taste. Average salt content in six sudžuka samples ranged from 3.1% to 4.0% (moderately salty), and in the other eight from 4.1% to 5.0% (quite salty). Toldrá (2015) states that optimal NaCl content values for fermented products are 2.5 to 3.5%. Only two samples (with average salt content of 3.5% and 3.4%) fit these optimal salt values.

Previous studies by other authors showed a wide range of salt content in sudžuk, ranging from 1.84%–8.33% (Trgo, 2022; Operta *et al*., 2008). Excessive salt content, in addition to negatively affecting sensory experience (oversaltiness) and nutritional quality of the product, can also have health implications due to excessive sodium intake given the association of high salt intake with hypertension and cardiovascular diseases in humans (WHO, 2012).

Water activity (aw) was 0.792–0.886 (average 0.858), while pH value varied between 4.35 and 5.03, with an average of 4.64. Seventeen sudžuka samples were classified as dry sausages (Aw 0.850-0.900), while the other five samples can be classified as extremely dry sausages (Aw < 0.850). Lower pH value (4.35–4.46) in individual samples (28, 18, 2, 3) indicates more intense fermentation and better stability, while higher pH value (e.g., sample 5) may signal weaker fermentation or different microbiological activities. Lower pH value may also indicate pronounced acidity of sausages, so nine sudžuka samples were extremely acidic (pH < 4.5), 12 samples acidic (pH range 4.5 to 5.0), and only one sudžuka sample was slightly acidic (pH>5.0). Pronounced acidity can negatively affect final quality and product acceptability. Possible causes are excessive activity or improper application of starter cultures, inadequate fermentation, or excessively low temperature in initial production phases. Based on pH and aw values, most sudžuka samples were classified as dry and acidic sausages, stable for storage under ambient conditions. Aw and pH values are within the limits previously established by other authors (Gasparik - Reichardt *et al*., 2005; Kozačinski *et al*., 2008; Operta and Smajić, 2012; Operta, 2018; Bešić, 2013; Muslić, 2020; Alić, 2019; Trgo, 2022).

Results of sensory quality analysis of sudžuka

Sensory analysis included parameters: appearance, cross-sectional appearance, smell, texture, taste, and aroma, and analysis results are presented in Figure 1. Analysis of variance showed the existence of statistically significant differences ($p < 0.05$) among sudžuka samples for all sensory properties, while Tukey's test identified different groups of samples with similar scores (marked with lowercase letters on graphs). Significant separation is noticeable, such as sample number 15 which received significantly higher scores, while sample number 4 showed significantly worse results compared to most other samples.

The highest average scores were achieved for appearance and cross-sectional appearance, while the lowest values were recorded for aroma and texture. Significant defects in sudžuka samples were inhomogeneous texture and difficulty removing casing, which is contrary to Rulebook requirements (82/2013), as well as pronounced acidity and oversaltiness (confirmed by low pH value and high salt content), which further diminishes product quality. Overall sensory quality was expressed as total points and quality class. Based on total points, only one sample (number 15) was classified in class I quality, five samples belonged to class II, while 11 samples belonged to class III (Figure 2).

As many as five sudžuka samples remained below standard, and no sample reached criteria for extra class. Similar classification of sudžuka from artisan production is presented by Operta (2008). Particularly concerning is the fact that multiple samples were classified below standard, meaning they should not be present on the market at all due to unacceptable quality. These observations confirm Toldrá 's conclusions (2006; 2015) that sensory properties largely determine product acceptability in the market, while cross-section homogeneity and uniform distribution of fatty and muscular tissue reflect manufacturing practice quality.

Results of principal component analysis (PCA)

Analysis of variance results showed that the first component (PC1) as the main differentiating factor explains 45.70%, and the second component (PC2) 20.20% of variance, meaning that PCA analysis results (PC1 and PC2) explain over 65% of total variability (Figure 3).
The first component (PC1) separated samples with higher moisture content and aw values from those with higher fat, salt, ash, and pH values, indicating pronounced negative correlation between these parameters. Namely, samples with higher fat and salt content had lower water content and lower aw value. Such a relationship is expected given that increased fat and salt content reduces water holding capacity and contributes to product stability during fermentation and drying.
The second component (PC2) is dominantly associated with sensory properties (smell, taste, aroma, texture, appearance, and cross-sectional appearance), which are grouped together and have positive contribution along PC2, indicating that differences in sensory quality cannot be fully explained by chemical composition alone, but also by technological factors (duration and conditions of fermentation, type of meat, spices, and microflora).

Based on the PCA plot and conducted cluster analysis, three sample clusters can be clearly distinguished:

- Cluster 1 (samples 1,2,3,6,7,13,14,16,18,19, and 22) – samples with higher fat, salt, and ash content, with lower water content and aw values, therefore more intense flavor, often too salty and nutritionally less favorable.
- Cluster 2 (samples 4, 5, 8, 9, 15, and 20) - samples with higher water content and aw values, with somewhat lower fat and salt content, therefore milder taste and softer texture.
- Cluster 3 (samples 10, 11, 12, 17, and 21) – samples associated with better sensory quality (smell, taste, aroma, texture, and appearance), indicating more successful fermentation and drying execution.

Proteins contribute to moderate sample separation and are considered a secondary differentiating factor compared to fat, salt, and moisture.

Samples with higher protein content often have lower moisture and lower water activity, which may mean they are more intensely dried and potentially have more intense flavor, but sometimes have harder texture. Therefore, protein content is more related to technological properties than to differences in sensory perception.

While chemical parameters significantly contribute to explaining overall variability (PC1), sensory properties provide an additional dimension of differentiation (PC2), indicating the need for simultaneous consideration of both chemical and sensory parameters when assessing quality and characterizing sudžuka.

The PCA plot additionally confirms clear negative correlation between moisture and fat, while sensory properties are positioned in the PC2 direction, visually confirming their independence from chemical parameters. Samples located closer to the graph center represent products of more balanced composition and uniform sensory profile, while extreme samples (e.g., 4, 15, and 21) deviate due to high values of individual components and may be candidates for recipe correction.

PCA analysis results of physicochemical properties in this study show a similar pattern as in Faria *et al*. (2024) for Portuguese sausages "chouriça de carne."

It should finally be emphasized that the obtained results clearly show that artisan production of sudžuka in Bosnia and Herzegovina is characterized by significant quality heterogeneity, with part of the products not meeting basic quality and acceptability regulations. The great variability in chemical and physical composition of analyzed samples can be explained by a combination of several factors.

First, samples were collected from different producers, which implies differences in raw materials, including type and quality of meat, fat content, water content, and animal age.

Second, the method of sudžuka preparation, including addition of salt, spices, and potential fermentation cultures, can vary from producer to producer, and even between different batches of the same production.

Third, the duration and conditions of fermentation and drying, temperature and environmental humidity, which directly affect water loss and fat and protein concentration, were not known for analyzed samples, which additionally contributes to heterogeneity.

Fourth, different amounts of added salt affect pH and aw values, and thus microbiological stability and final chemical composition.

With the aim of contributing to quality, i.e., achieving more consistent and safer sudžuka, recommendations for quality improvement would be: stricter raw material quality control, meat cooling control, reduction of fat and salt proportion in recipes, standardization of production procedures, with emphasis on fermentation and drying, and producer education.

Ultimately, combining chemical, sensory, and multivariate analyses (PCA) proved to be an effective approach for objective quality assessment of traditional fermented sausages and identification of parameters that most contribute to differences among samples.

Table 1. Physicochemical Characteristics of Sudžuka (Average Values)

Samples	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	NaCl (%)	Aw	pH
1	31,86±1,02 (5-8)	28,94±0,21 (3,4,5)	25,85±0,21 (5-8)	5,49±0,08 (4,5)	4,40±0,17 (5,6,7)	0,865±0,004 (6-8)	4,46±0,06 (2,3)
2	30,56±0,99 (5-8)	30,38±0,16 (3,4,5)	23,20±0,25 (3)	5,63±0,04 (5)	4,63±0,05 (7,8,9)	0,875±0,005 (8-11)	4,41±0,03 (1,2)
3	33,30±0,71 (7,8)	31,31±0,16 (4,5,6)	27,94±0,11 (9)	4,50±0,01 (1)	3,44±0,02 (1)	0,874±0,004 (8-10)	4,64±0,02 (4)
4	20,12±1,21 (1)	36,37±0,36 (8)	26,53±0,46 (8)	6,54±0,04 (8)	5,19±0,06 (10)	0,807±0,004 (2)	5,03±0,03 (10)
5	25,51±1,28 (2,3,4)	31,55±0,73 (4,5,6)	21,35±0,16 (1,2)	6,63±0,01 (8,9)	5,60±0,14 (11)	0,842±0,005 (3,4)	4,91±0,01 (9)
6	32,01±1,88 (6,7,8	27,31±1,05 (2,3)	25,23±0,23 (4,5,6)	6,19±0,05 (7)	5,10±0,12 (10)	0,870±0,001 (7-9)	4,40±0,01 (1,2)
7	30,88±1,56 (5-8)	32,53±0,01 (5,6,7)	23,25±0,15 (3)	5,96 ±0,11 (6,7)	4,95±0,05 (9,10)	0,859±0,001 (5-7)	4,51±0,03 (3)
8	24,66±1,64 (1,2,3	34,93±0,43 (6,7,8)	24,39±0,31 (4)	6,79±0,13 (8,9,10)	5,85±0,11 (11)	0,841±0,002 (3,4)	4,66±0,01 (4,5)
9	28,88±1,71 (3,4,5,6,7)	23,30±1,17 (1)	30,97±0,16 (10)	7,10±0,05 (10)	5,72±0,06 (11)	0,850±0,002 (4,5)	4,71±0,02 (4-6)
10	42,87±4,47 (9)	24,72±0,71 (1,2)	28,17±0,23 (9)	5,10±0,01 (3)	3,91±0,04 (2,3,4)	0,884±0,002 (10,11)	4,39±0,04 (1,2)
11	27,00±1,38 (2,3,4,5)	32,44±1,86 (5,6,7)	26,25±0,21 (7,8)	4,77±0,01 (1,2)	3,91±0,11 (2,3,4)	0,869±0,002 (7-9)	4,82±0,04 (7,8)
12	24,91±0,81 (1,2,3,4)	35,37±1,59 (7,8)	23,33±0,08 (3)	6,69±0,11 (8,9)	5,88±,004 (11)	0,792±0,001 (1)	4,77±0,02 (6,7)
13	33,30±1,93 (7,8)	27,05±1,16 (2,3)	26,06±0,11 (6,7,8)	5,24±0,05 (3,4)	3,78±0,06 (1,2,3)	0,877±0,001 (9-11)	4,43±0,01 (1-3)
14	29,70±1,94 (4,5,6,7,8	31,15±1,32 (4,5)	25,12±0,23 (4,5,6)	6,13±0,19 (7)	5,10±0,06 (10)	0,855±0,000 (5,6)	4,87±0,01 (8,9)
15	22,89±0,97 (1,2)	36,07±0,52 (7,8)	25,34±0,31 (4,5,6,7)	5,69±0,04 (5,6)	4,66±0,08 (7,8,9)	0,834±0,002 (3)	4,87±0,03 (8,9)
16	34,11±0,89 (8)	30,42±1,39 (3,4,5)	23,38±0,32 (3)	5,06±0,16 (2,3)	4,03±0,04 (3,4)	0,874±0,001 (8-10)	4,72±0,02 (5,6)
17	27,05±1,30 (2,3,4,5,6)	32,40±0,50 (5,6,7)	26,02±0,14 (6,7,8)	5,53±0,01 (4,5)	4,52±0,07 (6,7,8)	0,865±0,003 (6-8)	4,92±0,02 (9)
18	34,57±1,26 (8)	23,22±0,86 (1)	28,61±0,44 (9)	5,13±0,06 (3)	4,04±0,06 (3,4,5)	0,872±0,001 (8,9)	4,35±0,01 (1)
19	33,13±0,80 (7,8)	31,55±0,59 (4,5,6)	25,02±0,13 (4,5)	5,46±0,05 (4,5)	4,18±0,13 (4,5,6)	0,871±0,003 (8,9)	4,46±0,03 (2,3)
20	29,62±1,02 (3,4,5,6,7,8)	35,00±1,43 (6,7,8)	21,01±0,08 (1)	4,47±0,04 (1)	3,52±0,06 (1,2)	0,886±0,002 (11)	4,70±0,05 (4,5)
21	44,62±0,95 (9)	22,18±0,39 (1)	22,19±0,26 (2)	6,89±0,03 (9,10)	5,96±0,19 (11)	0,873±0,002 (8-10)	4,45±0,01 (2,3)
22	28,48±1,06 (3,4,5,6,7)	27,93±0,32 (2,3,4)	26,00±0,16 (6,7,8)	5,74±0,06 (5,6)	4,86±0,18 (8,9,10)	0,839±0,003 (3,4)	4,49±0,02 (3)

*Different numbers next to the mean values indicate significant differences between samples according to Tukey's test, $p < 0.05$. The Tukey test grouped the samples into homogeneous groups, where samples with the same number are not significantly different, while samples with different numbers are significantly different

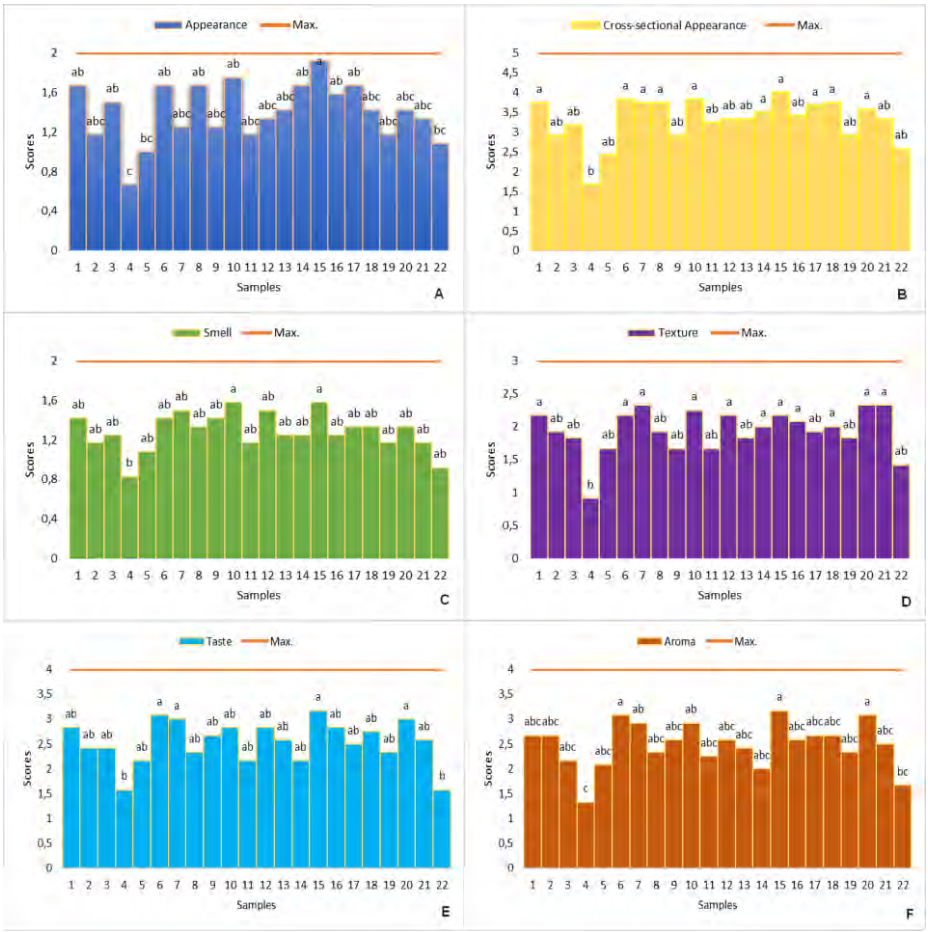

Figure 1. Mean Sensory Scores of Sudžuka Samples Across Six Sensory Attributes

*Different letters (a,b,c) indicate significant differences among samples according to Tukey's test ($p < 0.05$)

*Panels: (A) Appearance, (B) Cross-sectional Appearance, (C) Smell, (D) Texture, (E) Taste, (F) Aroma

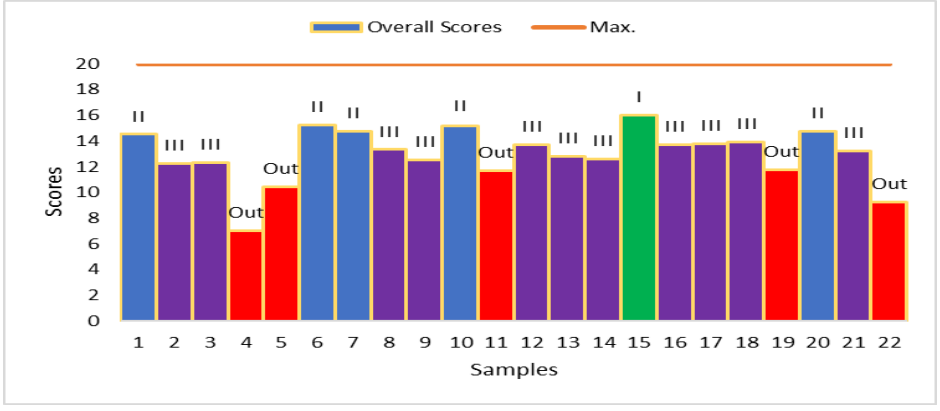

Figure 2. Overall Scores and Ranking of Sudžuk Samples

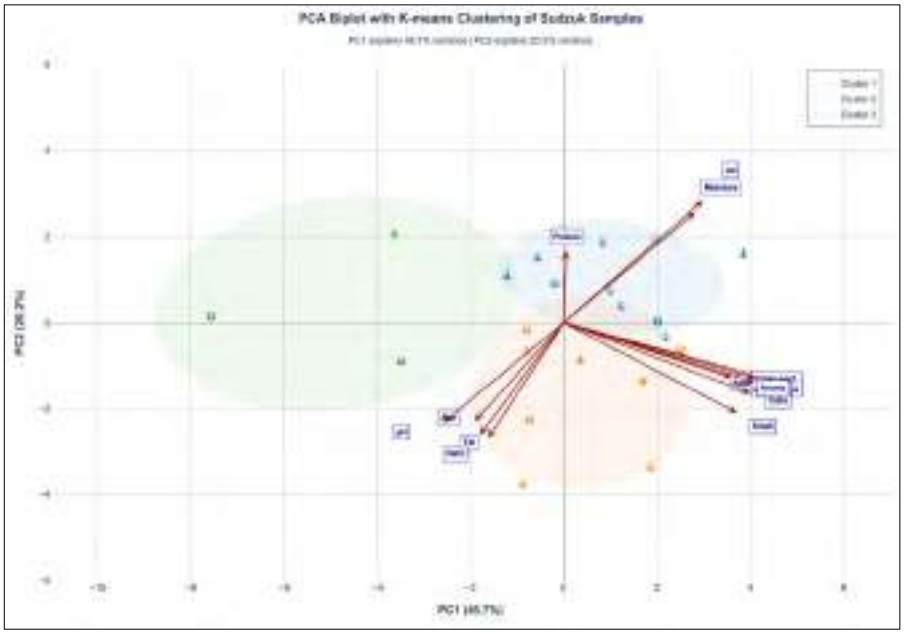

Figure 3. PCA Bioplot of Sudžuk Samples Based on Physicochemical and Sensory Properties with 95% Confidence Ellipses

CONCLUSIONS

Analysis of 22 sudžuka samples from domestic artisan producers in Bosnia and Herzegovina showed pronounced variability in chemical composition and sensory quality, indicating inconsistent production practices and absence of standardization.

Although most samples meet basic nutritional parameters, especially water and protein content, a significant number of products show high fat and salt content and too low pH value, which negatively affects nutritional value, stability, and sensory quality of the product. Sensory evaluation indicated that no sample reached extra class, while the largest number of samples belonged to class III, and a significant portion was unsuitable for the market.

PCA analysis confirmed sample groupings according to dominant chemical and sensory parameters, emphasizing that current production is not completely uniform. The obtained results clearly indicate the need for improvement and standardization of recipes and technological procedures, especially in salting and fermentation phases, to reduce variations in chemical and sensory profile, as well as revision of normative protein requirements, e.g., setting minimum content of at least 20%, to preserve nutritional value.

Future research should focus on more detailed analysis of the impact of specific production phases and recipes on chemical and sensory profile, to further improve consistency, stability, and overall quality of domestic products, thereby ensuring their competitiveness and recognition in domestic and regional markets.

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SUDŽUKA ZANATSKIH PROIZVOĐAČA U BOSNI I HERCEGOVINI: HEMIJSKI SASTAV, STABILNOST I SENZORSKI KVALITET

Sažetak

Sudžuka je tradicionalna suha fermentirana kobasica koja zauzima značajno mjesto u ishrani i kulinarskoj tradiciji Bosne i Hercegovine. Cilj ovog istraživanja bio je procijeniti fizikalno-hemijske i senzorne karakteristike uzoraka domaće sudžuke

proizvedene u različitim obrtničkim radnjama i mesnicama diljem Bosne i Hercegovine, te utvrditi stepen njihove homogenosti međusobne sličnosti. Rezultati analiza su pokazali postojanje statistički značajnih razlika između uzoraka u svim ispitivanim parametrima, što ukazuje na heterogenost u hemijskom sastavu i senzornom kvalitetu sudžuke. Najveće varijacije zabilježene su u sadržaju vode (20,12–44,62%), sadržaju masti (22,18–36,37%), zatim u sadržaju proteina (21,01–30,97%), dok su nešto manja varijacije zabilježena u sadržaju pepela (4,50–7,10%) i sadržaju soli (3,44–5,96%). Aktivitet vode varirao je od 0,792 do 0,886, a pH vrijednost od 4,35 do 5,03.
Senzorna analiza kvaliteta pokazala je da niti jedan uzorak nije dosegao eksra klasu, samo jedan uzorak je pripadao I klasi, pet uzoraka klasi II, jedanaest uzoraka klasi III, dok su četiri uzorka bila ispod standarda, tj. neprikladna za tržište. PCA analiza identificirala je tri klastera, naglašavajući da varijacije u kvalitetu proizilaze iz razlika u recepturama, sirovinama i tehnološkim procesima fermentacije i sušenja. Dobiveni rezultati ukazuju na potrebu standardizacije receptura i proizvvodnih procesa, kontrolu sadržaja soli, optimizaciju fermentacije i sušenja te edukaciju proizvođača, s ciljem poboljšanja nutritivne vrijednosti i senzornog kvaliteta sudžuke. Kombinacija hemijskih, senzornih i multivarijantnih analiza pokazala se učinkovitom za objektivnu procjenu tradicionalih fermentiranih proizvoda.
tri grupe: uzorci s većim udjelom masti, soli i pepela; uzorci s većim sadržajem vode i aw vrijednosti; te uzorci diferencirani senzorskim svojstvima. Rezultati istraživanja ukazuju na neujednačenost receptura i tehnoloških procesa kod zanatskih proizvođača, te ističu potrebu za standardizacijom receptura, kontrole fermentacije i udjela masti i soli, kako bi se postigao stabilniji, nutritivno prihvatljiv i senzorski kvalitetan proizvod.

Ključne riječi: *sudžuka, fizikalno-hemijski parametri, senzorni kvalitet, fermentirane kobasice, Bosna i Hercegovina*

QUALITY AND TECHNOLOGY OF KAJMAK AND SKIMMED MILK CHEESE IN THE AREA OF ROMANIJA MOUNTAIN

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Abstract

Kajmak is an autochthonous dairy product that has been produced in the mountainous Dinaric system of the Balkans for centuries. It is consumed as "young" or "mature" which is obtained after the ripening process. It is characterized by high fat content and significant protein content, primarily casein. Smoked Kajmak from the area of the Romanija mountain is of special quality, which acquires a mild taste and smell from the smoke. In this paper, the technology, chemical composition and sensory quality of Kajmak from the wider area of Romania were investigated. Kajmak is produced from cow's milk. Within the framework of these studies, the content of dry matter and fat of milk for the production of Kajmak was examined, as well as the influence on the content of dry matter, fat and fat in dry matter and also the yield of Kajmak. The technology of Skimmed milk cheese, which is made from skimmed milk after removing of fat layer - Kajmak, was also investigated. The yield, content of dry matter, fat and fat in dry matter of Skimmed milk cheese were tested. The distribution of milk ingredients in Kajmak, Skimmed milk cheese and whey was analyzed.
The results showed a good quality of Kajmak, with a high content of fat and fat in dry matter. The technology varied depending on the production conditions and the raw material, so this caused considerable variations in the chemical composition, yield and sensory properties of Kajmak. By analyzing the distribution of milk ingredients in production, it was established that the largest percentage of milk dry matter turned into whey due to generation of its largest quantity in Kajmak/Skimmed milk cheese production. Correlation analysis showed that the production parameters of Kajmak and Skimmed milk cheese were interrelated. Correlation analysis showed that the yield of Kajmak was influenced by dry matter content of the milk, and the content of fat and fat in the dry matter of the Kajmak is influenced by the fat content of the milk.

Keywords: *Kajmak, Skimmed milk cheese, fat, dry solids, quality*

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INTRODUCTION

It is assumed that Skorup-Kajmak originated as a stage in the development of the butter production process in primitive conditions. The indigenous technology of young or unripe Kajmak is, in its basic principles, very similar to the traditional method of producing sour cream in households. In principle, it represents a fat layer removed from the surface of cooled boiled milk after a certain period of standing. In terms of fat content, Kajmak is between butter, on the one hand, and cream and full-fat cheeses, on the other hand. By undergoing the ripening process, old or mature Kajmak is formed from young. In terms of fat content, only butter and anhydrous milk fat are richer than it. In terms of a certain amount of protein, the ripening process and the development of acidity and other compounds, it approaches cheeses (Sarić, 1995; Bijeljac and Sarić, 2005).

Kajmak is a product that has been produced in Bosnia and Herzegovina and the wider region since ancient times. The word "kaymak" is of Turkish origin and means „cream". The term "skorup" is of Slavic origin and comes from the word "kora" (Bijeljac and Sarić, 2005). In the mountainous areas of the Dinaric system, the name Skorup was retained for a longer time, and in cities and markets, Kajmak (Dozet *et al.,* 2010). As stated by Zdanovski (1947), the term Skorup is more commonly used in Croatia, and the name Kajmak in Serbia and Macedonia. In Montenegro, the name Skorup is used exclusively and in Bosnia and Herzegovina mostly Kajmak. The more precisely Kajmak is a specific autochthonous dairy product for the area of the Dinaric mountain system and some authors stated it is produced in some parts of Croatia (Lika), Bosnia and Herzegovina, Montenegro, Macedonia and Serbia (Zdanovski, 1962; Dozet and Stanišić, 1972; Bijeljac and Sarić, 2005; Puđa *et al*., 2008). Zdanovski *et al.* (1966) state that Kajmak is produced in all areas of Bosnia and Herzegovina except northern Bosnia and the wider area of the Vlašić Mountains. In Bosnia and Herzegovina, it is produced in western, central and eastern Bosnia and also Herzegovina. The regions of eastern Herzegovina (Gacko-Kajmak from anmal skin bag) and eastern Bosnia (Romanija-Rogatica) – smoked Kajmak are distinguished by the quantity and quality of the product (Dozet and Stanišić, 1972). Dozet *et al.* (1981) state that the production of Kajmak is best in the area of eastern Bosnia in the regions bordering Montenegro and Serbia. Mountain Romanija is a typical Kajmak producing region.

The specificity of Kajmak from the wider area of Rogatica and Romanija mountain is smoking, so it turns more yellow and acquires a specific pleasant taste and smell from the smoke, and by smoking, a kind of preservation of Kajmak is done. Another characteristic of Kajmak technology from Romanija is that the cream rises when the milk under it curdles (Dozet, 1962; Zdanovski *et al.,* 1966, 1970; Bijeljac and Sarić, 2005; Dozet *et al.,* 2010). Zdanovski (1956) states in his work that "Kajmak is famous from Romanija mountain, which is smoked with smoke from beech wood". The technology, yield and quality of Kajmak from the area of Rogatica and Romanija mountain were examined by Dozet *et al.* (1981, 1996, 2010), and Zdanovski *et al.* (1966), while the chemical composition of Kajmak from the area of eastern Bosnia

(Romanija-Rogatica) is reported by Zdanovski *et al.* (1970), Dozet and Stanišić (1972), Dozet *et al.* (1973; 1974; 1983; 2007a,b,c and Pandurević *et al.* (2008). Sarić (1995), Dozet *et al.* (2004) and Bijeljac and Sarić (2005) described in detail the quality and technology of Kajmak from the wider area of Romanija mountain. Stanišić *et al.* (1990) and Sarić (1995) established the interdependence of the fat content in milk and the fat content in Kajmak and the fat in the dry matter of Kajmak in the production of Kajmak from the area of Romanija mountain, and Dozet *et al.* (1981) between the fat content of milk and the amount of Kajmak. The influence of the length of creaming on the yield of Kajmak from Romanija mountain was determined by Đurković (1975) and Sarić (1995). Skimmed milk cheese is produced from the milk that remains after removing the cream crust. Zdanovski *et al.* (1966) and Dozet *et al.* (1996, 2004) showed the technology, yield and composition of fresh Skimmed milk cheese, while Dozet (1962) and Zdanovski *et al.* (1972) described the composition of Skimmed milk cheese.
The aim of the work was to examine the technology, yield and chemical composition of Kajmak in the area of Romanija mountain. Also, technology and yield were monitored, and the chemical composition of fresh Skimmed milk cheese in the production of "Romanijski" Kajmak was tested. The main goal was to investigate the influence of the content of dry matter and fat in milk as a starting raw material for the production of "Romanijski" Kajmak on the content of dry matter, fat and fat in the dry matter, and on the yield of Kajmak. Since it is a production with two co-products (Kajmak and Skimmed milk cheese), the dependence of the content of dry matter, fat and fat in the dry matter of fresh Skimmed milk cheese, and the yield on the content of dry matter and fat in milk, as well as the distribution of dry matter in the production of Kajmak, were examined.

MATERIAL AND METHODS

The wider area of Romanija mountain (the municipality of Rogatica and the municipality of Pale) was selected for the tests. A total of 12 households were included in the research, 6 from the area of the municipality of Rogatica (localities Osovo, Borike, Barakovac) and 6 from the area of the municipality of Pale (localities Barakovac and Krivače). Kajmak technology was monitored in all households and samples of milk, young Kajmak and fresh Skimeed milk cheese were taken. During all the research, the indicators and stages in the technological process were monitored, and in order to obtain data on the yield (Y=kg obtained Kajmak-Skimmed milk cheese x 100/kg of milk used) and quantity of milk/kg of product (100/R), the total quantities of milk, Kajmak and Skimmed milk cheese were measured.

Chemical and sensory analyses were done in the Dairy Laboratory of the Faculty of Agriculture and Food Sciences, University of Sarajevo. Since the total content of dry matter and fat are the most important factors in the production of Kajmak, the analyses included testing the content of dry matter and fat in milk, and dry matter, fat and fat in the dry matter of Kajmak and Skimmed milk cheese. The dry matter content of milk was determined gravimetrically, by drying in an oven at 102±2°C (ISO 23318:2022), and the milk fat content was determined by the Gerber method (ISO 19662:2018). The content of dry matter in Skimmed milk cheese was determined gravimetrically by drying in an oven at 102±2°C (ISO 5534:2004), and the fat content by the Van Gulik method (ISO 3433:2008), whereby for Kajmak, modified methods were used according to Pravilnik o metodama uzimanja uzoraka i metodama hemijskih i fizičkih analiza mlijeka i proizvoda od mlijeka (1983). The fat content in the dry matter of Kajmak and Skimmed milk cheese was determined by calculation according to Bylund (2003). The sensory evaluation of Kajmak and Skimmed milk cheese was performed by an expert panel composed of 7 members using a system of maximum 20 points where the following characteristics were evaluated: appearance, color, consistency, smell and taste. The distribution of individual ingredients from milk and their transfer to Kajmak implies the calculation of the percentage of dry matter of Kajmak as well as Skimmed milk cheese. By calculating the distribution of dry matter, the quantity of milk, Kajmak and Skimmed milk cheese with the dry matter of milk, Kajmak and Skimmed milk cheese were taken into account. The rest that remains in the whey is obtained by summing the distribution of Kajmak and Skimmed milk cheese and subtracting the value from 100.

Quantity of milk x % dry matter of milk
Quantity of Kajmak x % dry matter of Kajmak
Quantity of Skimmed milk cheese x % dry matter of Skimmed milk cheese

$$\begin{array}{ll} \text{Obtained milk value} & 100\% \\ \underline{\text{Obtained Kajmak value (Skimmed milk cheese)}} & \underline{x} \end{array}$$

$$x = \frac{\text{obtained Kajmak value (Skimmed milk cheese) x } 100\%}{\text{obtained milk value}}$$

Mathematical-statistical analysis of data referred to the calculation of basic parameters of descriptive statistics. The correlation between the values of the chemical parameters of raw milk, Kajmak and Skimmed milk cheese and the yield in production was tested using the Pearson's correlation coefficient. The Microsoft Excel 2010 program was used to calculate the basic parameters of descriptive statistics and Pearson's correlation coefficient.

RESULTS AND DISCUSSION

In all chosen households, the technology of Kajmak and Skimmed milk cheese was followed. Indigenous production is of small capacity and differs quite a bit in terms of production methods and parameters. Therefore, the quality of products on the market is often uneven.

Autochthonous technology of Kajmak and Skimmed milk cheese in the area of Romanija mountain

The most important factor in the production of any dairy product is quality milk. For the production of Kajmak, cow's, sheep's or mixed milk is used. In all surveyed households, cow's milk was used as a raw material for the production of Kajmak. Of all the ingredients, milk fat has the greatest influence on the quantity and quality of Kajmak, because Kajmak is a product that can contain almost and over 90% of fat in the dry matter. Therefore, only the content of dry matter and fat was analyzed in milk for the production of Kajmak.

Table 1. Chemical composition of cow milk for Kajmak manufacture
Tabela 1. Hemijski sastav mlijeka za proizvodnju Kajmaka

Indicators (%)	Min.	Max.	Mean	St. dev.	CV (%)
Dry matter	10.65	17.62	12.45	1.78	14.29
Fat	1.90	5.50	3.77	0.93	24.66
Non-fat dry matter (NFDM)	7.29	12.12	8.68	1.26	13.89

It can be seen that fat is the most variable component with the highest coefficient of variation and varies in a wide range from 1.90 to 5.50%. The dry matter and non-fat dry matter (NFDM) content is more uniform. The average fat content and NFDM meet the provisions of the Regulation on the quality of fresh raw milk (2011), while individual values deviate from the prescribed ones. Dozet *et al.* (1975) state that the dry matter content for milk from hilly and mountainous areas ranges from 10.40 to 14.30%. For cow's milk for the production of Kajmak from the area of eastern Bosnia, the average dry matter and fat content was recorded as 13.08 and 3.68%. The average NFDM content was 9.40% (Dozet *et al.*, 1974a). Milk from the experimental production of Kajmak had 12.10, 8.20 and 4.10% dry matter, NFDM and fat (Dozet *et al.*, 1996). The fat content depends on the year and period, i.e. diet, and is lower at the beginning of the grazing season, and higher as the end of the season approaches.

In the cow's milk for the production of Kajmak in the area of Romanija mountain in the summer period (2007-2008), it varied in average from 3.75% in May to 3.82% or 4.10% in September (Dozet *et al.*, 2010). For cow's milk for the production of Kajmak from the area of Romanija mountain, the average fat content was 3.75% (Zdanovski *et al.*, 1972) or 4.05% with variations from 2.80 to 5.10% (Sarić, 1995). Cow's milk for the production of Kajmak from the hilly-mountainous area of the wider Sarajevo region had a fat content of 3.20% to 5.30% (hilly area) and from 2.65 to 5.90% (mountainous area). It can be stated that the content of dry matter, fat and NFDM is somewhat lower, but that it corresponded to the values reached by other authors examining the production of Kajmak from the area of Romanija mountain.

Kajmak is produced in huts specially designed for this purpose, which are usually located near the house. They are made of wood so that they allow better air circulation, and the floors are earthen or concrete. The advantage of a hut is that the milk does not come into contact with other products, which means there are fewer opportunities for it to absorb foreign odors. Since this is a mountainous area with a large number of days with low temperatures, there is a stove or hearthstone in the huts where the fire burns. Milk is boiled on the stove or it is done in the house, and the fireplace, in addition to heating, has the main function, which is to produce smoke. The presence of smoke is a characteristic of Kajmak from this area. Oak, beech or spruce wood is burned on the fireplace. Smoking makes the kajmak more yellow and gives it a smoky taste and smell, and this is how preservation is done. The season for producing Kajmak in huts is from early May to early November, but it can last longer.

Figure 1. Huts for Kajmak manufacture (old building-left and a newer one-right)
Slika 1. Kolibe za proizvodnju Kajmaka (stara gradnja-lijevo i novija-desno

Figure 2. Interior of hut - chimney and smoking of Kajmak
Slika 2. Unutrašnjost kolibe – ognjište i dimljenje Kajmaka

The production of Kajmak begins with fresh raw cow's milk, which is strained into larger, deeper containers in which the milk is boiled. The container with the milk is placed on an already heated stove and stirred occasionally to prevent burning. After boiling, the milk is left to boil for another 5-15 minutes, stirring occasionally. This also achieves the appropriate dry matter content in the milk. This is especially necessary during the grazing period in May, June and July, when the dry matter content in the milk is lower. After boiling, the milk is poured into prepared shallow containers where the Kajmak is separated. Most housewives do the cooking at home, and after pouring, the containers with the milk are then transferred to huts for cooling and crust formation. In another variant, everything is done in the same containers, both cooking and creaming, which are then shallower and smaller. Creaming or forming is the process of separating cream on the surface of boiled milk that occurs when the milk gradually cools. This operation has the greatest range of time variation. The duration of the creaming process is from 1 to 3 days, depending on the weather conditions and the season. In Romanija, the formed crust of Kajmak is removed when the milk underneath has curdled. However, on warmer days, the milk curdles more quickly, which is too short a period to separate the entire amount of Kajmak, which is why its quantity is lower. In colder weather conditions, the hut must be heated, and the separation of Kajmak is prolonged and a larger quantity is obtained. The crust is removed andKajmak is placed in containers to drain.

Figure 3. Posude sa mlijekom - formiranje kore
Slika 3. Milk containers – crust formation

Figure 4. Formed crust – Kajmak (left) and draining of Kajmak (right)
Slika 4. Formirana „kora“ Kajmaka (lijevo) i cijeđenje Kajmaka (desno)

Drained Kajmak contains a lower moisture content and is of better quality, but this is not often practiced, especially if it is to be consumed young. Kajmak obtained can be consumed immediately or sold on the market as "young". A ripening phase is necessary for the production of "mature" Kajmak. The „young“ Kajmak is stacked for ripening in traditional wooden containers - tubs. As it is stacked, salt is added layer by layer and a cloth, wooden lid and a stone are placed on top. In order to create anaerobic ripening conditions, it is necessary to pour whey from fresh cheese or brine over the Kajmak. The minimum ripening process is 7-10 days, full maturity is achieved after 2-3 months, but it can last and be stored for up to a year. Storage is in cool places such as basements

or huts. This way, „mature“ Kajmak is obtained, which is most often collected in the fall to be consumed in the winter.

Figure 5. “Young” Kajmak (left) and “mature” Kajmak (right)
Slika 5. Mladi Kajmak (lijevo) i zreli Kajmak (desno)

It can be stated that certain stages and conditions of the production process play a key role in achieving high yield and quality of Kajmak. For research in this work, samples of „young“ Kajmak were used, so the measured yield and the analyzed chemical composition refer to it.

After removing the Kajmak, skimmed milk remains, from which, through appropriate processing, Skimmed milk cheese is produced. It has different names in different parts of Bosnia and Herzegovina (Vareni sir, Torotan, Tarenik, Tučenik, etc.). After the Kajmak has been removed, milk can, depending on the degree of acidity, coagulate in different ways: spontaneously with the help of heat, by adding vinegar, and by adding a small amount of rennet. During the research in this paper, spontaneous milk coagulation was most often used, but in a small number of cases when spontaneous coagulation did not occur, it was done by adding rennet or vinegar. In any case, the milk is placed on a warm stove over low heat.

Figure 6. Spontaneous milk coagulation (left) and milk coagulation with added rennet (right)

Slika 6. Spontana koagulacija mlijeka (lijevo) i koagulacija mlijeka sa dodatkom sirila (desno)

The lactic acid that has formed in the milk allows for curdling in approximately 30 minutes. In the case when the milk has not coagulated, rennet is added to speed up the curdling process. After that, it is left on the stove for a few minutes for the whey to come to the surface, and then it is removed to let the cheese mass cool slightly, not completely, because then squeezing would be difficult. Squeezing is done by pouring the cheese mass into a linen bag that is placed over a strainer where it is squeezed for a while. The cheese obtained in this way is called Skimmed milk cheese („Posni sir“). It is mainly used fresh for household needs or for sale. It can be left to ripen. At this time, the cheese is chopped, salted, mixed, placed in vats and weighed in the same way as Kajmak to create anaerobic conditions.

Figure 7. Spontaneously formed curd (left) and fresh Skimmed milk cheese (right)

Slika 7. Spontano izdvojeni gruš (lijevo) i svježi Posni sir (desno)

Yield of Kajmak and Skimmed milk cheese in the area of Romanija Mountain

To calculate yield and quantity of milk/kg of product, the amount of milk before cooking and the quantity of "young" Kajmak and fresh Skimmed milk cheese were taken into account. Yield and quantity of milk/kg of Kajmak and Skimmed milk cheese are shown in table 2.

Table 2. Yield in Kajmak and fresh Skimmed milk cheese manufacture
Tabela 2. Randman u proizvodnji Kajmaka i Posnog sira

Indicators	**Min.**	**Max.**	**Mean**	**St. dev.**	**CV (%)**
Yield (kg Kajmak/100kg milk)	2.91	10.38	5.16	2.18	39.56
Kg milk for 1 kg of Kajmak	10.38	34.36	20.52	7.24	35.28
Yield (kg Skimmed milk cheese/100kg milk)	8.41	21.03	13.84	4.02	29.03
Kg milk for 1 kg of Skimmed milk cheese	4.75	11.89	7.81	2.31	29.56

Values for yield of Kajmak are quite low, and milk consumption is high. From 100 liters of milk, an average of 5.16 kg of Kajmak and 13.84 kg of Skimmed milk cheese is obtained, and 1 kg of Kajmak requires an average of 20.52 liters of milk, while an average of 7.81 liters of milk is used to produce 1 kg of Skimmed milk cheese. A partial explanation for this is that the tests were carried out in the period of May, June and July when the content of fat and dry matter of milk is lower, which can be seen in table 1. D o z e t *et al.* (2010) emphasize that the fat content in milk significantly affects the quality and total quantity of Skorup-Kajmak produced. Producers make Skorup-Kajmak in the period when the composition and quality of milk allows for maximum production. According to a survey conducted among the producers of "Romanijski Skorup-Kajmak" from 10 liters of milk in the period up to July, about 600 g of Skorup-Kajmak (16.67 liters of milk/1 kg of Kajmak) is obtained, and in the period from August to mid-October, 1 kg of Skorup-Kajmak is obtained from 10 liters of milk (10 liters of milk/1 kg of Kajmak). High coefficients of variation for Kajmak yield and quantity of milk/kg of product, in addition to the variability in milk composition, point to significant differences in the procedures and conditions of Kajmak production. Variability is lower in Skimmed milk cheese compared to Kajmak, which can be seen from the lower coefficients of variation.

According to the literature (Jovanović, 1933) from 100 liters of milk, 4.66 kg of Kajmak is obtained (21.46 liters/1 kg of Kajmak), and since 1.27% of fat remains in skim milk after creaming, another 1.36 kg of butter and 66 kg of cheese are obtained from skimmed milk. Zdanovski (1962) states that 100 litarske of cow's milk yield about 4.50

kg of Kajmak (22.22 liters of milk/1 kg of Kajmak) and about 10 kg of „vareni“ (skimmed milk) cheese. From 100 liters of cow's milk with 3.50% fat, 6.16 kg of Kajmak (16.23 liters for 1 kg of Kajmak) and 11.5 kg of Skimmed milk cheese were obtained (Zdanovski *et al.,* 1966). Other sources report similar data. From 100 liters of cow's milk with an average of 3.50% fat, an average of 6.73 kg of Kajmak was obtained, and an average of 15.78 liters of milk was used for 1 kg of Kajmak (the amount of milk after cooking was taken into account). As the content of fat in milk increased from 3.00 to 3.90%, the amount of milk needed for 1 kg of Kajmak decreased (from 21.06 to 11.62 liters), and the yield increased (from 4.75 to 8.61). At the same time, an average of 12.24 kg of Skimmed milk cheese was obtained from 100 liters of cooked milk (Dozet *et al*., 1981). In experiments in households at Romanija mountain, an average of 6.06 kg of Kajmak was obtained from 100 liters of cow's milk, that is, an average of 17.41 liters of milk/1 kg of Kajmak was used. The interdependence of the fat content in milk and the length of creaming with yield was established (Sarić, 1995). By comparison with the data from the literature, it can be said that the determined yield of Kajmak in this work approaches the lower limits, while, in contrast, the yield of fresh Skimmed milk cheese is close to the maximum values. This makes sense, especially considering the relatively short length of creaming (1-3 days).

In the production of Kajmak from sheep's or mixed cow's or sheep's milk, the yield is higher and milk quantity/kg of Kajmak is lower compared to the production from cow's milk. According to some data, 0.80% fat remains in the skimmed milk after removing the Kajmak obtained from milk with 5.90% fat (probably mixed op. aut.) (Bajčetić, 1955). Đurković (1975) established that in the area of Romanija, from 100 liters of milk, on average, 9.04 kg of Kajmak (11.06 liters of milk/kg of Kajmak) can be obtained. Kajmak was produced from cow's and sheep's milk. Tests in the same field showed that from 100 liters of mixed cow's and sheep's milk with 6.50% fat, 11.83 kg of Kajmak was obtained (8.45 liters/1 kg of Kajmak), and from skimmed milk with 1.10% fat, 31.66 kg of fresh Skimmed milk cheese was obtained (Zdanovski *et al.,* 1966). According to some data, Kajmak producers at Romanija consume 7-14 liters of milk/1 kg of Kajmak (probably mixed sheep's and cow's milk or only cow's milk, not stated rem. authors). At the same time, 10-14 kg of Skimmed milk, „vareni“ cheese can be produced from 100 liters of milk from skimmed milk after removing Kajmak (Dozet *et al.,* 1996).

Quality of Kajmak and Skimmed milk cheese in the area of Romanija mountain

Analyses of the chemical composition were performed on samples of young Kajmak and fresh Skimmed milk cheese. In addition to the amount of Kajmak and Skimmed milk cheese produced, the amount of dry matter and fat in milk also affects their composition and sensory properties. As can be seen from the data in table 3, Kajmak has a high content of fat in dry matter above the minimum limits stipulated by Rulebook on dairy products and starter cultures (2011), which requires a minimum of 65.00% fat

in dry matter. In terms of average dry matter content, it is at the very limit stipulated by Rulebook on dairy products and starter cultures (2011) (minimum 60.00%), and some samples are even below the limit. The extremely high fat content and the relatively low proportion of dry matter can be linked to the relatively low yield and the short period of creaming, as well as the production season (May, June, July).

Table 3. Chemical composition of Kajmak and Skimmed milk cheese
Tabela 3. Hemijski sastav Kajmaka i Posnog sira

Indicators	**Min.**	**Max.**	**Mean**	**St. dev.**	**CV (%)**
Kajmak					
Dry matter (g/100g)	54.28	66.19	59.93	4.35	7.25
Fat (g/100g)	39.00	63.00	54.38	7.65	14.06
Fat on dry matter basis (DM - %)	71.48	99.18	90.49	9.09	10.04
Skimmed milk cheese					
Dry matter (g/100g)	14.55	31.92	26.44	5.31	20.08
Fat (g/100g)	1.50	9.00	5.25	2.40	45.71
Fat on dry matter basis (DM - %)	10.30	28.67	18.98	6.24	32.88

Young Kajmak contains a high percentage of dry matter (66.04%), fat (57.51%) and fat in dry matter (87.17%), and mature 67.73, 58.56 and 85.51% resp. This places it in the group of dairy products with an extremely high energy value, ranging from 2000 to 2500 kJ (Bijeljac and Sarić, 2005). The chemical composition of Kajmak varies due to differences in specific technology and initial raw materials (Dozet and Stanišić, 1972). According to the way dairy animals are fed, the composition of milk changes, which affects the quantity and quality of the product (Dozet *et al.*, 2010). Therefore, the chemical composition of Kajmak varies depending on the period of production, so for Kajmak from the area of Rogatica, Borik and the Sjemeč mountain, a higher content of dry matter and fat was found in the autumn period compared to period spring-summer (69.16% and 59.70% resp. 66.61% and 56.67%) (Zdanovski *et al.*, 1970), which can be attributed to differences in nutrition and composition of grazing in different periods of production of "Romanijski Skorup-Kajmak". Fat content in dry matter is a very important component that is fairly constant regardless of the degree of maturity of Kajmak or the period of production (85.99% autumn and 85.15% spring-summer) (Zdanovski *et al.*, 1970). In the samples of young and mature Kajmak from the area of

Romanija-Rogatica-eastern Bosnia, the content of dry matter varied in the range 66.31-71.48%, fat 57.50-61.08% and fat in dry matter 85.24-87.80% (Dozet and Stanišić, 1972; Dozet *et al.,* 1987, 2007a,b,c, 2010; Sarić, 1995; Pandurević *et al.,* 2008). All data indicate the constancy of fat in dry matter content regardless of season and maturity. It seems that the content of fat in milk and the length of creaming are very important in this regard, because it was established that there is a connection between them and the content of fat and fat in the dry matter of Kajmak (Sarić, 1995).

The content of the basic components of Skimmed milk cheese corresponds to some data from the literature, but compared to most data, the content of dry matter is lower, and compared to some others, the content of fat and fat in dry matter is higher. According to the content of fat in the dry matter, it is actually in the group of semi-fat cheeses (Rulebook on dairy products and starter cultures, 2011) which shows that a significant part of the fat has passed into the cheese and partly explains the relatively low yield of Kajmak. This shows that for good control in the production of Kajmak, it is necessary to monitor the yield and composition of Skimmed milk cheese. The average composition of sour fresh cheese made from skimmed milk after removing Kajmak is as follows: 30.28% dry matter, 5.36% fat, 16.78% fat in dry matter, 20.28% protein, 1.42% salt, 2.32% ash and 1.00% lactic acid (Jovanović, 1964). The composition of the Skimmed milk cheese in Kajmak production from the Romanija area is following: dry matter 35.00%, fat 3.50%, fat in dry matter 10.00%, protein 32.40%, ash 0.68% (Zdanovski *et al.,* 1966) while the average composition of Skimmed milk cheese after the production of Kajmak from cow's milk is as follows: 33.57% dry matter, 1.75% fat and 5.23% fat in dry matter (Dozet *et al.,* 1981). Zdanovski *et al.* (1972) and Dozet *et al.* (1974a) give data for the content of dry matter, fat and fat in the dry matter of Skimmed milk cheese: 30.75 and 39.42%, 4.35 and 6.80% and 13.47 and 16.10% resp.

Sensory analysis of Kajmak and Skimmed milk cheese was performed (Table 4 and Table 5). Young Kajmak should meet the following quality requirements: it should be white or yellowish in color; it should have a pleasant smell and a mild taste; it should have a flaky structure with pieces of boiled milk curd (Rulebook on dairy products and starter cultures, 2011).

According to the average total score, Kajmak was classified as Class I. Three samples were in the extra class (above 18.10 points), and most ones were in the first class, while one sample did not receive even the minimum number of points (out of class), which significantly lowered the average score. For taste, this sample received only 4.50 points due to the pronounced bitterness. The ratings of the remaining samples for taste were good. The smell and taste of most samples were mild, typically milky with a specific smell and taste of smoke.

Table 4. Sensory evaluation of Kajmak
Tabela 4. Senzorna ocjena Kajmaka

Property	**Min.**	**Max.**	**Mean**	**St. dev.**	**CV (%)**
Appearance	0.50	2.00	1.60	0.39	24.37
Color	1.00	2.00	1.73	0.31	17.91
Consistency	1.00	3.00	2.56	0.52	20.31
Odor	1.00	3.00	2.44	0.62	29.56
Taste	4.50	9.25	8.19	1.30	15.87
Total	8.50	18.50	16.50	2.76	16.72

Table 5. Sensory evaluation of Skimmed milk cheese
Tabela 5. Senzorna ocjena Posnog sira

Property	**Min.**	**Max.**	**Mean**	**St. dev.**	**CV (%)**
Appearance	0.75	0.50	0.69	0.11	22.00
Color	1.50	2.00	1.92	0.16	10.67
Consistency	3.00	3.75	3.52	0.29	9.67
Odor	2.00	3.00	2.60	0.36	18.00
Taste	4.50	9.50	8.27	1.32	29.33
Total	13.25	19.00	17.00	1.63	12.30

Even Skimmed milk cheese is classified in the first class according to the average overall rating, like Kajmak, the ratings are still slightly higher compared to Kajmak. Three samples were in the extra class, one was on the very border, while there were no samples outside the class, and only one sample was in the Class II. The appearance of the cheese was uneven, and the color and consistency quite uniform and regular. The results of chemical analyzes and sensory evaluation showed quite uneven quality.

Distribution of dry matter and correlation relationships in Kajmak and Skimmed milk cheese manufacture in the area of Romanija mountain

Calculating the distribution of milk dry matter as the initial raw material in the production of Kajmak is a good indicator of the correctness of the technology and profitability in production. The distribution shows how much dry matter of milk goes into Kajmak, Skimmed milk cheese and whey in the production of Skimmed milk cheese after removing Kajmak. In the literature, data for the distribution in production of different types of cheese can be found.
Jovanović *et al.* (2006) examined the distribution in the production of semi-hard cheeses based on milk protein aggregates and found that the average distribution of dry matter between cheese and whey was 57.37:42.63%. Dozet *et al.* (1978a) are in the production of Travnik cheese, and Seratlić *et al.* (2006) in the production of Gorgonzola type cheeses with blue-green molds found the distribution of dry matter in cheese and whey to be 46.11:53.89% and 63.06:36.91%, resp. Some authors have shown that there were differences in the distribution of dry matter between cheese and whey in white brine cheeses produced from sheep's and cow's milk. In the production of Travnik cheese from sheep's milk, the distribution of dry matter in cheese and whey was on average 50.66:49.34%, and from cow's milk it was higher in favor of whey, 39.12:60.88% (Dozet *et al.*, 1979). Similar results were obtained by Savić *et al.* (2015) in the autochthonous production of Sjenica cheese from sheep's and cow's milk. The distribution of dry matter in cheese and whey was more favorable in the case of sheep's milk (61.14:38.85%) compared to cow's milk (48.68:51.32%). The dependence of the distribution on the fat content in milk in the production of Travnik cheese was monitored by Dozet *et al.* (1978b). Reducing the fat content in milk from 3.75 to 3.00% did not significantly change the distribution of dry matter in cheese and whey. In the production of streched curd cheeses, the distribution of dry matter in cheese and whey was from 40.68:59.32% to 42.86:57.14 (Dozet *et al.*, 1974b). Bijeljac (1987) also found significant differences in the distribution of milk dry matter components in the production of hard cheese of the Livno type and white brine cheese of the Travnik type.

Table 6. Distribution of milk dry matter in production of Kajmak (%)
Tabela 6. Distribucija suhe materije u proizvodnji Kajmaka (%)

Products	**Min.**	**Max.**	**Mean**	**St. dev.**	**CV (%)**
Kajmak	15.17	62.31	33.53	12.20	36.38
Skimmed milk cheese	14.81	37.76	26.62	6.20	23.29
Whey	15.67	63.05	40.67	12.31	30.27

The distribution of milk ingredients in the production of Kajmak has not been studied so far. The calculation is somewhat more complicated than in the production of cheese,

because in the traditional production, Kajmak, Skimmed milk cheese and whey are produced (product, co-product and by-product), while in traditional cheese production only whey is still taken into account. The distribution data varies significantly and, if looking at the average values, the proportion of dry matter that goes in the whey is quite high. However, if one bear in mind that most of the lactose and a good part of the mineral matter, and some of the whey protein that may remain after cooking the milk go into whey, and the fact that whey has the highest amount of all (and the amount must also be taken into account), then this is not surprising. Finally, similar results were obtained in cow's milk cheese production, as can be seen from the results found in literature. However, Kajmak and Skimmed milk cheese taken together make up a larger portion.

In an effort to determine the relationship between the content of dry matter and fat of milk with the content of dry matter, fat and fat in the dry matter of Kajmak and Skimmed milk cheese, and the yield of Kajmak and Skimmed milk cheese, correlations were examined using the Pearson's correlation coefficient.

In production of Kajmak, a strong positive correlation was established between: dry matter and fat content of milk (r=0.740), dry matter and fat content of Kajmak (r=0.795), fat and fat in dry matter content of Kajmak (r=0.874) and dry matter content in milk and Kajmak yield (r= 0.718). A moderately strong positive correlation coefficient exists between fat content in milk and fat content in Kajmak (r=0.500), dry matter content in milk and fat in dry matter content in Kajmak (r=0.372), fat content in milk and dry matter content in Kajmak (r=0.416). There were no other significant correlations with yield or they were negative. In the case of Skimmed milk cheese, the correlations were weaker, and a strong ones were recorded between: content of dry matter and fat of cheese (r= 0.861) and fat in dry matter of cheese (r= 0.732) and content of fat and fat in dry matter of cheese (r= 0.977). A moderately strong positive correlation coefficient were recorded between: dry matter content of Kajmak and cheese (r= 0.404) and dry matter content of Kajmak and fat content of cheese (r= 0.569). High negative correlation coefficients were determined in the relationships between yield of Kajmak and dry matter content of cheese (r= -0.767) and fat content of cheese (r= -0.610), yield and dry matter content of cheese (r= -0.730), yield and fat content of cheese (r= -0.716) and yield and fat in dry matter content of cheese (r= -0.633). This shows as the mass of Kajmak or Skimmed milk cheese increases, the content of fat and dry matter in the cheese decreases. Correlation results are in agreement with the results obtained by Sarić (1995), who established a strong dependence of fat and fat content in the dry matter of Kajmak on the fat content in milk, and a slightly weaker relationship was established with yield (Stanišić *et al.*, 1990). It can be concluded that the indicators of Kajmak and Skimmed milk cheese are mutually dependent and intertwined. Yield of Kajmak and to a lesser extent fat in the dry matter of Kajmak depend on the dry matter content of the milk, and the content of fat depend to a good extent on the fat content of the milk, as shown by the correlation analysis.

CONCLUSIONS

Kajmak is an autochthonous product of the Balkan countries, which is characterized by a high fat content and can be consumed both as "young" and "mature". The region of Romanija mountain is known by the production of Kajmak of high and special quality. What distinguishes it from Kajmak from other region is the smoking process, so it is characterized by a mild smell and smoky taste. Kajmak from Romanija mountain in research had good quality, with a high content of fat and fat in dry matter. Due to non-standardized technology and uneven content of dry matter in milk, the chemical composition and yield of Kajmak varies considerably. Skimmed milk cheese is produced from the milk that remains after removing the "crust" of Kajmak. Due to the non-uniformity of technological parameters and raw materials, the composition and yield of Skimmed milk cheese also varied. By analyzing the distribution of milk ingredients in Kajmak, Skimmed milk cheese and whey, it was established that the largest percentage goes into whey due to the large mass of whey in production. It was determined that the fat content of milk for the production of Kajmak has a significant influence on the fat content of Kajmak, and the dry matter content of milk has an effect on the yield and fat in dry matter content of Kajmak. It can be stated that Kajmak is a high-quality, specific dairy product that deserves a special place in the classification of dairy products. Research has shown that standardization of the parameters of the technological production process is necessary in order to achieve a more uniform quality and yield of Kajmak.

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KVALITET I TEHNOLOGIJA KAJMAKA I POSNOG SIRA NA PODRUČJU PLANINE ROMANIJE

Sažetak

Kajmak je autohtoni mliječni proizvod koji se proizvodi u planinskom Dinarskom sistemu Balkana već vijekovima. Konzumira se kao "mladi" ili "zreli" koji nastaje nakon procesa zrenja. Karakterizira ga visok sadržaj masti i značajan sadržaj proteina, prvenstveno kazeina. Posebno je kvalitetan dimljeni Kajmak sa područja planine Romanije koji dimljenjem poprima blagi okus i miris po dimu.
U ovom radu je istraživana tehnologija, hemijski sastav i senzorni kvalitet Kajmaka sa šireg područja Romanije. Kajmak je proizveden od kravljeg mlijeka. U okviru ovih istraživanja ispitan je sadržaj suhe materije i masti mlijeka za proizvodnju Kajmaka, te uticaj na sadržaj suhe materije, masti i masti u suhoj materiji kao i randman Kajmaka. Takođe je istražena tehnologija Posnog sira koji se pravi od obranog mlijeka nakon skidanja masnog sloja – Kajmaka. Ispitan je njegov randman, sadržaj suhe materije, masti i masti u suhoj materiji, Analizirana je distribucija sastojaka mlijeka u Kajmak, Posni sir i surutku.
Rezultati su pokazali dobar kvalitet Kajmaka, sa visokim sadržajem masti i masti u suhoj materiji. Tehnologija varira zavisno od uslova proizvodnje i sirovine pa je to uslovilo i prilična variranja u sastavu, randmanu i senzornim svojstvima Kajmaka. Analizom distribucije sastojaka mlijeka u proizvodnji ustanovljeno je da najveći procenat suhe materije mlijeka pređe u surutku zbog toga što se u proizvodnji Kajmaka/Posnog sira generiraju najveće količine surutke. Korelaciona analiza je pokazala da su parametri proizvodnje Kajmaka i Posnog sira međusobno povezani. Korelaciona analiza je pokazala da je randman Kajmaka je pod uticajem suhe materije mlijeka, a na sadržaj masti i masti u suhoj materiji Kajmaka utiče sadržaj masti mlijeka.

Ključne riječi: *Kajmak, Posni sir, mast, suha materija, kvalitet*

COMPARATIVE ANALYSIS OF OVEN-DRYING AND KARL FISCHER TITRATION WITH DIFFERENT SOLVENTS FOR WATER DETERMINATION IN EVAPORATED MILK

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Original scientific paper

Abstract

A crucial aspect of every food product's quality is its water content. The possibility of sample degradation or chemical transformation, as well as the possible loss of volatile chemicals during heating, make it extremely difficult to determine with accuracy. Karl Fischer (KF) titration is one of the most extensively used analytical procedures since it is based on a well-established chemical reaction and has specificity for water. However, in complicated matrices, particularly those that contain both sugars and proteins, even KF titration might produce unreliable findings. Foods often have complex compositions. In many cases they are composed of proteins, sugars, fats, water, and many other constituents. This study evaluates the suitability of two different methods for water content measurement in evaporated milk samples. Two different extraction solutions were used with KF method: solvent - (KF) and boiling methanol -KF (BM). Measuring with solvent as extraction solution was made on two temperatures: room temperature - (KF) and 50 °C - KF (50 °C). Classical heating oven (Oven) was used as reference. Every measurement by KF titration was made in ten replications. Measurements with heating oven were made in five replications. A total of 105 determinations were conducted. For statistical evaluation, descriptive statistics (maximum, minimum, average and standard deviation), correlations and Student´s t-test were used. All methods showed high precision. Comparisons were tested and differences were evaluated at a given confidence level ($p < 0.05$). There is statistically significant difference between KF (room temperature) and KF (BM) and KF (50°C) and KF (BM). KF and KF (50 °C) did not show statistically significant difference. All methods are in good agreement with heating oven. Classical KF at room temperature is recommended due to comparable precision and shorter analysis time.

Keywords: *Water content; Karl Fischer titration; evaporated milk; extraction solvent; analytical comparison*

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INTRODUCTION

Water constitutes anywhere from as little as 1% to as much as 80–90% of the total weight of food materials, highlighting its essential role in food systems (Joardder *et al*., 2019). The unique physicochemical properties of the water molecule continue to captivate chemists, physicists, and food scientists alike. Accurately quantifying water content in various substances remains a significant analytical challenge. Despite appearing straightforward, this task is often complex and can yield inconsistent or conflicting results. This complexity arises from water's diverse interactions with a wide range of molecular species, leading to variable physicochemical behaviors depending on the specific chemical environment (Isengard, 2006).

The conventional approach to determining water content is based on the weight loss technique, which involves first weighing a sample and then heating it to a specific temperature in a drying oven to promote water evaporation. The sample will have lost water by evaporation after a predetermined amount of time, at which point it is weighed once more. Water loss is the cause of the weight difference if water is the only volatile component in the sample (De Caro *et al*., 2001). Water and other evaporative fluids are not distinguished by drying techniques such as hoover drying, freeze drying, infrared drying, microwave drying or conventional oven drying. These methods provide the mass loss that the product undergoes under the given circumstances, not the water content (Felgner *et al*., 2008). One chemical method for determining the water content of different materials is Karl Fischer titration (KFT). Only the water content of a sample may be detected using this technique; other components cannot. The following reaction equation (eq. 1) describes the chemical reaction that produces this selectivity and involves the water in the sample, an alcohol, imidazole as a base, sulfur dioxide, and iodine (Scholz, 1984).

Equation 1: $H_2O + I_2 + SO_2 + 3RN + ROH \rightarrow (RNH)_2SO_4R + 2(RNH)I$.

KF is a practical technique for determining the amount of water in a variety of materials, including samples that are insoluble or less soluble. In complex food matrices such dairy and meat products, honey, sweets, chocolate, fruits and vegetables, spices, and cereal items, the water content can be readily and specifically ascertained (Hădărugă *et al*., 2016; Hădărugă *et al*., 2012). The extraction of water during KF titration in complex samples could be a limitation of this method. One complex diary product is evaporated milk. Evaporated milk is produced by evaporating water from milk, without adding sugar or any preservatives. The canned version undergoes heat sterilization at temperatures between 118 and 122 °C for a few minutes (Hess, 2003). Evaporated milk has lower amount of water (arround 75 %), in comparison to milk (arround 88%) (Hariono *et al*., 2024; Nouh *et al*., 2017; Fox *et al*., 2015).

Due to the problematic water determination in complex foods (difficult water extraction), the aims of this research arise:

- Comparing two different Karl Fischer solvents and temperatures for water determination.
- Suggestion of the right method for determination of water content in evaporated milk.

MATERIALS AND METHODS

Samples

Samples of evaporated milk for analysis were commercially available, from same producer. They were labeled as samples 1, 2 and 3. To test the method's performance for different sample matrices, all samples had different amounts of proteins, fats and sugars (Table 1.)

Table 1. Basic composition (%) evaporated milk samples stated on the product label

Sample	1	2	3
Proteins (%)	2.8	5.8	5.8
Fats (%)	12.0	12.0	3.0
Sugars (%)	4.0	7.6	8.1

Methods

For determination of water content in samples of evaporated milk the volumetric Karl Fisher titration was used. The measurements were conducted by means of 905 Titrando (Metrohm) instrument. Prior to the measurements the samples were tempered by the room temperature. Samples were taken with syringe with needle. The mass of the syringe with needle and sample was determined before and after the introduction of sample into the titration cell. For extraction medium two different substances were used: commercially available solvent (KF) and methanol KF (BM). Karl Fischer solvent (Sigma Aldrich) is often used for extraction of water from samples; it is two component solvent based on methanol. The extraction procedure with solvent was conducted at two different temperatures: room temperature - (KF) and 50 °C - KF (50 °C). Pure methanol (Sigma Aldrich) is also used for water extraction. In this research the extraction of water was also conducted in boiling methanol. Titrating with Karl Fischer in boiling methanol is a practical method that increases the speed and accuracy of the analysis. This is because heating to the boiling point of methanol (65 °C) enhances the solubility and extraction of water from the sample. The stoichiometry of the Karl Fischer reaction remains unchanged (Isengard & Striffler, 1992). As reference method a classical heating oven (Oven) was used.

A single titration typically takes 1-2 minutes, making the KF titration a quick, accurate, and precise analysis method. Another advantage of this method is its broad measurement range, which essentially covers the entire water content range of 1% to 100%. This allows samples with varying water contents to be titrated volumetrically using a single instrument (De Caro *et al*., 2001). The difference between coulometric and volumetric method is that in volumetric method, the amount of reagent consumed indicates the amount of water. It is normally used for higher amounts of water ranging from 0.1% to 100%. Prior to sample measurements the instrument was standardized with standard with known water content. All measurements were made in ten parallels. Instrument parameters are presented by Table 2.

Table 2. Instrument parameters

Stop criteria:	Absolut drift: 20 µg/min
Titrant	Titrant 2 (Sigma Aldrich)
Working medium	20 mL solvent + 20 mL formamide (Sigma Aldrich)
Temperature:	50 °C
Measuring cell:	Volumetric
Sample mass:	0.1500-0.2500g

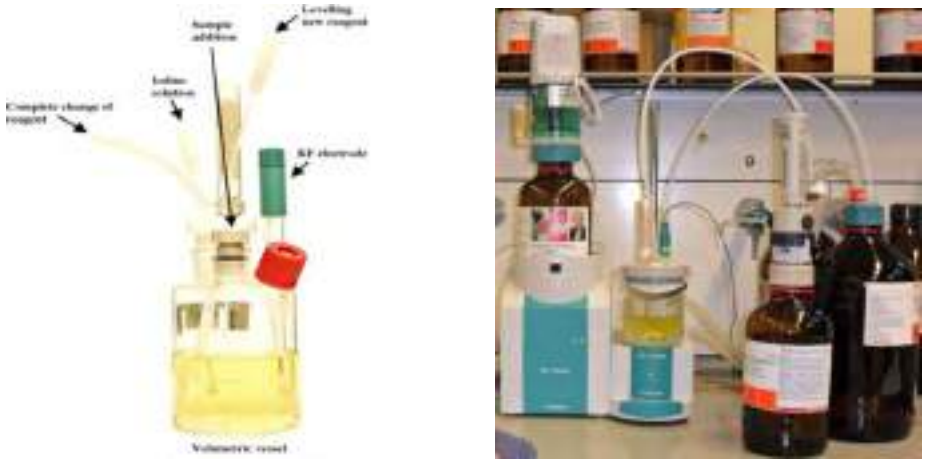

Figure 1. Volumetric reaction chamber setup (Felgner *et al*., 2008), and Classical Karl Ficher titration device

As reference method the classical oven was used. The heating process was conducted on 105 °C for four hours. Sample mass from 2-4 g was weighted with precision of ±0.0001 g, mixed with silicate sand and heated. After the heating the sample was weighed again. The heating and weighting process continued until the constant mass was reached.

Statistical evaluation

Using metrics like the highest and minimum value, mean (average), and standard deviation (STDEV), descriptive statistics provide an overview of a data set's fundamental characteristics and shed light on its central tendency, variability, and distribution (Ibe, 2014). A statistical metric used to define the linear relationship between two variables is correlation. The correlations in this study are used to determine linearity between used methods. The correlation coefficient (r) ranges listed below show how strong the patterns and connections under investigation are: If the association is between 0.0 and 0.19, it is considered extremely weak; if it is between 0.20 and 0.39, it is considered weak; if it is between 0.40 and 0.59, it is considered moderate; if it is between 0.60 and 0.79, it is considered strong; and if it is between 0.80 and 1.0., it is considered very strong (Papageorgiou, 2022). T test: One popular technique for comparing the mean results of two methods is the student's t-test. The means must be near each other in value if the difference is not statistically significant (Rita & Ekholm, 2007). The standard threshold for significance in a t test is set at $p = 0.05$, as is the case with other significance tests. A t test result is deemed statistically significant if the p-value is less than 0.05. On the other hand, a result is considered insignificant if the p-value is greater than 0.05. (Krzywinski & Altman, 2013). The basic statistical analysis was performed on ten replications within all used methods. Correlations between methods were performed on all three different samples together.

RESULTS AND DISCUSSION

Sample 1

The results of water content measuring of sample 1, by several different techniques are shown within table 3 and figure 2.

Table 3. Results of water measurement of sample 1.

	KF				KF (BM)		
Sample	Mass	Water (%)	Water 50 °C (%)	Extraction Time (s)	Mass	Water (%)	Extraction time (s)
1	0.0398	79.14	78.66	160	0.0685	76.36	180
2	0.0321	79.32	78.51	160	0.0422	76.28	180
3	0.0516	79.91	78.19	160	0.07	76.19	180
4	0.0564	79.91	79.25	160	0.1011	77.41	180
5	0.0348	79.86	78.10	160	0.0601	75.36	180

6	0.0308	78.54	78.56	160	0.0531	78.02	180
7	0.0322	78.64	78.81	160	0.0302	77.57	180
8	0.0666	78.88	81.57	160	0.0311	77.72	180
9	0.0573	81.42	78.58	160	0.1457	77.41	180
10	0.0348	79.92	78.16	160	0.0513	78.00	180
Max.	0.0666	81.42	81.57	160	0.1457	78.02	180
Min.	0.0308	78.54	78.10	160	0.0302	75.36	180
Mean	0.0436	79.55	78.84	160	0.0653	77.03	180
STDEV	0.01	0.85	1.02	0	0.03	0.91	0
Oven mean:				79.60%			
Oven STDEV:				0.08			

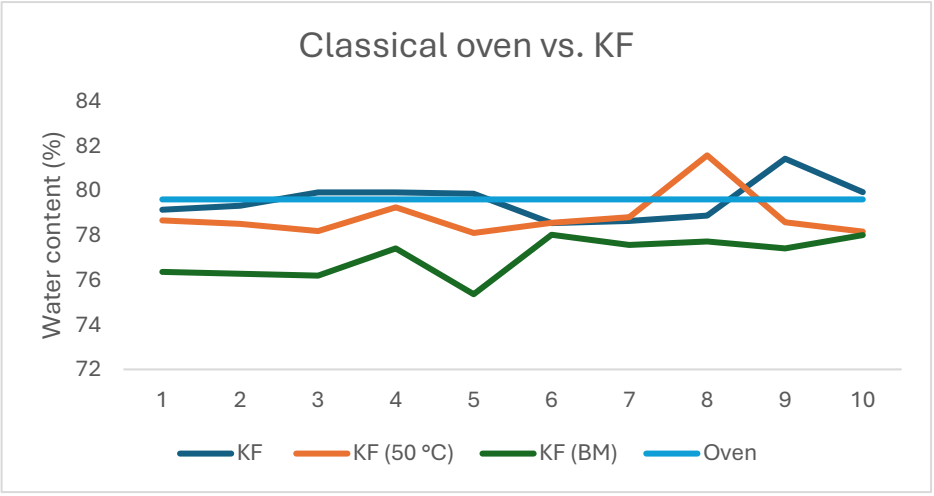

Figure 2. Comparison of reference method with different KF conditions (solvents and temperatures)

The highest mean water content in sample 1 was obtained using the classical Karl Fischer titration performed in solvent at room temperature, yielding a value of 79.55%. This indicates that under these conditions, the Karl Fischer method achieved the most efficient extraction and quantification of water. A comparable average value was obtained using the classical oven-drying method (79.60%), suggesting strong agreement between these two analytical techniques. Similar water content levels have been reported by Lewis (2023), supporting the reliability of these findings. The determination of moisture content in evaporated milk samples by drying techniques is also recommended by *National Condensed Milk Regulation* (2011).

Notably, sample 1 exhibited the lowest concentrations of proteins and sugars among all analyzed samples, which may contribute to its relatively higher apparent water content due to reduced matrix interactions and fewer hygroscopic constituents.
Furthermore, the solvent-based Karl Fischer titration at room temperature yielded the lowest standard deviation across ten replicates, demonstrating excellent precision and reproducibility of this analytical approach.

Sample 2

Table 4. Results of water measurement of sample 2.

		KF			KF (BM)		
Sample	Mass	Water (%)	Water 50 °C (%)	Extraction Time (s)	Mass	Water (%)	Extraction time (s)
1	0.0359	71.68	70.68	150	0.0469	71.87	160
2	0.0509	72.38	71.18	150	0.0369	72.12	160
3	0.0354	72.01	70.97	150	0.042	71.33	160
4	0.0444	73.62	70.44	150	0.0321	70.24	160
5	0.0384	73.01	70.87	150	0.0248	70.88	160
6	0.0355	72.87	72.38	150	0.0432	71.21	160
7	0.0518	72.35	71.14	150	0.0308	71.99	160
8	0.0533	72.18	71.56	150	0.0446	70.93	160
9	0.0589	73.26	71.43	150	0.0344	72.11	160
10	0.0381	72.40	71.43	150	0.0291	72.05	160
Max.	0.0589	73.62	72.38	150	0.0469	72.12	160
Min.	0.0355	71.68	70.44	150	0.0291	70.24	160
Mean	0.0442	72.58	71.21	150	0.03648	71.47	160
STDEV	0.01	0.59	0.54	0	0.007431	0.65	0
Oven mean:				72.59%			
Oven STDEV:				0.08			

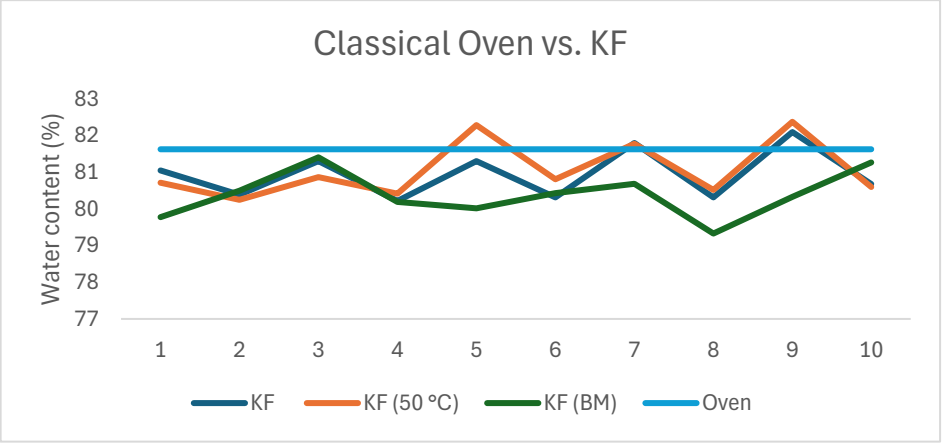

Figure 3. Comparison of reference method with different KF conditions (solvents and temperatures)

When the water content of "Sample 2" was quantified by the classical Karl Fischer titration in solvent at ambient temperature, the highest mean value obtained was 72.58 %. The near-equivalent mean result obtained by the conventional oven-drying method (72.59%) suggests that, under these conditions, both methods extracted essentially the same water fraction.

Importantly, Sample 2 also exhibited higher protein and sugar levels compared to Sample 1, implying that the matrix contained greater amounts of hydrophilic ("water-binding") constituents. The fact that the KFT solvent-extraction approach yielded the highest mean—and indeed the lowest standard deviation over ten replicates - demonstrates both the efficacy of the extraction protocol in this matrix and the high precision of the method.

This observation is consistent with earlier work indicating that KFT can offer superior repeatability and extraction of "strongly bound" water in complex matrices relative to some gravimetric methods (Thiex & Richardson, 2003).

Sample 3

Table 5. Results of water measurement of sample 3.

		KF			KF (BM)		
Sample	Mass	Water (%)	Water 50 °C (%)	Extraction Time (s)	Mass	Water (%)	Extraction time (s)
1	0.0576	81.05	80.39	150	0.0492	79.78	160
2	0.0353	81.31	80.22	150	0.092	80.50	160
3	0.0315	81.31	80.32	150	0.0266	81.41	160
4	0.0297	81.80	80.32	150	0.0495	80.19	160
5	0.0364	82.10	80.68	150	0.0386	80.02	160
6	0.0313	80.72	80.25	150	0.0598	80.43	160
7	0.0363	80.87	80.42	150	0.0308	80.69	160
8	0.0353	82.29	80.81	150	0.0787	79.33	160
9	0.037	81.78	80.52	150	0.0652	80.33	160
10	0.0428	82.38	80.60	150	0.0213	81.27	160
Max.	0.0576	82.38	80.81	150	0.0920	81.41	160
Min.	0.0297	80.72	80.22	150	0.0213	79.33	160
Mean	0.03732	81.56	80.45	150	0.05117	80.39	160
STDEV	0.01	0.59	0.19	0	0.02	0.63	0
Oven mean:				81.63%			
Oven STDEV:				0.106			

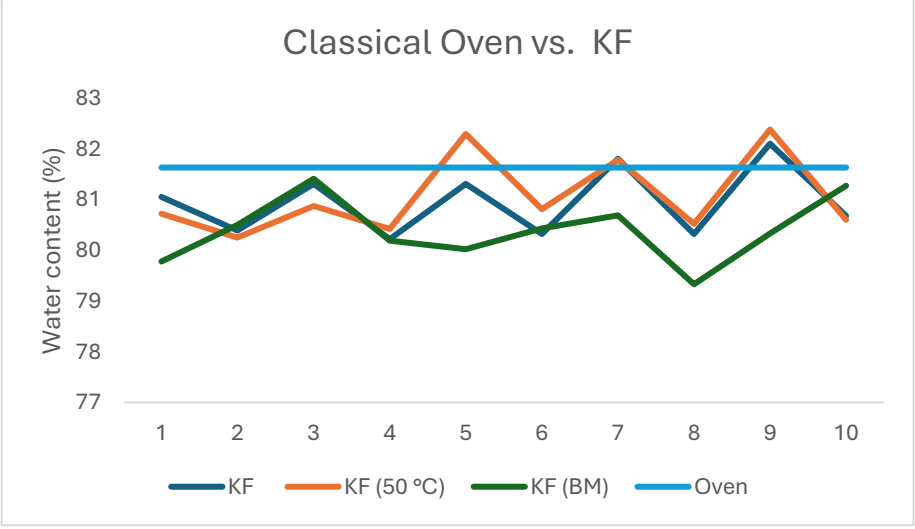

Figure 4. Comparison of reference method with different KF conditions (solvents and temperatures)

The highest mean water content was observed in Sample 3, as determined by the conventional Karl Fischer titration method using a solvent at ambient temperature, with a recorded value of 81.56%. This result indicates that the solvent-based Karl Fischer technique efficiently extracts and quantifies the total water content in evaporated milk. Comparable results were obtained using the conventional oven-drying method, which yielded an average value of 81.63%, confirming the consistency between both analytical approaches. The elevated water content in this sample was anticipated, as Sample 3 exhibited the lowest fat concentration among all analyzed samples. Since fat content inversely influences water retention in milk products, reduced lipid fractions typically correspond to higher relative water contents. Reports concerning water quantification in low-fat evaporated milk remain limited, as most published data pertain to regular evaporated milk formulations (Hariono *et al.*, 2024). Furthermore, the low standard deviation obtained across ten replicates for the solvent-based Karl Fischer method demonstrates its high analytical precision and repeatability for determining water content in dairy matrices.

Correlations

The highest correlation between methods is presented by figure 5.

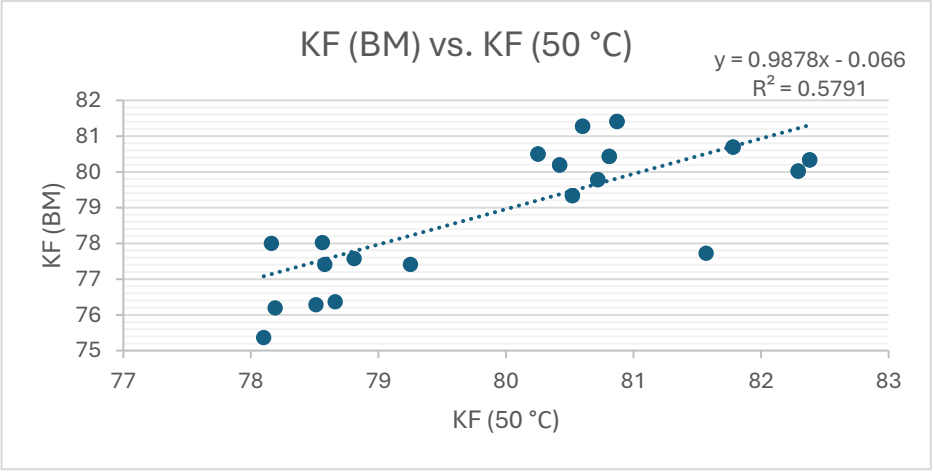

Figure 5. Correlation between results of KF(BM) and KF (50 °C)

All Karl Fischer (KF) titration methods exhibited moderate inter-method correlations, indicating a reasonable degree of agreement among the analytical techniques. The strongest correlation (r = 0.760) was observed between the KF method performed at 50 °C and the method employing the BM solvent system. Such a correlation coefficient reflects that these two analytical protocols yield comparable trends in water quantification, suggesting consistency in their relative measurement behavior. Nevertheless, a strong correlation does not inherently confirm the accuracy or trueness of the methods. Instead, it indicates that when one method records a relatively higher or lower water content, the corresponding method tends to exhibit a proportional variation in the same direction, implying systematic alignment in measurement patterns rather than equivalence in absolute values.

Students t-test analysis

The results of Students t-test analysis are shown by table 7.

Table 7. t test results

KF vs. KF (50 °)

	KF		KF (50 °C)		
N:	30	N:	30		
Mean:	80.485	Mean:	80.322		
Variance:	0.95014	Variance:	1.8434		
Difference between means:	0.16233				
Uneq. var. t :	0.53197	p:	0.59698	t value (p=0.05):	2

KF vs. KF (BM)

	KF		KF (BM)		
N:	30	N:	30		
Mean:	80.485	Mean:	79.274		
Variance:	0.95014	Variance:	3.1059		
Difference between means:	1.2107				
Uneq. var. t :	3.2926	p:	0.0019	t value (p=0.05):	2

KF (50 °) vs. KF (BM)

	KF (50 °C)		KF (BM)		
N:	30	N:	30		
Mean:	80.322	Mean:	79.274		
Variance:	1.8434	Variance:	3.1059		
Difference between means:	1.0483				
Uneq. var. t:	2.581	p:	0.0019	t value (p=0.05):	2.0

The results of the independent t-tests comparing the different Karl Fischer (KF) titration methods revealed statistically significant differences between the standard KF method and KF (BM), as well as between KF (50 °C) and KF (BM) ($p < 0.05$). Conversely, no statistically significant difference ($p > 0.05$) was detected between the standard KF method and KF (50 °C), indicating that these two conditions produce comparable mean water content values. This outcome suggests that temperature elevation to 50 °C does not substantially influence the quantification efficiency or analytical response of the KF method under the tested conditions, whereas the use of the BM solvent system introduces a systematic deviation relative to the standard protocol.

CONCLUSIONS

For the determination of water content in evaporated milk, the classical Karl Fischer (KF) titration employing a standard solvent system at ambient temperature is recommended, as it offers an optimal balance between analytical accuracy and operational efficiency. The KF titration conducted at 50 °C produced comparable results, with the *t*-test revealing no statistically significant difference between the two methods ($p = 0.597$). All KF approaches exhibited moderate inter-method correlations, indicating a consistent linear relationship among the measurement trends across the techniques. Although the classical oven-drying method demonstrated the lowest standard deviation, suggesting superior measurement precision, it required substantially longer analytical durations (several hours) compared to the KF titration methods, which typically achieve complete analysis within a few minutes. Consequently, while the oven-drying method remains valuable for reference validation, the classical KF titration represents a more practical and time-efficient approach for routine determination of water content in evaporated milk.

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USPOREDBA PEĆNICE I KLASIČNE KARL FISCHER TITRACIJE S RAZLIČITIM OTAPALIMA ZA ODREĐIVANJE VODE U UZORCIMA ISPARENOG MLIJEKA

Abstract

Ključni aspekt kvalitete svakog prehrambenog proizvoda je njegov sadržaj vode. Mogućnost degradacije uzorka ili kemijske transformacije, kao i mogući gubitak hlapljivih kemikalija tijekom zagrijavanja, izuzetno otežavaju točno određivanje. Karl Fischer (KF) titracija jedan je od najčešće korištenih analitičkih postupaka jer se temelji na dobro utvrđenoj kemijskoj reakciji i ima specifičnost za vodu. Međutim, u složenim matricama, posebno onima koje sadrže i šećere i proteine, čak i KF titracija može dati nepouzdane nalaze. Hrana često ima složen sastav. U mnogim slučajevima sastoji se od proteina, šećera, masti, vode i mnogih drugih sastojaka. Ovo istraživanje bavi se mjerenjem sadržaja vode u složenoj hrani koja sadrži masti, proteine i šećere te mnoge druge spojeve. Za ovo istraživanje korištena su tri različita uzorka kondenziranog mlijeka. KF metodom korištene su dvije različite otopine za ekstrakciju: otapalo i kipući metanol (BM). Mjerenje s otapalom kao otopinom za ekstrakciju provedeno je na dvije temperature (sobna temperatura i 50 °C). Klasična peć za zagrijavanje korištena je kao referenca. Svako mjerenje KF titracijom provedeno je u deset ponavljanja. Mjerenja s pećnicom za zagrijavanje provedena su u pet ponavljanja. Na kraju je izmjereno 105 uzoraka. Za statističku evaluaciju korištena je deskriptivna statistika (maksimum, minimum, prosjek i standardna devijacija), korelacije i Studentov t-test. Sve metode pokazale su visoku preciznost. Postoji statistički značajna razlika između KF i KF (BM) te KF (50 °C) i KF (BM). KF i KF (50 °C) nisu pokazali statistički značajnu razliku. Sve metode se dobro slažu s pećnicom za zagrijavanje. Za mjerenje sadržaja vode u uzorcima kondenziranog mlijeka predlaže se klasična KF na sobnoj temperaturi.

Ključne riječi: *sadržaj vode, Karl Fischer, rastvarač, ključali metanol, temperatura*

APPLICATION OF AGROTECHNICAL MEASURES AND ECONOMIC SUCCESS IN WHEAT AND MAIZE CULTIVATION IN THE BRČKO DISTRICT AREA

Merima Makaš*[1], Dimitrije Ševo[1], Drena Gadžo[1], Emir Bećirović[1]

Original scientific paper

Abstract

In Bosnia and Herzegovina, wheat and maize are the most important crops, holding a dominant position in the country's arable land. Consequently, this paper analyses wheat and maize production in the Brčko District, focusing on the applied agrotechnical measures and the economic results, as reflected by the gross margin per hectare. The research involved 30 farms in the district, with more than 1.5 hectares of the targeted crops. Data was collected through structured survey questionnaires, which included detailed questions about the applied agrotechnical practices, yields, costs, and revenues. The results indicate that average yields are 5.3 tons/ha for wheat and 8.7 tons/ha for corn. Economic analysis shows that the gross margin was 639 KM/ha for wheat and 1,611 KM/ha for corn. The higher financial results for maize are partly due to higher yields and more stable production. Conversely, the moderate gross margin for wheat highlights the need to optimize agrotechnical measures to boost productivity and economic profitability. The largest share of total costs is for mechanization and mineral fertilizers, while the most notable irregularities in applying agrotechnics occurred in fertilization, mainly due to the lack of soil fertility analysis. Therefore, this paper recommends conducting soil analysis before fertilization to optimize costs and prevent unnecessary fertilizer application.

Keywords: *corn, wheat, Brčko District, agrotechnical measures, gross margin*

INTRODUCTION

Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) represent two of the most important cereal crops within the crop production systems of Bosnia and Herzegovina. According to data from the Agency for Statistics of BH (2025), the harvested area of wheat was 59,569 ha, and that of maize was 121,966 ha, which accounted for 44.2% of the total cultivated arable land in BiH. Sustainable and profitable production of these crops depends on a wide range of factors, among which agrotechnical measures play a central role—from the choice of variety or hybrid, crop rotation, and soil tillage, to sowing, fertilization, plant protection, harvesting, and storage.

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Each of these elements must be viewed as equally important, as final yield is often limited by the step that is executed least effectively (Marinković *et al*., 2008). Agrotechnics forms the foundation for organizing and executing all production processes in agriculture, and its importance is particularly evident in arable crop systems. As a set of interconnected measures, it aims to create optimal conditions for plant growth and development, ensure the efficient use of land and inputs, and ultimately achieve high and stable yields (Glišić & Đurović, 2015). Several authors emphasize that both the choice of variety/hybrid and the level of applied agrotechnics have a comparable influence on cereal yields (Kovačević & Rastija, 2014), while weather conditions contribute to yield variability that can often be mitigated through timely and proper implementation of technical measures. Particularly important are measures such as soil tillage, crop rotation, fertilization, weed, disease and pest control, irrigation, and the selection of well-adapted varieties or hybrids. The proper combination of these practices forms the basis of sustainable production, enabling a balance between economic efficiency and the preservation of the agroecosystem (Tomić & Marković, 2019).

Under the growing pressures of climate change, particularly more frequent droughts and heatwaves, the importance of agrotechnical practices becomes even more pronounced. Recent study shows that integrated crop management (ICM) can increase wheat and maize yields by 16-30 % while improving resource-use efficiency (Deng *et al*., 2022; Yamini *et al*., 2025). At the same time, diversifying crop rotations—especially by including legumes and other complementary crops—tends to increase yields and net returns while reducing greenhouse gas emissions (Yang *et al*., 2024).

Additionally, in dry climate conditions, adjusting irrigation and sowing density improves the physiological and agronomic parameters of cereal crops, thereby increasing their resistance to stress (García-Caparros *et al*., 2025). Furthermore, agroecological practices such as intercropping contribute to reducing weeds and the need for mineral fertilizers, increase nitrogen use efficiency, and stabilize yields (van Cossel *et al*., 2025). Modern trends in agriculture focus on integrated management of agronomic practices, combining traditional knowledge with precision agriculture technologies, digital monitoring, and soil conservation (FAO, 2020). Such an approach allows for resource reduction, biodiversity preservation, and adaptation of production to the demands of sustainable development (Lal, 2021).

Jaćimović *et al*. (2011) observed that nitrogen has the greatest impact on wheat yield when examining the efficiency of mineral nutrition, where the application of only nitrogen (100 kg N/ha) resulted in an increase in yield of 85% or 2 tons/ha compared to the control. The greatest increase in yield per kilogram of fertilizer used was with nitrogen (an average of 32.20 kg of grain per kg of N used over two years); followed by phosphorus (10.52 kg of grain per kg of P_2O_5), and the least with potassium (5.85 kg of grain per kg of K_2O). The agronomic efficiency of nitrogen tended to decrease with increasing fertilization intensity.

The effects of inter-row cultivation depend on whether herbicides were applied or not, the level of weed infestation, and whether the year was normal, wet, or dry. Lazić *et al*.

(1995) documented that on a plot partially weeded with wild mustard, one cultivation increased the yield by 4.4%, and two cultivations by 18.9%. Also, in another study by the same author, in the second year, one cultivation increased the yield by 7.8%, and two by 9.8%.

Crop rotation can significantly reduce the number of weeds in crops (Liebman and Dyck, 1993). Crop sequences, whether two-year or three-year, as a single system of plant production, can be more effective in weed suppression than monoculture. Weed infestation is mainly a logical consequence of improper selection of predecessors, the effects of crop rotation, and untimely or insufficient weed control. Growing crops in rotation is sometimes not only the most important measure but also the only one that effectively supports weed protection. Crop rotation practically prevents the overrepresentation of certain species and hinders their spread (Kovačević *et al.*, 2008). Regarding soil contamination, Saulić *et al.* (2017) observed twice as much weed seed in soybean monoculture compared to when it was grown in a soybean-wheat-maize rotation. Increased amounts of weed seed in monoculture were also noted by Forcella and Lindstrom (1988), who reported levels twice as high as in the soybean-maize rotation.

With modern scientific advances, high-yielding varieties and hybrids have been developed, and to express their potential, it is necessary to increase soil fertility through fertilization. To achieve a significant increase in yield, overall agricultural techniques need to be elevated to a new level, with fertilization playing a particularly important role, as it contributes 50 to 70% to yield increase (Gašpar, 2000).

Brčko District of Bosnia and Herzegovina possesses exceptional natural resources for the development of primary agricultural production. Agricultural land covers 16.980 hectares (2024), which accounts for 71.5% of the total district territory, with the largest part located along the Sava River and classified as high-quality land. Of this area, arable land (plowed and cultivated land) occupies 12.427 hectares, or 68.1% of the total land. In the structure of arable land, the most represented are arable lands at 60.7% (Study, 2007).

In most of the territory, pseudogley soils are present, which have poorer physical and chemical characteristics (clayey, more difficult to cultivate, acidic reactions), while more favorable agricultural lands (eutric cambisols, fluvisols, humofluvisols) are found in the valleys of the Tinja, Brka, and Sava rivers (Study, 2007). According to data from 2024 (BHAS, 2025), the most widespread arable crop in the Brčko District was grain corn, covering 5,027 hectares, which confirms its role as a strategic crop in human nutrition as well as in livestock. In addition to corn, significant areas are occupied by wheat (1,978 ha), soybeans (2,041 ha), oats (682 ha), barley (886 ha), rapeseed (2,437 ha). This production structure indicates a relatively diversified crop system but also a dominant orientation toward cereal production.

Despite the demonstrated importance of these two crops in agriculture in Bosnia and Herzegovina, as well as in the Brčko District, there are no extensive studies dealing with the economic aspects of cultivating these two crops on a larger number of farms. This was precisely the main motivation for creating this research.

MATERIALS AND METHODS

The research was conducted on a sample of 30 agricultural farms from different parts of the Brčko District. A semi-structured interview was used to collect information about land ownership structure, applied agrotechnical measures (crop rotation, soil cultivation, sowing, fertilization, crop protection), used machinery and fuel consumption, as well as achieved yields and selling prices. The average farm size in the sample was 71.8 hectares, with a predominance of mixed farms (crop-livestock). Based on the collected data, calculations of income and variable costs per hectare for wheat and maize were made. Income was calculated as the product of yield and purchase price in the harvest year, including subsidies per hectare, while variable costs included seeds, mineral fertilizers, plant protection products, machinery costs (fuel, services), and other direct costs. The gross margin (GM) was defined as the difference between total income and total variable costs per hectare (Kay *et al.,* 2015):

$$GM = Revenue – Variable\ cost$$

Data consolidation and all necessary calculations have been done in MS Excel.

It is known that yields in agriculture are prone to variability, and the prices of products on the Bosnian market are quite unstable, so an additional sensitivity analysis of these crops to their changes was conducted. It was verified how the success of the achieved GM would change with variations in prices and yields within the range of 15 – 50%.

RESULTS AND DISCUSSION

In the production of wheat and maize in the Brčko District, farmers mainly apply recommended agrotechnical measures throughout the annual production cycle. This primarily includes systematic soil cultivation, including ploughing, harrowing, or disking. Then, soil fertilization and timely sowing. As observed in the interviews conducted, a shortcoming in farmers' work is the lack of adequate soil analysis. Such an analysis would reveal the actual nutrient requirements of the soil and help improve soil fertility, thereby advancing agricultural production and agrotechnical practices. Additionally, research has shown that farmers do not practice crop rotation, and these two crops are grown in monoculture. This practice certainly affects the increased occurrence of weeds, diseases, and pests. It can also lead to a higher need for chemical treatments.

Therefore, although most agrotechnical measures are implemented to an adequate method used in this area, the lack of adequate crop rotation and soil analysis certainly could affect the quantity and quality of yields achieved.
The results of the wheat production calculation (Table 1) per hectare indicate relatively modest economic efficiency, consistent with general trends across Bosnia and Herzegovina's continental regions. The achieved yield of 5.3 tons/ha can be considered satisfactory for the agro-ecological conditions of the Brčko District, but the total income of 1,890 KM, including subsidies, shows that opportunities for a more significant economic result are limited. Variable costs of 1,251 KM/ha make up nearly two-thirds of the total income, resulting in GM of only 639 KM/ha. It is noticeable that wheat, as a crop with a lower market price and smaller yields, struggles to achieve high profitability without extremely rational input use.

Table 1. Calculations of gross margin in wheat production per ha

(BAM/ha)

Description	Unit	Quantity	Price	Total
A) REVENUE				
Wheat	Kg	5,300	0.30	1,590.00
Subsidies	Ha	1	300	300.00
Total Revenue				**1,890.00**
B) VARIABLE COSTS				
Seeds	Kg	270	1.00	270.00
NPK 15:15:15	Kg	250	0.75	187.00
KAN 27%	Kg	356	0.53	188.29
Plant protection				136.00
Mechanization costs				390.00
Other expenses				80.00
Variable costs				1,251.29
GM (A-B)				**638.71**

The cost structure shows that mechanization (390 KM) and mineral fertilizers (a total of 375 KM) account for over 60% of total variable expenses, which is consistent with the cost profile of this crop in Bosnia and Herzegovina. On the other hand, costs for seeds (270 KM) and plant protection (136 KM) indicate standard production intensity, without significant deviations from usual practices. It is worth noting that the lack of systematic soil fertility analysis leads to non-selective use of mineral fertilizers, which increases costs and does not necessarily improve yield.

Table 2. Calculations of gross margin in maize production per ha

(BAM/ha)

Description	Unit	Quantity	Price	Total
A) REVENUE				
Maize	kg	8.700	0.30	2,610.00
Subsidies	ha	1	300	300.00
Total Revenue				**2,910.00**
B) VARIABLE COSTS				
Seeds *	packing	2,5	80.00	200.00
NPK 15:15:15	kg	270	0.75	202.00
KAN 27%	kg	340	0,53	180.00
Plant protection products				110.00
Mechanization costs				407.00
Other expenses				200.00
Total variable costs				1,299.00
PVT				**1,611.00**

*Note: one package contains 25,000 grains

Results of the calculation for maize (Table 2) per hectare show a significantly more favorable economic picture. An achieved yield of 8.7 tons/ha, with a selling price of 0.30 KM/kg and a subsidy of 300 KM, results in a total revenue of 2,910 KM. After deducting variable costs of 1,299 KM, the producer achieves GM of 1,611 KM/ha, which is a highly positive result. The results clearly indicate that corn, as a higher-yielding crop with prices similar to those of wheat, has greater potential to generate economic profit, especially in years with favorable weather conditions.

The cost structure shows that the dominant items are machinery (407 KM) and mineral fertilizers (382 KM), which together account for about 60% of total variable costs. Costs for seeds (200 KM) and plant protection (110 KM) demonstrate a reasonable balance between price and the technological requirements of the hybrids most used in this area. It is worth noting that protection costs are lower, which may be due to favorable climatic conditions or moderate weed and disease pressure, despite the lack of adequate crop rotation when cultivating this crop. Besides, the machinery at the investigated sites is mostly over 15, some even over 25 years old, which certainly reduces their efficiency and increases resource consumption in the form of fuel and lubricants, as well as the frequency of machinery breakdowns and the need for repairs.

To assess how price and yield affect the gross margin, a sensitivity analysis was conducted.

Table 3. Sensitivity analysis of gross margin in wheat production in the Brčko District area

In BAM

Change in %		Yield						
		-50	-30	-15	0	15	30	50
Price	-50	-554	-395	-276	-156	-37	82	241
	-30	-395	-172	-5	162	329	496	718
	-15	-276	-5	197	400	603	806	1,076
	0	-156	162	400	639	877	1,116	1,434
	15	-37	329	603	877	1,151	1,426	1,791
	30	82	496	806	1,116	1,426	1,736	2,149
	50	241	718	1,076	1,434	1,791	2,149	2,626

The sensitivity analysis of gross margin for wheat (Table 3) shows that this crop is extremely sensitive to changes in yield and selling price. The basic scenario underestimates yield to 5,300 kg/ha, with a wheat selling price of 0.3 BAM, variable cultivation costs of 1,251.29 BAM/ha, and an achieved gross margin of 638.71 BAM/ha. It is evident that even with a 15% drop in yield and price, PVT enters the negative zone, indicating a relatively narrow economic margin for producing wheat profitably. The lowest scenario (–50% yield and –50% price) results in a loss of –554 KM/ha.

It is observed that a 30% increase in yield and price results in a visible improvement in GM, and that with an increase in either parameter within these limits, GM increases by as much as 75%, or 477 BAM. If yields and prices increase by 30%, this would enable the realization of GM of 1,736 BAM, an increase of 172% compared to the initial scenario.

Positive scenarios confirm that a combination of price and yield increases of up to +50% can raise the GM to a respectable 2,626 KM/ha, but such situations are the exception, not a realistic basis for production planning. The results clearly indicate that wheat's economic stability is relatively fragile and that, for sustainable profitability, it is crucial to improve fertilization precision and reduce mechanization costs by adopting more efficient technological solutions and purchasing newer mechanization.

The sensitivity analysis of maize production (Table 4) shows that this crop is significantly more resilient to changes in yield and selling price. It is already noticeable at the outset that maize retains the ability to achieve a positive or at least marginally sustainable GM even in negative scenarios, as can be seen from the fact that the combination of –15% price and –15% yield still yields 887 KM/ha. Only the extreme negative scenario (–50/–50) results in a loss of –347 KM/ha, which is significantly milder than for wheat.

Table 4. Sensitivity analysis of gross margin in maize production in the Brčko District area

In BAM

Change in %		Yield						
		-50	-30	-15	0	15	30	50
Price	-50	-347	-86	110	306	502	698	959
	-30	-86	280	554	828	1,102	1,376	1,742
	-15	110	554	887	1,220	1,552	1,885	2,329
	0	306	828	1,220	1,611	2,003	2,394	2,916
	15	502	1,102	1,552	2,003	2,453	2,903	3,503
	30	698	1,376	1,885	2,394	2,903	3,412	4,091
	50	959	1,742	2,329	2,916	3,503	4,091	4,874

The results clearly indicate that maize enters the high GM zone in the baseline scenario (1,611 KM/ha), while positive price or yield gap variations of 15–30% lead to a strong increase in GM, reaching 2,003 BAM/ha—an increase of 24%. With a simultaneous 30% increase in yield and price, the achieved GM would amount to 3,412 KM/ha, an increase of up to 112%.

CONCLUSIONS

This study offers a clear and practical overview of how agrotechnical practices and economic outcomes shape wheat and maize production on farms in the Brčko District. The results show that most farmers adhere to the main principles of crop production - timely soil preparation, fertilization, sowing, and crop protection. Yet, two shortcomings stand out: the lack of soil fertility analysis and the widespread use of monoculture. Both issues increase the risk of nutrient imbalances, greater weed and pest pressure, and ultimately more variable yields, all of which directly influence economic performance.

The economic calculations reveal a noticeable contrast between the two crops. Wheat, with an average yield of 5.3 t/ha, achieves a relatively modest gross margin of 639 BAM/ha. Mechanization and fertilizer expenses account for more than 60% of total variable costs, making wheat highly sensitive to changes in input prices and yield levels. The sensitivity analysis underscores this fragility, showing how even moderate declines in yield or price can push wheat into negative economic results.

Maize shows a considerably stronger and more stable economic position. With an average yield of 8.7 t/ha and a gross margin of 1,611 BAM/ha, maize remains profitable even with partial reductions in yield or price. Optimistic scenarios amplify economic returns, confirming that maize is better aligned with the agro-ecological conditions of the Brčko District and generally more resilient to production risks.

Taken together, the findings highlight the need for greater agrotechnical precision - especially through regular soil testing, more balanced fertilization, and the introduction of crop rotation. These improvements would increase resource efficiency and support more stable yields and higher gross margins over time.

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PRIMJENA AGROTEHNIČKIH MJERA I EKONOMSKI USPJEH U PROIZVODNJI PŠENICE I KUKURUZA NA PODRUČJU BRČKO DISTRIKTA

Sažetak

U Bosni i Hercegovini pšenica i kukuruz predstavljaju najvažnije ratarske kulture, koje zauzimaju dominantno mjesto u strukturi korištenih oraničnih površina. Stoga, u ovom radu se analizira proizvodnja pšenice i kukuruza na području Brčko Distrikta, s naglaskom na analizu primjenjenih agrotehničkih mjera i postignutih ekonomskih rezultata izraženih putem pokrića varijabilnih troškova po hektaru. Istraživanje je obuhvatilo 30 poljoprivrednih gazdinstava u Distriktu, a osnovni uslov je bio da imaju proizvodnju na više od 1,5 ha pod posmatranim kulturama. Informacije su prikupljene kroz struktuirane anketne upitnike, koji su sadržavali detaljna pitanja o primijenjenim agrotehničkim praksama, prinosima, troškovima i prihodima. Rezultati pokazuju da prosječni prinosi iznose 5,3 t/ha za pšenicu i 8,7 t/ha za kukuruz. Ekonomskom analizom utvrđeno je da je pokriće varijabilnih troškova iznosilo 639 KM/ha za pšenicu i 1.611 KM/ha za kukuruz. Bolji finansijski rezultat kukuruza djelomično je posljedica viših prinosa i stabilnije proizvodnje. S druge strane, umjerenije pokriće troškova kod pšenice ukazuje na potrebu za optimizacijom agrotehničkih mjera radi povećanja produktivnosti i ekonomske isplativosti.

Najveći udio u ukupnim troškovima imaju troškovi mehanizacije i upotreba mineralnih đubriva, dok su najznačajnije nepravilnosti u primjeni agrotehnike zabilježene upravo u segmentu đubrenja, zbog izostanka analize plodnosti tla. Stoga preporuka ovoga rada jeste sprovođenje analize tla prije đubrenja radi optimizacije troškova i izbjegavanja nepotrebne primjene hranjiva

Ključne riječi: *kukuruz, pšenica, Brčko Distrikt, agrotehničke mjere, pokriće varijabilnih troškova*

DEVELOPMENT OF PREFABRICATED MODULAR STRUCTURES AS AN INCENTIVE FOR RURAL DEVELOPMENT

Mladen Burazor[1], Mirza Bašalić*[1], Dženis Avdić[1], Andrea Pavlović[1]

Original scientific paper

Abstract

The global population has shifted from rural to urban areas. This shift inevitably means that more land is being urbanised and at the same time, with the growing population, there is a need for more food to be produced. The question that has been raised is how to minimise the impact of the construction works when dealing with agricultural land.
The study explores the legal, structural, and economical aspects of building construction for livestock sheltering on agricultural land. However, these structures can also be used for various purposes, including storing food, living spaces, tourism accommodation, and equipment storage. It is hypothesized that modular structures based on prefabricated wooden frames are the most viable option, as they present a strong incentive for rural development.
The article proposes modular prefabricated structures that are temporary, built in situ, and use minimal energy for transportation and construction. The main structural material is wood, and organic insulation materials which are environmentally acceptable due to their low embodied energy and minimal ecological impact.

Keywords: *Adaptable structures, land use, modular structures, prefabricated elements, agricultural buildings*

INTRODUCTION

Urban vs rural – local implications

For the last >15 years, urban – rural population dispersion worldwide took course in favour of the urban areas, with more than 58% of people living in the cities. According to the UN data, last year of global equilibrium was back in 2007 (Our World in Data, 2025) and since then, there is a constant pressure on the cities and urban areas to withstand growing population.
Roots of population movements and migrations were traditionally linked to the industrial revolution back in the late XIX century. Today's migrations are more than peoples' search for better positions and prosperity. They are mirroring much complex economic, political, cultural and social atmosphere on the global level and are hard to predict.
In contrast to the traditional understanding of urban-rural migrations, rural areas are not abandoned as one might think. Industrialization of the rural areas for food production is

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taking over to the self – sufficient farming. Increased population, with more than 8 billion people on the planet, is demanding food production on a very large scale, leading to less people in rural areas and much more industrialized way of producing food. Inevitably, the changes in the ways how the food is produced, had to be made to secure enough resources.

Bosnia and Herzegovina is not far behind the world trends in this matter, with estimation of 51% of population living in the urban areas in 2024. Historically speaking, the agrarian reform in former Yugoslavia was a key socio-economic policy implemented during different periods, particularly after World War I and World War II. Its primary goal was to abolish feudal relations, reduce land ownership inequality, and provide land to impoverished peasants (Lampe, 2000; Marković, 1987).

The agrarian reform was conducted in several distinctive phases.

First reform took place after the First World War and lasted between 1919 – 1931. During this phase, main focus was directed towards dismantling of the large estates, especially in Bosnia and Herzegovina, where such ownership structures were prevalent (Hoare, 2013). Land confiscated by the state, was redistributed between peasants, though the process was slow and inconsistently applied (Lampe, 2000). Justification of such actions wasn't always perceived well, especially by those who lost their holdings of the land, which lead towards later tensions and conflicts (Marković, 1987).

Second phase took place after the World War II, between 1945 – 1953, and it was conducted under the socialist government and regime. It was far more radical than the first phase and it included nationalization of the privately owned land as well as establishment of the collective agricultural cooperatives (Singleton, 1976). This was aligned with the communist ideology of the promotion of collective farming and elimination of the privately owned land (Hoare, 2013).

In conclusion, the key impact of both phases of the agrarian reform on Bosnia and Herzegovina can be downsized to several points:

- Impact on the social structure was significant in both reforms and it created economic challenges for former landowners (Lampe, 2000; Hoare, 2013).
- Resistance from the peasants towards the collectivization of farming was far more damaging for the whole process and lead towards its failure (Singleton, 1976).
- Reforms were successful in the context of modernization and mechanization of agriculture, but had limited impact on individual motivation and productivity in rural areas (Marković, 1987).

Although the agrarian reforms in Bosnia and Herzegovina had a major impact on every aspect of life in Bosnia and Herzegovina, such as structure, economy, and political dynamics, especially towards the end of the socialist era (Lampe, 2000), it must be noted that majority of BH population is still farming in traditional and less organized way, with agriculture being their primary occupation.

Comparing the year 2006 and 2015, agriculture (together with forestry and fishing) accounted to 8,1% vs 6,2% of the GDP value in BiH (Ministarstvo vanjske trgovine i ekonomskih odnosa, 2018). Data from the year 2015 show that around 147.000 people in BiH are involved in the agricultural production (full-time or part-time) (Agencija za unapređenje stranih investicija u Bosni i Hercegovini, 2025). Also, according to the Agency for the Promotion of Foreign Investments in Bosnia and Herzegovina, there is around 50% of the agricultural land within the country that has not been utilised[1]. From these numbers it can be conducted that BiH is following the global trend of people leaving the agricultural sector and at the same time there is a large potential in the land to improve food production.
An unfortunate consequence of moving people from rural to urban zones is the conversion of the use of the land from agricultural to construction in those contact zones. This (legal) change of use is usually an irreversible process where the land suitable for farming is lost to permanent building structures. In this paper, an alternative to permanent building structures for the use in agricultural realm is proposed that can also provide an incentive for rural development.

Farming in BiH

In Bosnia and Herzegovina, more than half of the country's total area consists of agricultural land, which is a limited natural resource: *"Agricultural land in BiH covers 2,572,000 hectares, which accounts for 50.3% of the total area of BiH"* (Federation of BH Parliament, 2009).
Due to an unregulated agricultural land market, the fragmentation of land parcels, complex land management, inaccessibility caused by landmines from the past war, soil erosion, and various other factors, existing land resources are not being used efficiently, let alone intensively. This leads to insufficient agricultural production.
As one of the most significant branches of agricultural production, livestock farming in Bosnia and Herzegovina plays a crucial role in the total Gross Value Added (GVA) of the agricultural sector, the export of agricultural products, and employment in rural areas.
“With 1.12 million hectares of natural grasslands, Bosnia and Herzegovina is well-suited for livestock farming and the production of milk and meat” (MOFTER, 2023).
A comparison of statistical data (table 1) on livestock numbers in BiH shows that these values remain relatively stable, with slight increases or decreases in certain categories depending on the year.

Table 1. Total number of livestock in Bosnia and Herzegovina 2022/2023 (MOFTER, 2021)

	BOSNIA AND HERZEGOVINA		
Types	2022	2023	Index 2023/2022
Cattle	392.163	383.486	98
Goats	63.075	62.716	99
Sheeps	1.065.043	1.029.138	97
TOTAL	1.520.281	1.475.340	97

The livestock sector in Bosnia and Herzegovina contributes approximately 37% to the total agricultural value, a relatively low percentage compared to more advanced agricultural nations, highlighting some structural issues within the sector (MOFTER, 2018).

The dairy industry is a crucial part of agriculture and the most significant segment of the livestock sector in Bosnia and Herzegovina. It underpins the sector's growth, with 13,000 to 14,000 farms producing milk for the market, generating partial or full income from this activity (MOFTER, 2018).

The meat industry has faced a decline in the production of all types of meat over the past decade, along with a mismatch between domestic supply and market demand. In 2016, net meat production was 85,000 tons, with poultry meat constituting about 50% of the total, followed by beef at 30%, pork at 15%, and sheep meat at 2% (MOFTER, 2018).

Addressing land-use challenges

In many countries in the world, there is a clear (legal) division in terms of land used for construction, food production and other purposes. This is usually incorporated via spatial planning documentation (spatial and urban plans), and in accordance with the characteristics of specific land, basic classification is made. In that respect we can differentiate construction land from forest land, agricultural land, and water surfaces (rivers, lakes and seas). The most important difference is that, in principle, construction is not allowed on the sites that are not designated for construction.

The Law on Agricultural Land of the Federation of Bosnia and Herzegovina, in the section that discusses the basic principles and management of agricultural land, defines that "agricultural land, as a fundamental means of agricultural production, has priority use for agricultural production over all other functions and purposes" (Federation of BH Parliament, 2009).

On agricultural land, the construction of buildings is allowed exclusively for agricultural purposes and in very limited capacity, depending on the conditions prescribed by spatial planning documentation. These are usually smaller auxiliary buildings used in agriculture (greenhouses, barns, tool and equipment storage, etc.): "A permanent change in the purpose of agricultural land is considered to be the physical disappearance of the land caused by construction or other use, whereby the land is permanently lost for agricultural production" (Federation of BH Parliament, 2009).

For the construction of permanent buildings on agricultural land to be possible, it is necessary to change the land's purpose, which involves a rather complex process which results with following consequences: permanent destruction of natural resources and change of the price of the land.
Once the land is used for construction, it usually means it's an irreversible process because once something is built upon it, it's very difficult to return the land to it's original natural state. Equally important issue is the change of the price of the land. Legal change from natural to construction state, means multiple change in the financial value and there are many examples of misuse of these procedures. The scenario is the same: individuals or companies buy agricultural land for low prices and afterwards, once the use is changed, it is sold for much bigger price.
For those reasons alone, it is important to find the modalities where required structures for the food production are constructure in such manner that do not permanently destroy land and that those structures can be easily moved or dismantled once they are not needed. Within the confinements of the forementioned Law, here, the modular structures that are proposed that can be easily assembled and disassembled on the given sites.

METHODOLOGY

From the legal point of view, it is possible and in fact in many circumstances, agricultural buildings are constructed in a classical manner. In villages, people construct their sheds, houses and barns where their livestock is held and they farm the fields. This is the case when people own their land but it' is a completely different story if the land is state owned and land is given under a lease. In those cases, construction on state land is not permitted and the duration of the lease periods are limiting construction options. In summary, classical construction is possible on privately owned land and temporary constructions are the only solution withing given time-constrains when building on state land. For this reason, temporary, modular construction is explored in detail especially in relation to modular vs typical prefabricated construction.
An architectural design proposal incorporating modular elements has been made which cand be used to construct sables, greenhouse and even houses. Also, a 1:1 prototype of the modular structural element has been made and tested in the laboratory conditions to ensure structural stability when used in construction. An axiomatic and comparative methods are used to emphasise the advantages of such modular systems. Also, an economical aspect is explored to ensure financial sustainability of the given proposal.

Hypothesis

In respect to legal, structural and economical aspects of building construction used mainly to shelter livestock a hypothesis is made that: *Modular structures based on the prefabricated wooden frames are the most viable option for construction on the agricultural land.* Furthermore, those kinds of structures, based on their economical availability, present an incentive for rural development.

Comparison: traditional vs prefabricated structures vs modular systems

Since the time of Ottoman rule and continuing to the present day, the use of agricultural land in Bosnia and Herzegovina has been regulated by various laws and rules (Bašalić, 2024). Both in the past and today, farmers often face challenges related to the exploitation of agricultural land, particularly with the construction of structures on land designated exclusively for agricultural production.

When analysing examples of temporary structures that were constructed on agricultural land, it is evident that livestock farmers in the region commonly constructed simple buildings using locally available materials (Bašalić, 2024). They built various types of rural shelters, often seasonal dwellings or auxiliary farm buildings for temporary housing of people, domestic animals, tools, and agricultural products. “The need for such temporary structures arises when shepherds, due to a lack of private pastures—especially during periods of drought—relocate with their livestock to mountainous regions, where they stay temporarily until returning home” (Bašalić, 2024). In the past, simple temporary stationary structures such as various types of huts or mobile houses in the Balkan region known as "torarice," and somewhat larger and more complex wooden huts called "povozače", were commonly used (Bašalić, 2024). These huts, often made of wood, were typically transported from one location.

Today, farm buildings for housing, raising and breeding of the animals are primarily constructed using conventional methods with reinforced concrete and masonry structural elements. “These cannot be classified as temporary structures because they are made of durable materials,” and their subsequent removal requires significant energy and financial investment (Bašalić, 2024). As a result, such agricultural buildings are usually constructed on land that has been permanently reclassified as building land, allowing construction.

On non-building land, it is possible to construct temporary prefabricated structures made of wood or similar materials, modelled after earlier temporary structures.

Temporary structures can also be built on agricultural land or land that does not have to be owned by the investor, provided they can be dismantled, removed, and the site restored to its original condition. Wooden prefabricated structures have a transient, temporary character and are in line to ways our ancestors constructed basic shelters while moving with their flocks (Bašalić, 2024).

Unlike traditional monolithic construction, which is almost entirely carried out on-site, industrial construction with prefabricated elements involves a process of production and building in controlled factory conditions using automated equipment for production, handling, storage, shipping of finished products, and final assembly and installation at the site. Prefabricated building with modular elements is significantly simpler and offers numerous advantages over the complex traditional construction method, especially for the construction of temporary structures that must be completely dismantled and removed from the site after use (see table 2).

Table 2. Comparative advantages of prefabricated modular building versus monolithic construction

	PREFABRICATED MODULAR BUILDING CONSTRUCTION	MONOLITHIC CONSTRUCTION
Flexibility	YES	NO
Compatibility	YES	NO
Mobility	YES	NO
The openness of the system	YES	NO
Recycling and reuse	YES	LIMITED
Higher quality	YES	NO
Cost - effectiveness	YES	NO
Dismantling	YES	NO
Higher productivity	YES	NO
Investor participation	YES	LIMITED
Use modern technology	YES	LIMITED
Phase investing	YES	LIMITED
Sustainability	LIMITED	LIMITED

Prefabricated construction with modular elements has a number of comparative advantages over the complex monolithic construction, especially when it comes to building temporary structures that need to be completely dismantled and removed from the site after use (Bašalić, 2024). In terms of the initial investment but especially in a long-term usage, prefabricated structures that can be re-used have an obvious advantage.

Choice of the materials – "green design"

The modular prefabricated structures proposed in this article are meant to be temporary, built in situ, and use as little energy as possible for transportation and construction. One of the most viable concepts for these structures is to be built using locally sourced materials and organic materials (Salihbegović *et al*., 2016) usually available on farm sites.

Wood, as the main structural material of proposed structures, and organic insulation materials like straw-bale/thatch, sheep wool, or sawdust are environmentally acceptable due to their low embodied energy (Mahboob *et al*., 2021) and minimal ecological impact. These materials are usually available locally and don't require too much energy for transportation and processing, compared to synthetic alternatives mainly used for these structures. Since the lifespan of proposed temporary modular structures is expected to be 5 to 10 years, all these materials are applicable with minimal additional layers, considering the main purpose is agriculture. The natural origin of organic insulating materials, their renewable sources, and biodegradability make these concepts environmentally sustainable, with a low carbon footprint and near-zero waste in a lifecycle.

The processing requirements for wood and organic insulation are minimal (Akpan *et al*., 2021), preserving their natural structure and reducing the energy inputs compared to heavily processed materials like fiberglass or foam. Furthermore, using locally available materials supports regional economies, minimizes supply chain emissions, and aligns with the principles of a circular economy. By integrating these materials into construction, it's possible to achieve a net-zero carbon footprint (Candidio *et al*., 2024), as they can also store carbon, offsetting emissions from other construction processes.
The lifespan of proposed natural and organic insulation materials varies depending on the type of material, environmental conditions, and maintenance practices. With proper maintenance and protection treatments, these built-in materials could last up to 30 years within the modular wooden structural frames. Wood, as the main structural material, requires protection from environmental factors, to keep moisture content steady and achieve the designed lifespan. Wood-based and organic insulations, such as sawdust or straw bale, also require moisture control and protection from insects and pests. Considering this, additional sealing layers, such as waterproof and vapor-tight membranes, should be introduced.

RESULTS AND DISCUSSION

Design of the prefabricated structures

When designing and constructing modular prefabricated buildings, it is crucial to develop a system that can offer various final configuration solutions, which are formed by connecting multiple suitable modules composed of individual components. The most optimal systems are those that use the smallest possible number of different components while maximizing repetition.
"A Through analysis and development of various modular structure variants, the most optimal solution for creating a prototype was identified as a construction system with two components: the basic "K160" and a shortened "K80" component derived from the basic one" (Bašalić, 2024).

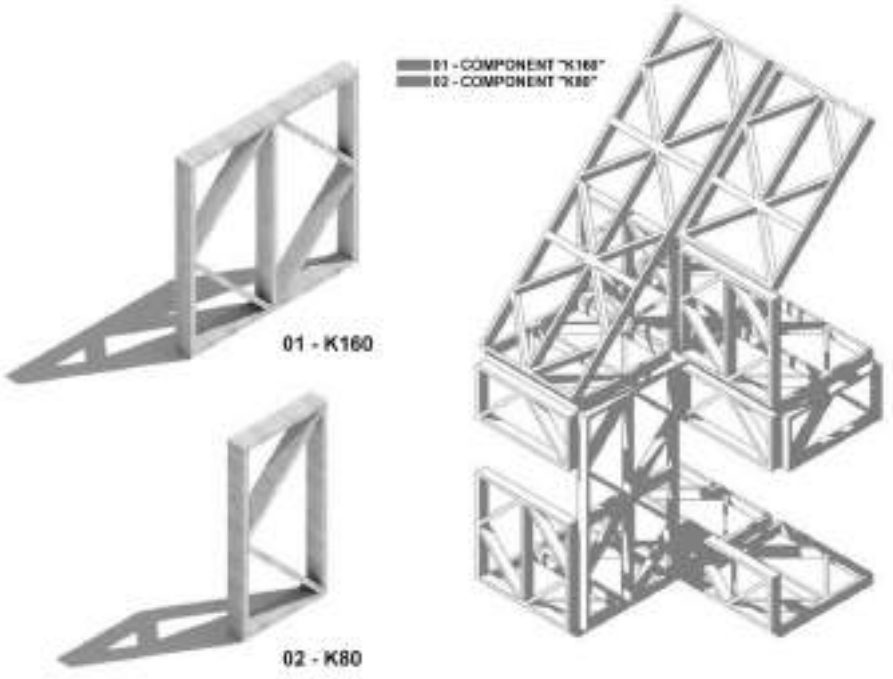

Figure 1. Model with components "K160" and "K80" (Bašalić, 2024).

The system involves configuring two components (see figure 1) that are repeated in different positions to form a specific shape for the enclosure wall, floor or ceiling (Bašalić, 2024).

Testing

Testing of the prepared construction samples was conducted at the Institute for Materials and Structures at the Faculty of Civil Engineering, University of Sarajevo. The aim of the experiment was to see how proposed components behave under the load and at what point structure collapses. The test was performed on a wooden component measuring 160 x 160 x 15 cm, made of spruce beams measuring 15 x 5 cm, connected with 2 mm thick metal plates and self-tapping wood screws of the "MASTER" type (5 x 50 mm and 6 x 100 mm) (Bašalić, 2024).

The first test involved horizontal loading of the wall structure element. “The testing was carried out on a component fixed in a press, cantilevered along its entire length, with the load applied at the very end of the component. The component was loaded in 26 steps, with displacements, cracks, joint loosening, and eventual structural failure recorded” (Bašalić, 2024).

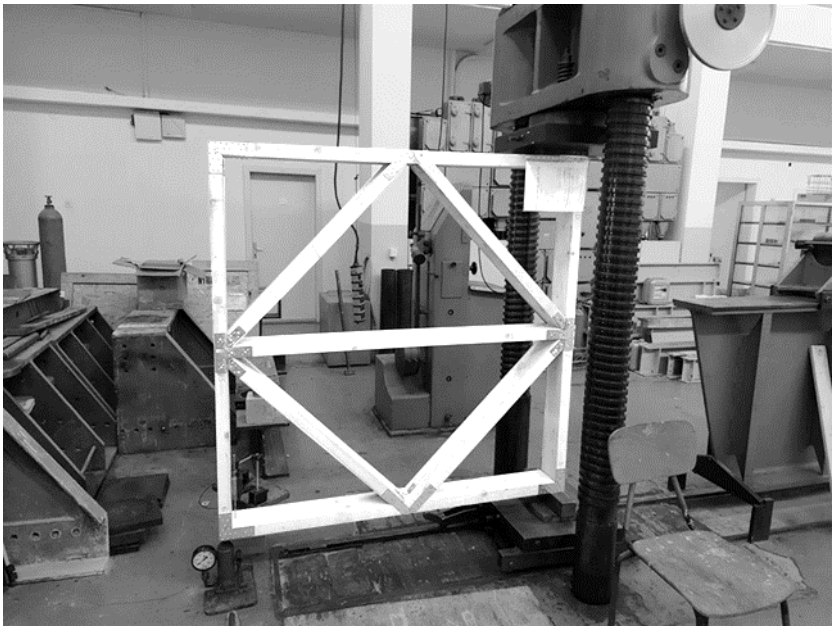

Figure 2. Testing Vertical Load on Floor Structure Element (Bašalić, 2024)

Second test (see figure 2) was conducted on the same component as in previous tests, but “…this time the component was placed horizontally and supported on four concrete supports positioned at its corners. The load was applied incrementally and evenly distributed across the entire surface of the component” (Bašalić, 2024). “The component was loaded in 12 steps, and displacement measurements were recorded at the centre of the component, the central element “K160”E4, and the edge element “K160”E2“ (Bašalić, 2024).

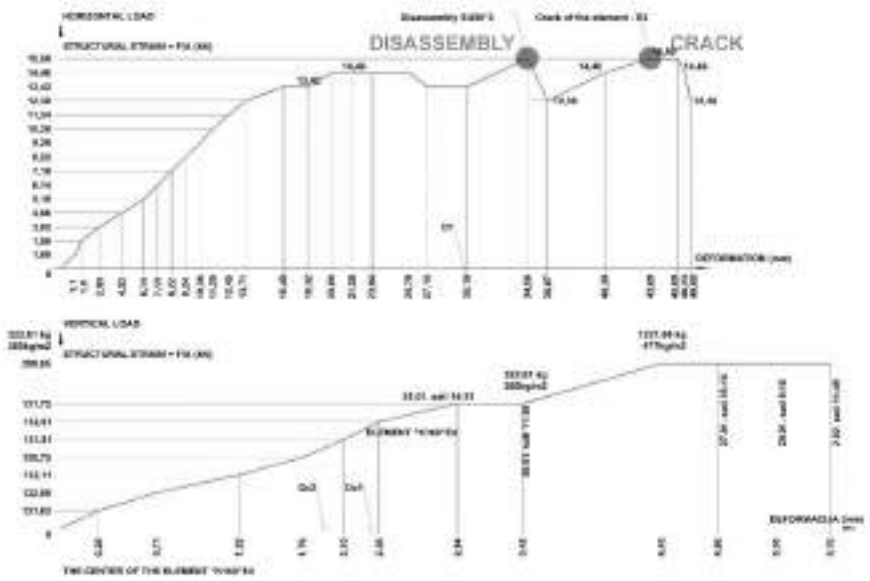

Figure 3. Graphical image of test results (Bašalić, 2024)

The results of the experiment showed that the: "… wooden component "K160" proved to be highly stable and durable (see figure 3), both under horizontal and vertical loads. Testing for horizontal and, especially, vertical loads resulted in minimal deformations within acceptable limits" (Bašalić, 2024).

Construction

The construction of prefabricated modular buildings involves an industrial building method and the use of pre-manufactured structural components such as foundations, columns, floor beams, façade panels, and similar elements. However, in this particular case, the size and weight of individual elements are adapted for easy loading, transportation, and on-site assembly. The assembly of the structure is usually carried out on pre-prepared foundations, which can be made of solid or loose material compacted into specific modules or excavated pits in the ground, with the prerequisite that they can be later removed from the site. The above-ground part of the structure should be designed using wooden elements, with structural joints that can be assembled in a traditional manner by fitting and connecting components using wood screws.

Discussion

Primary use

Modular prefabricated temporary structures can primarily be used for housing animals, but they are also suitable for storing food, as living spaces for people, accommodation

facilities in tourism, equipment storage, or a combination of these purposes (see figure 4).

Figure 4. 3d Model

“The structures are adaptable, functionally flexible, and customizable to accommodate different types and numbers of animals. Additionally, by adding or removing certain modules, they can be adapted for human habitation, cow milking, auxiliary storage, and other purposes” (Bašalić, 2024).

When it comes to buildings for housing animals on farms, one of the essential aspects is that they are constructed in accordance with regulations governing this field. “In Bosnia and Herzegovina, the Regulation on the Conditions that Farms Must Meet and Conditions for Animal Protection on Farms is in force. This regulation states that "*Farms referred to in Article 1 of this Regulation must be constructed in accordance with professional zoohygienic principles, in a way that ensures optimal microclimatic and zoohygienic conditions specific to each animal species, enables the application of rational production technologies, and ensures good health and welfare of the animals*" (Federal Ministry of Agriculture, Water Management and Forestry, 2009).

“When designing and sizing these structures, it is essential to provide all animals with spaces that eliminate the risk of injury and suffering and ensure freedom of movement suited to their species, breed, age, developmental stage, and other specific characteristics” (Bašalić, 2024).

The dimensions of animal housing facilities must be tailored to comply with relevant domestic standards, professional literature, and the standards applied in developed European countries.

Alternative use

Prefabricated structural elements can be used for an alternative use such as green houses or housing units. Based on the user needs, outside layers of these structures can be changed to glass cladding (panels) or polycarbonate sheets if it’s going to be used to produce vegetables. Classic pivoting windows system can be installed for ventilation as well as the shading system to prevent excess insolation and heat accumulation.

If prefab structure is to be used as housing unit, classical exterior cladding can be applied with sufficient thermal insulation to withstand harsh winter conditions in mountain parts. Basic electric appliances can be powered by mobile solar panels and power generators whilst rain water can be collected for sanitary purposes or irrigation.

Energy efficiency

Proposed options for thermal insulation and external, outermost layer materialization include both, organic, bio-degradable, locally sourced materials, and as-designed, state-of-the-art, contemporary insulations with water- and vapor-proof membranes. Even though some of the locally sourced materials might not be as efficient as contemporary manufactured options, they still meet the requirements, especially for the temporary structures meant to be backup facilities, seasonal storages, or farmhouses (see figure 5). Organic materials, especially those intended to provide enough energy efficiency in terms of overheating protection during intense heat gains throughout the summer season, could provide recyclable or biodegradable options for achieving a low carbon footprint. We are here discussing affordable versus most efficient materialization for different needs and purposes.

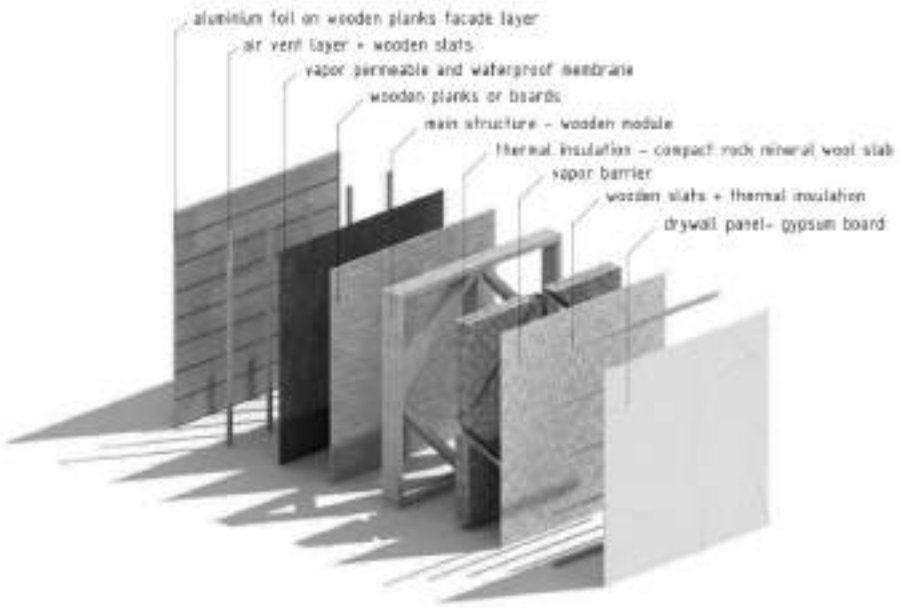

Figure 5. Facade wall layers – as-designed option (Bašalić, 2024).

In terms of the most affordable options, we can also talk about the most eco-friendly options, since affordability includes transportation costs, processing, and manual labour needed for erecting these buildings. As mentioned earlier, we can use locally sourced and available materials such as sheep wool, straw bales, sawdust, and local wood. Most of these materials meet the requirements for the minimal U value necessary, given the module dimensions and thermal insulation infill space.

Sheep wool infill provides the module with U=0.283 W/m2K, which meets the requirements for walls even in the colder region of Bosnia and Herzegovina, given the interior is tempered to 18°C or above. In a southern region, with a somewhat warmer climate, this structure meets the requirements even for the housing units.

If we talk about agricultural purposes for temporary structures heated between 12°C and 18°C, this materialization meets the requirements for walls and roofs, in both colder, and warmer regions. Straw bale infill could be used for backup units with lower interior temperatures (12°C to 18°C) with U=0.452 W/m2K. Both sheep wool and straw bale provide stable vapor exchange and summer thermal stability, guaranteeing interior comfort.

The most efficient materialization, proposed in the as-designed option, using compact rock mineral wool slabs as a thermal insulation layer, provides U=0.261 W/m2K and stable water vapor diffusion, as well as overheating protection with satisfying summer thermal stability.

Even though this option is not as efficient in terms of carbon footprint as others, it provides better fire hazard protections as well as the most comfortable and stable interior parameters, so it can be applied to housing units as well as farming and agricultural facilities. With different insulation material options, as well as a ventilation layer, this proposed module design could provide energy-efficient agricultural-purpose units as well as farmhouse units.

CONCLUSION

Through this paper, several points were made regarding the options for improving the construction of farming facilities in rural parts. Firstly, from a legal point of view, it is less time-consuming and it requires less paperwork to build temporary structures that can be modified (upscaled/downscaled) when the needs change. Construction in a proposed manner is fully reversible and natural land is not significantly or permanently disturbed. From the financial point of view, construction costs are considerably lower when prefabrication is used. Modula elements that are not heavy or bulky and that can be assembled by a single person on site, means that heavy machinery is not required and simple power tools are enough for a person do assemble these constructions. The size of basic modular elements is such that owners can easily transport them even with their personal cars and trailers from the local DIY centres. The choice of construction timber, as the main structural material, is well-founded within an ecological/sustainability framework. It’s a material that is widely available and affordable and can be easily reused. Based on the aforementioned arguments, it can be concluded that modular

structures based on prefabricated wooden frames are the most viable option for construction on agricultural land.

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RAZVOJ PREFABRICIRANIH MODULARNIH KONSTRUKCIJA KAO POTICAJ ZA RURALNI RAZVOJ

Sažetak

Globalna populacija se preusmjerila iz ruralnih u urbana područja. Ova promjena neminovno znači da se sve više zemljišta urbanizira, a istovremeno, s porastom broja stanovnika, javlja se potreba za većom proizvodnjom hrane. Postavlja se pitanje kako minimizirati utjecaj građevinskih radova na poljoprivredno zemljište.
Ova studija istražuje pravne, strukturne i ekonomske aspekte izgradnje objekata za smještaj stoke na poljoprivrednom zemljištu. Međutim, ovakve strukture mogu se koristiti i za različite druge namjene, uključujući skladištenje hrane, stambene prostore, turistički smještaj i skladištenje opreme. Pretpostavka je da su modularne strukture zasnovane na prefabrikovanim drvenim okvirima najprihvatljivija opcija i kao takve mogu da predstavljaju snažan poticaj za ruralni razvoj.
U članku se predlažu modularne prefabrikovane strukture koje su privremenog karaktera, grade se na licu mjesta i zahtijevaju minimalnu energiju za transport i izgradnju. Glavni konstruktivni materijal je drvo, dok se za izolaciju koriste organski materijali koji su ekološki prihvatljivi zbog svoje niske ugrađene energije i minimalnog ekološkog utjecaja.

Ključne riječi: *Adaptabilne konstrukije, korištenje zemljišta, modularne konstrukcije, prefabricirani elementi, poljoprivredni objekt*

Index autora / Authors' index

IN MEMORIAM
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Prof. dr. Ahmed Smajić rođen je 1958. godine u mjestu Pokrivenik, općina Rogatica. Osnovnu školu završio je u Rogatici, a srednju tehničku - mašinski smjer u Sarajevu. Na Poljoprivrednom fakultetu - odsjek za preradu i kontrolu poljoprivrednih i prehrambenih proizvoda diplomirao je 1983. godine.
Od septembra 1984. godine zapošljava se u Srednjoškolskom centru u Kotor Varoši, gdje je radio 1984/85. školsku godinu. U septembru 1985. godine zaposlen je u svojstvu asistenta-pripravnika na Poljoprivrednom fakultetu u Sarajevu, na predmetu Prerada mesa i drugih stočnih proizvoda.
Magistarski rad odbranio je 1988. godine, a doktorsku disertaciju 1991. godine. Iste godine izabran je u zvanje docenta na predmetima Prerada mesa i drugih stočnih proizvoda i Osnovi tehnologije stočarskih proizvoda.

Odmah na početku rata uključio se u redove odbrane na području Boljakovog potoka, gdje je vršio dužnost koordinatora za desnu obalu Miljacke. Osnivač je prve vojne ekonomije u R BiH na lokalitetima kasarne "Jusuf Džonlić". Dr. Smajić je dao izuzetan doprinos na oživljavanju još desetine takvih ekonomija na području grada. Od novembra 1993. godine vrši funkciju Predsjednika IO općine Novi Grad. Jedan je od osnivača Sportskog društva "Olimpik". Bio je član je predsjedništva Rukometnog saveza R BiH. Jedan je od inicijatora za osnivanje Kulturnog društva Bošnjaka na području općine Novi Grad. Prof. dr. Ahmed Smajić u februaru 1996. godine preuzima i vrši dužnost kao prvi poslijeratni ministar u Federalnom ministarstvu poljoprivrede, vodoprivrede i šumarstva.

Od 1995. do 2000. godine prof. Smajić je proveo u zvanju vanrednog profesora. Od 2000. godine izabran je u trajno zvanje redovnog profesora Poljoprivredno-prehrambenog fakulteta u Sarajevu, sve do penzionisanja 2019. godine. Od 1988. do 2009. godine radio je kao predavač-profesor na Pedagoškoj akademiji Univerziteta u Sarajevu.
Iako, ozbiljno narušenog zdravlja, u naponu svoje intelektualne-akademske karijere, profesor je imao izuzetno plodotvoran akademski rad na matičnom fakultetu. Obnašao je dužnost Upravnika Instituta za tehnologiju poljoprivrednih i prehrambenih proizvoda. U dva mandata od 2000. do 2007. godine, vršio je dužnost Šefa odsjeka za prehrambene tehnologije. Bio je član je Upravnog odbora Poljoprivrednog/Poljoprivredno-prehrambenog fakulteta u Sarajevu od 2005. do 2013. godine. Obnašao je funkciju predsjednika Komisije za doktorate na Poljoprivredno-prehrambenom fakultetu. Idejni je tvorac i rukovodilac postdiplomskog studija *„Kontrola kvaliteta hrane i pića"*. Bio je glavni i odgovorni urednik Radova PPF-a u periodu od 2007. do 2015. godine.
Koristeći svoj društveni angažman, prof. Smajić je inicirao izmjenu naziva Fakulteta. Na bazi te inicijative, Skupština Kantona donijela je Odluku o davanju saglasnosti za promjenu naziva Javne ustanove Poljoprivredni fakultet u naziv Javna ustanova Poljoprivredno-prehrambeni fakultet Sarajevo.

Na 13. sjednici Upravnog Odbora Fakulteta održanoj 2006. godine, inicirao je da u diplomama diplomanata Odsjeka za tehnologiju poljoprivrednih i prehrambenih proizvoda, umjesto "diplomirani inžinjer poljoprivrede" piše "diplomirani inžinjer prehrambene tehnologije".
Bio je mentor i/ili član komisija u više od 90 diplomskih, magistarskih, *baccalaureat i* završnih radova. Također, bio je mentor kod četiri kandidata za odbranu disertacije na Poljoprivredno-prehrambenom fakultetu, te član komisije za odbranu pet disertacija na drugim fakultetima.
Izradio je 14 modula/predmeta na Poljoprivredno-prehrambenom fakultetu u skladu sa Bolonjskom deklaracijom, bio predsjednik ili član pri izboru 32 kandidata u zvanja asistenta, višeg asistenta, docenta, vanrednog profesora i redovnog profesora. Autor je 20 recenziranih knjiga i preko 80 naučnih i stručnih radova.
Nagrada za najuspješnijeg profesora Poljoprivredno-prehrambenog fakulteta u Sarajevu dodijeljena mu je 2008. godine. Bio je voditelj ili saradnik u brojnim naučnim i stručnim projektima. Učestvovao je na mnogim domaćim i međunarodnim naučnim i stručnim skupovima, te bio član brojnih organizacionih i naučnih odbora.
Za svoj dugodišnji, plodotvoran rad prof. Smajić je dobitnik niza plaketa, povelja, medalja, oredna i zahvalnica, od kojih izdvajamo neke:
1. Plaketa Bosanski stećak Armije RBiH;
2. Zlatna plaketa – najveće Općinsko priznanje Novog Grada;
3. Zlatna plaketa povodom 25. jubilarnog sajma Gradačac;
4. FAO srebrna medalja Generalnog direktora Jacques Dioufa;
5. Povelja GRAS-a povodom 100 godina rada;
6. Povelja Saveznog udruženja agronoma - stočara Republike Austrije;
7. Plaketa Unije veterana Grada Sarajeva;
8. Orden II reda Lovačkog saveza BiH;
9. Zahvalnica Pedagoške akademije povodom 50 godina za poseban radni doprinos u periodu od 1992-96. godine;
10. Zahvalnica Poljoprivrednog fakulteta povodom 63 godine rada;
11. Zahvalnica Preporoda Opštine Novi Grad;
12. Zahvalnica Agropedološkog zavoda Sarajevo povodom 60 godina postojanja;
13. Zahvalnica Udruženja veterinara BiH;
14. Zahvalnica Poljoprivrednog instituta Sarajevo;
15. Priznanje Austrijskog udruženja uzgajivača goveda Simental pasmine;
16. Priznanje za pomoć demobilisanih boraca Opštine Tuzla;
17. Zahvalnica mnogih općina (1995-2001);
18.Nagrada za najuspješnijeg profesora Poljoprivredno-prehrambenog fakulteta u Sarajevu za 2008. godinu;
19. Certifikat Who´s Who in the World 2009. godine;
20. Priznanje povodom 45 godina postojanja sajma u Gradačcu;
21. Zahvalnica fonda Bošnjaci u Sarajevu;
22. Dekanova nagrada u povodu 85 godina PPF-a.

Kada bi upoznali Ahmeda Smajića činilo se kao da ga znate skoro čitav život. Spadao je među ljude koji vas odvode na pomisao da ga uvijek poznajete, čija vas neposrednost plijeni, a energija ne može da ostavi ravnodušnim. Bio je sagovornik poslije kojeg ste se osjećali podstaknuti i ispunjeni neobičnom kreativnom energijom.

Prof. dr. Amir Ganić

UPUTSTVO ZA OBJAVLJIVANJE RADOVA

Radovi Poljoprivredno-prehrambenog fakulteta Univerziteta u Sarajevu (Radovi) su godišnjak u kojem se objavljuju naučni, izuzetno i stručni radovi, te izvodi iz doktorskih i magistarskih teza odbranjenih na Poljoprivredno-prehrambenom fakultetu Univerziteta u Sarajevu (Fakultet).

Radovi imaju karakter naučnog časopisa i kao takvi podliježu propozicijama za takve publikacije. Od broja 52 Radovi su indeksirani kod CAB Publishing - UK.

Članci za objavljivanje se klasificiraju, po preporuci UNESCO-a, u ove kategorije: naučni radovi, prethodna saopštenja, pregledni i stručni radovi. Autori predlažu kategoriju za svoje članke, recenzenti preporučuju, a konačnu odluku o kategorizaciji donosi Redakcija Radova. Naučni radovi sadrže rezultate izvornih istraživanja. Njihov sadržaj treba da bude izložen tako da se eksperiment može reprodukovati i provjeriti tačnost analiza i zaključaka. Prethodna sopštenja sadrže one značajne naučne rezultate, koji zahtijevaju hitno objavljivanje. Ova istraživanja mogu biti vremenski kraća od uobičajenih. Pregledni radovi sadrže pregled neke problematike na osnovu već publikovanih tekstova, koja se u pregledu analizira i diskutuje. Stručni radovi su korisni prilozi iz područja struke, koji ne predstavljaju izvorna istraživanja.

Članci se pišu na bosanskom, srpskom, hrvatskom ili engleskom jeziku. Na početku rada treba pisati naziv rada (velikim slovima) na maternjem i na engleskom jeziku, a nakon toga ime (imena) autora. Naziv radne organizacije autora upisuje se u fusnotu (Ariel 7). Ispod imena autora obavezno se upisuje i kategorija rada.

U časopisu se publikuju radovi iz oblasti: poljoprivredna biljna proizvodnja, animalna proizvodnja, prehrambene tehnologije i održivi razvoj agrosektora i ruralnih područja.

Poželjno je da članci naučnog karaktera imaju uobičajenu strukturu naučnog rada i to: rezime (na bosanskom, srpskom i hrvatskom), uvod, pregled literature (može se dati i u uvodu), materijal i metode rada, rezultati istraživanja, diskusija (može biti objedinjeno sa rezultatima istraživanja), zaključci, literatura, summary na engleskom jeziku. Rezime i summary na našim jezicima i engleskom jeziku mogu imati maksimalno 200 riječi, uz obavezno upisivanje ključnih riječi. U spisku literature daju se samo autori i radovi koji se spominju u tekstu. Latinska imena biljaka, životinja i mikroorganizama treba (osim imena autora) pisati kurzivom. Tabele, grafikoni i slike moraju imati svoj naziv, a ako ih je više i broj. Broj i naziv tabele pišu se u istom redu, iznad tabele, dok se broj i naziv grafikona, crteža i slika pišu ispod tih priloga. U tabelama, grafikonima i slikama naslove, zaglavlja i objašnjenja poželjno je dati i na stranom jeziku. Slike i grafički prikazi moraju biti visokog kvaliteta, u rezoluciji ne manjoj od 300 dpi i formatima JPEG, PNG ili TIFF, kako bi se osigurala besprijekorna reprodukcija u knjizi.

Radovi, po pravilu, ne bi trebali prelaziti osam autorskih kartica (do 14.400 znakova, uključujući razmake).

Za sadržaj članka odgovara autor. Članci se prije objavljivanja po "*double blind*" principu recenziraju od strane dva nezavisna recenzenta. Redakcija, uz konsultovanje sa autorima, zadržava pravo manjih redaktorskih i jezičkih korektura u člancima.

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Elektronsku verziju rada treba pripremiti u Wordu u formatu stranica 170 x 240 mm, sa slijedećim veličinama margina: gornja i donja 2,2 cm, lijeva 2,0 cm, a desna 1,5 cm, te formatirati parne i neparne stranice. Isključivo koristiti font Times New Roman, veličina 11, dok za fusnote treba koristiti font Arial, veličina 7. Tekst treba da je obostrano poravnat. Nazive poglavlja u radu treba pisati velikim slovima, boldirano i sa srednjim poravnanjem, te jednim redom razmaka od teksta.
Prilikom formatiranja članka ne treba uređivati zaglavlje i podnožje članka (Header and Footer) niti numerisati stranice.
Autorima čiji maternji jezik nije engleski strogo se preporučuje da osiguraju profesionalnu lekturu teksta ili koriste alate za jezičku provjeru, poput *Grammarly*-ja. Prilikom pisanja na engleskom jeziku treba koristiti jasne engleske izraze bez žargona i izbjegavati duge rečenice. Prihvatljivi su i britanski i američki „spelling“, ali on mora biti konzistentan u cijelom tekstu rada na engleskom jeziku.
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Redakcija

INSTRUCTION FOR PUBLISHING PAPERS

"Radovi Poljoprivredno-prehrambenog fakulteta Univerziteta u Sarajevu" ("Works of the Faculty of Agriculture and Food Sciences of University of Sarajevo), hereinafter: "Radovi" (the "Works") is an almanac in which (original) scientific papers, exceptionally professional papers, and also some excerpts from doctoral/PhD or master theses defended at the Faculty of Agriculture and Food Sciences (the Faculty) of University of Sarajevo (Univerzitet u Sarajevu) are published.

"Radovi" (the "Works") has a character of scientific magazine and, as such, is subject to the propositions for such publications. Since its issue no. 52, "Radovi" (the "Works") has been indexed at CAB Publishing - UK.

Articles for publishing are classified, according to the recommendation by the UNESCO, into these categories: (original) scientific papers, previous statements, (scientific) review and professional papers. The authors propose the category for their articles; critics recommend it and final decision on their categorisation is made by the Editorial Board of the "Radovi" (the "Works"). (Original) Scientific papers contain results of authentic research. Their content should be presented in such a manner that an experiment may reproduce and verify accuracy of the analyses and conclusions. Previous statements contain those significant scientific results that require urgent publishing. This research can be shorter in time than the usual ones. (Scientific) Review papers contain an outline of certain problems based on previously published texts that are analysed and discussed about in the review. Professional papers are useful articles/works from the professional domain that do not present authentic research.

Articles are written in one of the three official languages of BiH (Bosnian/Serbian/Croatian) or English. The title of the paper should be written at the beginning of the paper (in capital letters) in one's mother tongue and in English and after that the author's name (authors' names). The author's working organisation name is written in the footnote (Ariel 7). It is mandatory to write out the category of the paper below the author's name as well.

Papers from the areas of agricultural plant production, animal production, food technologies and sustainable development of agro-sector and rural areas are published in the journal.

It is desirable that articles of scientific character have common structure of a scientific paper, namely: summary in one of the three official languages of BiH (Bosnian/Serbian/Croatian), introduction, references (may be given in the introduction, too), material and methods, results of research, discussion (may be integrated with results of research), conclusions, bibliography and summary in English. Summary in one of the three official languages of BiH (Bosnian/Serbian/Croatian), and summary in English respectively may have maximum 200 words, with mandatory enlisting of the key words. In the list of bibliography, only authors and papers that are mentioned in the text are given. The authors' names in the text are written with expanded spacing. Latin names of plants, animals and micro-organisms should be written in italics. Tables, graphs and pictures must have their title and if they are numerous, their number. The

number and the title of the table are written in the same row above the table while the number and the title of the graph, drawing and pictures are written below them. It is desirable to give titles, headings and explanations in the tables, graphs and pictures in the foreign language, too. Graphs and drawings should be done exclusively in black-and-white technique. Tables should be framed in lines of thickness of 1/2 pt, without shading of individual cells or rows and columns. Pictures and graphic illustrations should be done impeccably to be top-quality reproduced in the book.

Papers, as a rule, should not be longer than 12 typed pages (with appendices). Excerpts from master theses may be even up to 15 pages, and from doctoral/PhD theses up to 25 typed pages.

The author is responsible for the contents of the article. Prior to their publishing, articles are reviewed under "*double blind*" principle by two independent reviewers. The Editorial Board, in consultations with the authors, reserves the right to minor editorial and linguistic corrections in the articles.

The author submits one's manuscript to the Editorial Board by the means of e-mail edited according to the instructions for writing papers. When sending papers to the Editorial Board it is obligatory to indicate the contact address and e-mail address in a separate document.

All the submitted manuscripts shall be subject to initial check in terms of meeting the criteria of the field which the magazine publishes papers from as well as technical preparation of the manuscript in accordance with the instruction to the authors.

Upon the initial check by the Editor, the submitted manuscript may be rejected without review if the Editor evaluates it is not in accordance with the journal's rules. Within the term of 20 days, the notification shall be sent to the author about either initial acceptance of the paper or reasons for its rejection.

Upon completion of the reviewing procedure which, as a rule, should not last longer than three months, the Editorial Board, based on final recommendations by reviewers, makes decision on publishing the pertinent paper or not. The Editorial Board then informs the author about their decision, in addition to the information on the issue and term of the article publishing which the paper accepted for publishing is going to be published in.

Electronic version of the paper should be prepared in Word, in page format of 170 x 240 mm, with the following size of margins: the upper and lower ones of 2,2 cm, the left one of 2,0 cm and the right one of 1,5 cm and then the even and odd pages formatted. The font of Times New Roman, size 11, is to be exclusively used, while for footnotes the font of Arial, size 7 should be used. The text should be aligned on both sides. The title of chapters in the paper should be written in capital letters, bold and with medium alignment as well as with one row of space from the text.

While formatting the article, neither header and footer nor page numbering should be arranged.

Authors whose mother tongue is not English are strongly recommended to provide professional corrections to the text that is going to be reviewed. While writing in English, clear English phrases without jargon should be used and long sentences should

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