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Pectin Extraction from Saba Banana Peel Waste: A Comparative Review of Philippine-Based Studies

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Abstract

The extraction of pectin from 'Saba' banana (*Musa acuminata* × *balbisiana*) peel has been widely investigated in previous studies and represents a promising approach to food waste valorization while addressing global pectin demand. This work compiles and compares previously published Philippine-based experimental results regarding ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), conventional acid extraction (AE), and enzymatic extraction (EE) of pectin from Saba banana peel. Published data were evaluated for pectin yield, purity (anhydrouronic acid and ash content), rheological behavior, emulsifying performance, and health-related properties, including cholesterol and bile acid-binding capacity. Across the reviewed studies, acid extraction achieved the highest reported pectin yield (up to approximately 20%), followed by microwave-assisted extraction (≈14%) and enzymatic methods (≈6%), with ultrasound-assisted extraction typically yielding 4–5%. However, yield alone does not determine pectin quality, as purity and functional properties are critical for food and pharmaceutical applications. Acid-extracted pectin (AP) demonstrated superior yield and anhydrouronic acid (AUA) content but exhibited higher ash content and inferior color quality, potentially limiting its applications without additional purification. MAE and UAE provided moderate yields while producing pectin with favorable functional properties. UAE pectin (UEP) exhibited higher protein content, low interfacial tension, and enhanced emulsifying capacity, generating smaller emulsion droplets and improved stability. MAE yielded pectins with higher purity and desirable low-methoxyl characteristics following purification. Rheological studies indicated that Saba banana pectins contributed to shear-thinning, non-Newtonian behavior in food systems. UEP increased beverage viscosity under physiological digestion conditions, potentially enhancing satiety effects. *In vitro* assays reported in the literature demonstrated that AP, EE pectin (EP), and MAE pectin (MEP) effectively bind cholesterol and bile acids, indicating promising lipid-lowering properties, with AP showing the strongest binding capacity. The comparative analysis highlights how the extraction method significantly impacts pectin yield, purity, and techno-functional performance, providing practical guidance for selecting extraction protocols tailored to specific pectin applications in food and nutraceutical innovation.

Keywords: *ultrasound-assisted extraction, enzymatic extraction, microwave-assisted extraction, banana peel, pectin*

I. INTRODUCTION

The utilization of agricultural wastes, particularly 'Saba' banana (*Musa acuminata* × *balbisiana*) peels, offers a promising solution to waste management problems while contributing to the increasing global need for functional ingredients for food and pharmaceutical applications sourced from natural materials (Israel et al., 2015; Khamsucharit et al., 2017; Rivadeneira et al., 2020). Pectin, a natural product that can be sourced from 'Saba' banana peel waste, is a structural polysaccharide abundant in plant cell walls. Pectin acts as a gelling agent, stabilizer, and emulsifier in applicable food products. In addition, its health-enhancing properties include lowering cholesterol and bile products in the human body (Estribillo et al., 2022; Khamsucharit et al., 2017; Xiang et al., 2024). While conventional

extraction techniques (acid extraction (AE) and enzymatic extraction (EE)) prioritized maximizing yield, newer eco-friendly methods have emerged to improve efficiency, reduce environmental impact, and retain functional qualities of pectin (Li et al., 2012; Phaiphan, 2022; Rivadeneira et al., 2020).

This paper compiles previously published experimental findings on pectin extraction from Saba banana peel and presents a comparative analysis of conventional (AE and EE) and emerging (ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE)) methods. No new experiments were conducted for the present work; all extraction conditions, yields, and analytical results discussed in this paper were taken from published sources, including Israel et al. (2015), Rivadeneira et al. (2020), Estribillo et al. (2022), Phaiphan et al. (2020), Phaiphan (2022), and Rodulfo et al. (2024), among others. This review presents a detailed comparative analysis of yield, purity, rheological behavior, and bioactive health benefits from pectin extracted using the aforementioned extraction methods.

II. DATA SOURCES AND COMPARATIVE APPROACH

In the published studies reviewed, pectin was extracted from dried and powdered 'Saba' banana peel obtained from banana processing facilities in the Philippines using method-specific standardized procedures. For AE, the reported study used a 4% solid-to-liquid ratio in HCl (0.5 N, pH 1.5), heated at 90°C for approximately 4 h (Israel et al., 2015; Estribillo et al., 2022). Meanwhile, EE conditions involved treating the peel with a cellulase solution (170–350 units per gram of dried material) at temperatures between 41°C and 50°C for approximately 3 h, allowing targeted cell wall degradation without resorting to harsh chemicals (Estribillo et al., 2022; Phaiphan et al., 2020). Published UAE protocol applied approximately 60% amplitude for 20 min in a sample with an 8:1 solid-to-liquid ratio submerged in H_2SO_4 (pH 2.0) solution, using cavitation to boost mass transfer efficiency (Phaiphan, 2022). The MAE study employed rapid heating at 195°C with an 8% solid-to-liquid ratio in HCl (pH 3.0), completing the process in 1 min, where rapid thermal activation resulted in material disruption to release pectin (Rivadeneira et al., 2020).

Across the reviewed studies, pectin samples were precipitated with ethanol at a 1:2 volume ratio, then subjected to uniform washing and drying steps to ensure consistency across treatments (Estribillo et al., 2022; Rivadeneira et al., 2020). Characterization methods reported in the literature included gravimetric yield determination, anhydrouronic acid (AUA) content quantification, ash content analysis, protein analysis, and colorimetric evaluation (Israel et al., 2015; Rivadeneira et al., 2020; Estribillo et al., 2022). Functional property assessments, including interfacial tension determination and droplet size analysis in model emulsion systems, were conducted for MAE pectin and UEP in selected studies (Estribillo et al., 2022), as these were identified as the most applicable types for food applications. In addition, rheological characterization was performed for MAE pectin and UEP using controlled shear rate measurements to determine flow behavior, consistency parameters, and shear-thinning characteristics under simulated physiological conditions (Müller-Maatsch et al., 2016; Rivadeneira et al., 2020).

For this review, extraction conditions, yield values, purity parameters, and functional property data were systematically extracted from the original articles and organized by extraction method (AE, EE, UAE, MAE). Where possible, representative values and ranges were compiled to enable cross-study comparison of yield, purity, rheological behavior, emulsifying capacity, and *in vitro* lipid-binding performance. The comparative framework emphasizes the relationship between extraction conditions, pectin structural characteristics, and techno-functional properties relevant to food and nutraceutical applications.

III. RESULTS AND DISCUSSION

Across the reviewed studies, extraction yields varied significantly among methods, with AE generally achieving the highest reported pectin recovery of approximately 20%, followed by MAE at about 14%, EE at approximately 6%, and UAE producing 4–5% yield (Estribillo et al., 2022; Israel et al., 2015; Rivadeneira et al., 2020). However, the literature consistently indicates that yield optimization does not necessarily correlate with quality parameters or functional performance. AUA contents, which indicate pectin purity, were reported to be high in UEP (69%) and AP (51%), confirming superior pectin concentration, while both EP and MEP had moderate AUA values of 17% and 26%, respectively (Estribillo et al., 2022; Israel et al., 2015). Ash content presented significant variation, with acid-extracted pectin showing elevated mineral content (>10%), potentially limiting direct food applications, whereas enzymatic, microwave, and ultrasound methods yielded pectins with more acceptable ash levels (2–4%) (Estribillo et al., 2022; Rodulfo et al., 2024).

Table 1. Characteristics of "Saba" banana peel pectin extracted using different methods, compiled from Philippine-based published studies.

Characteristics	Ultrasound-Assisted Extraction	Microwave-Assisted Extraction	Acid Extraction	Enzymatic Extraction
Yield, %	4 to 5	14	20	6
Anhydrouronic Acid, %	69	26	51	17
Ash, %	2	4	14	4

Functional properties analysis revealed that UEP demonstrated superior emulsifying capacity, producing emulsions with smaller droplet sizes compared to MEP. In terms of interfacial tension, both exhibited low values (34 mN/m and 32 mN/m, respectively), indicating that droplets can form stable emulsions (Estribillo et al., 2022). Protein content was notably higher in UEP (8%) compared to MEP (1%), contributing to a more stable emulsification performance in the former (Estribillo et al., 2022).

The comparative evaluation of published studies reveals that extraction method selection should align with intended applications and functional requirements rather than solely maximizing yield (Estribillo et al., 2022; Phaiphan, 2022; Rivadeneira et al., 2020). Acid extraction, while producing the highest yield and AUA content, requires additional purification steps to address ash content and color quality limitations (Estribillo et al., 2022; Israel et al., 2015). The harsh extraction conditions (high temperature, low pH, extended time) ensure complete protopectin hydrolysis but may compromise some bioactive properties and result in higher processing costs for purification (Emaga et al., 2008; Estribillo et al., 2022).

Emerging extraction technologies demonstrate compelling advantages for specific applications. UAE's cavitation-induced cell disruption preserves protein-pectin associations, resulting in enhanced emulsifying properties particularly valuable for stabilizing oil-in-water emulsions in food products and pharmaceutical formulations (Phaiphan, 2022). The rapid extraction time (20 min vs. 3–4 h for acid extraction) and moderate temperature conditions contribute to energy efficiency and potential preservation of thermolabile compounds (Li et al., 2012; Phaiphan, 2022). MAE offers an optimal balance of extraction efficiency and product quality, with the rapid heating mechanism enabling selective pectin extraction while minimizing degradation reactions (Rivadeneira et al., 2020).

Rheological studies consistently report that pectins obtained from Saba banana peel using the four extraction methods contribute shear-thinning, non-Newtonian behavior in aqueous solutions (Rivadeneira et al., 2020; Müller-Maatsch et al., 2016). Moreover, *in vitro* assays reported in the literature demonstrated that AP, EP, and MEP effectively bind cholesterol (40–55% binding capacity) and bile acids (up to 50% binding capacity), indicating promising lipid-lowering properties. Under simulated digestive conditions, published results showed that emulsions using UEP were stable in all stages of in vitro digestion. While UEP provided a more stable emulsion before digestion, subjecting the emulsions to oral, gastric, and intestinal digestion yielded performance comparable to commercial pectin counterparts (Estribillo et al., 2022).

The demonstrated lipid-lowering potential of AP, EP, and MEP, with AP showing the strongest bile acid binding capacity, confirms the health-promoting properties of 'Saba' banana peel pectin reported in the literature (Fang et al., 2018; Massa et al., 2022). The mechanism likely involves both physical bile acid sequestration and enhancement of fecal sterol excretion, supporting the established role of soluble dietary fiber in cholesterol metabolism regulation (Fang et al., 2018; Massa et al., 2022; Phaiphan, 2022). The rheological properties observed in published studies, particularly the shear-thinning behavior and increased viscosity under physiological conditions, may contribute to satiety enhancement and glycemic response modulation through delayed gastric emptying and reduced nutrient absorption rates (Rivadeneira et al., 2020; Weber et al., 2024; Wikiera et al., 2015).

IV. CONCLUSIONS

Previously published extraction studies on Saba banana peel pectin were compared in terms of yield, purity, and functional properties. Acid extraction offers the highest reported yield, though quality improvements require additional purification, while ultrasound- and microwave-assisted methods support efficient, eco-friendly processing and produce pectin with enhanced techno-functional traits appropriate for food and nutraceutical applications. Matching the extraction technique to the intended application allows for the tailored production of pectin, promoting both waste valorization and the development of health-promoting food ingredients.

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A LevelDB Approach to Organism-Specific Storage of Theoretical Peptides

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Abstract

Efficient organization and retrieval of theoretical peptide information are essential for proteomic research. This work presents a database design for digested protein sequences based on LevelDB, using a key based on organism identity (NCBI Taxonomy ID) and peptide mass. Unlike existing mass-centric peptide databases (e.g., MaCPepDB), which primarily index peptides by mass across large combined protein sets with organism information applied only as an additional filter, the proposed approach uses a composite key to organize entries per organism and enables direct access to peptides from a selected organism. Protein sequences from the UniProtKB/Swiss-Prot database were digested *in silico*, and the resulting peptide masses were stored with fixed decimal precision under each organism's taxonomy identifier. Each key therefore defines a specific combination of organism and discretized mass value, while the associated value contains all peptides corresponding to that stored mass within the given organism's Swiss-Prot protein dataset. For a selected organism, mass-based queries are performed either for a single mass value, matched exactly at the chosen precision, or within a specified mass range, in both cases retrieving all peptides with stored masses falling between the given bounds. For each organism, proteins are first digested into peptides and effectively ordered by mass through the sorted LevelDB key space, enabling efficient range-based searches over user-defined mass ranges and allowing researchers to explore peptide profiles across different species or strains in a biologically meaningful way. The database operates locally without a separate server, making it portable and easy to maintain.

Keywords: *proteomics, bioinformatics, LevelDB, optimized peptide database, in silico digestion*

I. INTRODUCTION

Theoretical peptide databases support a wide range of proteomics data-processing and interpretation workflows (Aebersold and Mann, 2016). A practical challenge arises when a single database is expected to contain peptides from many organisms: peptide masses are not unique identifiers, and identical or similar mass values may occur across different organisms. As a result, mass-based indexing often returns an unnecessarily large set of peptides and requires additional filtering by taxonomy, protein origin, or other metadata (Federhen, 2012). Many existing solutions therefore prioritize a global mass index and apply organism-level constraints only as a secondary filter (Uszkoreit et al., 2021). Moreover, data analysis and interpretation tasks such as biotyping or proteomic profiling naturally start from an assumption about the organism – or a short list of candidate organisms – and, ideally, should retrieve candidate peptides within that context from the outset (Singhal et al., 2015). In this work, we propose an organism-specific organization of theoretical peptides. The main contribution is an indexing concept based on a composite key, implemented in the ordered embedded key–value database LevelDB (Dean and Ghemawat, 2011). This design enables exact lookups at the chosen discretized mass and efficient retrieval over mass ranges within the selected organism. As a result, biological interpretability is improved and fast local searches are supported without the need for a server (Dong et al., 2021).

II. MATERIALS AND METHODS

A. DATA SOURCE AND PEPTIDE GENERATION

As a source of protein sequences, we used curated Swiss-Prot entries because they provide high reliability for generating theoretical peptides and allow accurate assignment of peptides to the corresponding organism (The UniProt Consortium et al., 2025). In an organism-oriented database design, the accuracy of the taxonomic label is important because taxonomy defines the primary partition of the key space (Federhen, 2012). Each protein record contains an amino acid sequence and the associated organism taxonomy identifier; additional annotations can be stored separately or included in the value field if needed.

Based on the selected protein sequences, theoretical peptides are generated by *in silico* digestion. Trypsin was chosen due to its widespread use in proteomics and its ability to produce peptides well suited for mass spectrometry analysis (Tsiatsiani and Heck, 2015). The digestion results in a list of peptide sequences for each protein, and each peptide inherits the taxonomy identifier from its source protein record. In practice, the database must handle duplicate peptide sequences within the same organism (e.g., originating from multiple proteins) as well as cases where different peptides can share the same discretized mass, defined as a fixed-precision integer mass obtained by scaling and rounding the monoisotopic mass.

For storage and fast retrieval, each peptide is assigned a discretized mass that serves as part of the key. Mass can be stored as a floating-point number, but this representation is not ideal for stable indexing. To ensure consistent key construction and efficient searching, we discretize peptide masses to a fixed precision and store them as integers. A common approach is $m_{int} = \mathrm{round}(m \cdot s)$, where m is the monoisotopic peptide mass and s is a scaling factor (Aebersold and Mann, 2016). In this work, we use a precision of four decimal places, i.e., $s = 10^4$. This discretization yields stable keys, avoids formatting ambiguities typical of floating-point values, and enables fast comparisons. Throughout the paper, we use m for continuous masses and m_{int} for their discretized integer representations. The choice of precision is a trade-off: finer mass precision reduces overlaps in discretized masses but increases the size of the key space; coarser mass precision increases overlaps and requires more disambiguation within the stored values.

B. STORAGE AND QUERY DESIGN

The key idea is to construct the key so that all peptides from the same organism occupy one contiguous block in the sorted key space and are ordered by mass within that block. In the equations, $taxID$ denotes the organism's taxonomy identifier, and m_{int} denotes the discretized peptide mass. Conceptually, $K = (taxID, m_{int})$. Because the key–value store sorts keys lexicographically, the numeric components must be encoded to preserve numeric ordering (Dean and Ghemawat, 2011). This ensures that keys are sorted first by the organism's taxonomy identifier and then by mass, so mass-based queries become local searches within the organism-specific region of the key space. After defining the key, it is necessary to specify how peptides associated with a given $(taxID, m_{int})$ pair are stored.

The value associated with the key $(taxID, m_{int})$ contains the peptides that match the discretized mass within the selected organism. Since discretization may cause multiple distinct peptides to share the same m_{int}, a single key can correspond to multiple peptides, so the value is typically stored as a list. In the presented implementation, the value stores the peptide sequences associated with $(taxID, m_{int})$, enabling straightforward and fast retrieval without additional steps.

For the proposed design, the storage system must support ordered keys, fast exact retrieval for individual keys, and efficient searches over key ranges. LevelDB is an embedded key–value database well suited for local use and supports iteration over keys in sorted order (Dean and Ghemawat, 2011). It requires no server component and has minimal infrastructure

requirements, making it appropriate for scenarios where the database is built and queried locally or distributed as a compact database file (Dong et al., 2021). From a query perspective, the ordered key space enables two main scenarios. The first is an exact lookup: given $taxID$ and a continuous query mass m (with arbitrary decimal precision), which is discretized to m_{int}, the key $K = (taxID, m_{int})$ is constructed and an immediate $Get\ (K)$ operation is performed. This mode is useful for single-mass lookups. The second scenario is a range query, where peptides are searched within a specified mass range rather than at a single discretized value. The user provides m together with a tolerance ($\pm ppm$ or $\pm \Delta Da$), which defines a continuous mass range $[m_{min}, m_{max}]$ around m. This mode is useful for tolerance-based searches around an observed mass. After mass discretization, the query bounds can be represented as an integer range $[m_{int,min}, m_{int,max}]$. The integer bounds are computed as $m_{int,min} = \text{round}(m_{min} \cdot s)$ and $m_{int,max} = \text{round}(m_{max} \cdot s)$. The corresponding start and end keys are defined as $K_{start} = (taxID, m_{int,min})$ and $K_{end} = (taxID, m_{int,max})$. The query is executed by positioning an iterator at K_{start} and then advancing through subsequent keys in sorted order until the key exceeds K_{end}. For each key encountered in this range, peptides whose discretized mass falls within the specified bounds for the selected organism are retrieved. This approach is efficient because the search is confined to a narrow, contiguous region of the sorted key space (Dean and Ghemawat, 2011). Range queries are one of the main motivations for using a composite key, as they naturally rely on iterating over keys in sorted order without additional indexing structures. By including the organism taxonomy identifier in both the start and end keys, it is ensured that the iterator remains within the selected organism even when mass ranges overlap across different organisms. The proposed workflow was implemented in Python as an application for *in silico* peptide generation, LevelDB database construction, and the execution of exact and range queries. The two query modes supported by the index are summarized in Table 1.

Table 1. Query modes in the index

Query mode	Input	Operation in the database	Output	Typical use
Exact lookup	$taxID, m$	Retrieve the value for key $K = (taxID, m_{int})$, where $m_{int} = \text{round}(m \cdot s)$	List of peptides for that key	When querying a single mass, the input mass is discretized for an exact key lookup
Range query	$taxID, m, tolerance \rightarrow [m_{int,min}, m_{int,max}]$	Iteration in sorted key space from $K_{start} = (taxID, m_{int,min})$ to $K_{end} = (taxID, m_{int,max})$	List of peptides for all keys in the range	When searching within a given mass range

III. RESULTS AND DISCUSSION

A. TAXONOMY IN THE PRIMARY KEY

The central difference between a global mass index and the proposed $(taxID, m_{int})$ index is that retrieval is, by design, constrained to a single organism. In a global mass index, a query returns peptides from multiple organisms and requires additional filtering, which can be costly and may reduce biological interpretability (Uszkoreit et al., 2021). In an organism-oriented design, the workflow is simpler: the organism is selected first, and the mass-based lookup (exact or range) is then performed exclusively within that organism's region of the key space. This is particularly well aligned with analytical workflows that start from a known or hypothesized organism, such as biotyping and organism-to-organism comparisons (Singhal et al., 2015). Fig. 1 shows an example query execution, summarizing the direct lookup workflow for a selected organism.

```
Direct lookup example (LevelDB / plyvel)

Query:
  taxID = 34
  mass  = 473.2598

Key encoding:
  SCALE  = 10000
  mass_i = round(mass * SCALE) = 4732598
  key    = struct.pack(">II", taxid_i, mass_i)

Output:
  Hits = 11
  Top hits (first 4):
    ALDR, LEGR, EAVR, LADR
    ...
```

Figure. 1. Example of a direct lookup by discretized mass within a selected organism. The query mass is discretized and combined with taxID into a composite key for exact peptide retrieval from LevelDB

In biotyping scenarios, the goal is to rapidly associate observed features with peptide evidence specific to an organism and compare samples across organisms or strains (Singhal et al., 2015). A database that returns candidate peptides already restricted to the selected organism directly supports this analytical workflow: the same mass range can be queried for multiple candidate organisms, allowing comparison of the resulting distributions and the total number of retrieved peptides.

B. PERFORMANCE CONSIDERATIONS AND LIMITATIONS

Exact retrieval by key reduces direct access to a single value and is typically very fast. In the experimental setup, the database occupied 316.91 MB on disk and contained 12,091,665 keys; the database build time was ~2 min. Mass range queries depend on the number of keys that fall within the specified bounds for the selected organism; thus, the cost increases with the number of matched records rather than with the overall size of the database. Database build time is determined by the number of generated peptides and the write throughput, and grouping keys by organism enables straightforward parallelization when needed. The discretization precision affects the overlap between discretized masses and the effective width of mass ranges, and modified peptides would require extensions such as additional metadata in the value field. Future work will include a comparative analysis between the developed database and MaCPepDB.

IV. CONCLUSIONS

This work presented an organism-oriented theoretical peptide database that incorporates taxonomy into the primary index. This approach constrains mass-based retrieval to the selected organism from the outset, improving biological interpretability and reducing unnecessarily large result sets compared to global mass indexes. The solution was implemented in LevelDB as a local, embedded database without a server and supports exact retrieval at discretized masses as well as mass range retrieval within an organism. Future work includes empirical evaluation (database size, build time, and query response time) and more compact value storage with metadata extensions for downstream analyses.

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Comparing Mediterranean Diet Adherence Between Mediterranean and Western Populations: Evidence from Croatia and the United States

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Abstract

The Mediterranean diet (MD) emphasizes whole, minimally processed foods and is associated with reduced risk of chronic disease and mortality among diverse populations. However, MD adherence varies globally due to cultural, socioeconomic, and geographic factors. To better understand how globalization and the nutrition transition influence dietary patterns across different cultural contexts, the aim of the present study was to compare MD adherence between Western (United States; US) and Mediterranean (Croatia) countries. This study used data from the 2017/18 National Health and Nutrition Examination Survey (NHANES; US; n = 4339) and the 2018-2023 Croatian national food consumption survey on adolescents and adults (NIPNOD; Croatia; n = 1672). For both national surveys, dietary data among adults (≥18 yrs.) were obtained from two 24-hour dietary recalls and averaged across both days. MD adherence was assessed using an adapted version of the literature-based Mediterranean diet score, with participants scored based on energy-adjusted intakes across nine food categories. The total MD score ranged from 0 (lowest adherence) to 18 (highest adherence). Independent t-tests were used to assess differences. The energy-adjusted MediLite score was higher in Croatia than in the US (7.35 vs. 6.82; $p<0.0001$). Preliminary analyses found that fruit (1.48 vs. 0.34; $p<0.0001$), dairy (1.20 vs. 0.63; $p<0.0001$), meat (1.37 vs. 1.04; $p<0.0001$), legumes (0.60 vs. 0.47; $p=0.0013$), and olive oil (0.03 vs. 0.01; $p=0.0001$) scores were significantly higher in Croatia than in the US, whereas grains (0.52 vs. 1.86; $p<0.0001$) and alcohol (0.65 vs. 0.97; $p<0.0001$) scores were significantly higher in the US. Fish and vegetable scores did not significantly differ between the two countries. The total MediLite score, associated with greater intake of several key Mediterranean diet components, was higher among Croatian adults compared to US adults; however, adherence to the MD was low in both countries. These results demonstrate the growing prevalence of Western dietary patterns in Mediterranean countries.

Keywords: *Mediterranean diet, national survey, cross-country comparison, Croatia, USA*

I. INTRODUCTION

The Mediterranean diet (MD) emphasizes whole, minimally processed foods, including fruits, vegetables, legumes, whole grains, olive oil, and moderate fish intake, and is consistently associated with reduced risk of chronic disease and all-cause mortality across diverse populations (Buckland et al., 2008; Trichopoulou et al., 2003). Despite its well-established health benefits, adherence to the MD varies substantially worldwide, influenced

by cultural traditions, socioeconomic conditions, food environments, and geographic access to key dietary components (Obeid et al., 2022; Vilarnau et al., 2019). The nutrition transition has contributed to shifts away from traditional dietary patterns toward Western diets characterized by higher intake of ultra-processed foods (UPFs) (Baker et al., 2020; Popkin, 2004). To better understand how globalization and the nutrition transition influence dietary behaviors across different cultural contexts, the aim of the present study was to compare MD adherence and its individual components between a Western country (United States) and a Mediterranean country (Croatia).

II. MATERIALS AND METHODS

The US sample was obtained from the 2017/18 National Health and Nutrition Examination Survey (NHANES) (CDC, 2025). Briefly, NHANES is a nationally representative, cross-sectional survey of American children and adults. Sociodemographic and health information is collected through in-person interviews and mobile examination center (MEC) visits. Dietary data are collected via two non-consecutive 24-hour dietary recalls administered using the USDA Automated Multiple Pass Method. Trained interviewers administered the first recall in person at the MEC and the second by telephone 3-10 days later. Dietary data were mapped onto the Food Patterns Equivalents Database (FPED) (Bowman et al., 2020).

The Croatian sample was drawn from a representative population of stratified random sample from the Croatian national food consumption survey on adolescents and adults (NIPNOD; 2018-2023), following the EU Menu methodology (EFSA, 2014). The sampling method and a detailed description of the study population are provided in earlier reports (Sokolić et al., 2024). Dietary data were collected through 24-hour recalls on two non-consecutive days by trained interviewers using a multi-pass protocol, conducted via video calls or in person. The collected recalls were analyzed using NutriCro® v. 3.0 software and information from nutrition labels on the food products. To assess the consumption of each food item, composite dishes were disaggregated using the recipe database (Sokolić et al., 2024).

Adults (≥18 yrs.) with completed dietary data were included in the analyses for each country. For both national surveys, dietary data were averaged across both days. MD adherence was assessed using an adapted version of the literature-based MD score (MediLite) proposed by Sofi et al. (Sofi et al., 2014). Participants were scored zero to two points based on energy-adjusted intakes across nine food categories: fruit, vegetables, legumes, grains, dairy, olive oil, meat, fish, and alcohol. Higher points were assigned for greater consumption of all components except dairy, meat, and alcohol. Lower consumption of meat and dairy was scored positively, while alcohol intake was scored maximum points (two points) for 12-24 grams/day, one point for less than 12 grams/day, and zero points for more than 24 grams/day.

The total MediLite score ranged from zero (lowest adherence) to 18 (highest adherence). Statistical analysis was performed using SAS 9.4, using two-sided $\alpha = 0.05$. Descriptive data were presented as mean and standard error, as their normal distribution was confirmed by the Shapiro-Wilk test. Energy adjustments were calculated using the residual method, a standard statistical approach used to account for between-person differences in total energy intake (Willett, 2012). Independent t-tests were used to assess differences in total MediLite score and each individual component score between countries. Survey weights were applied to NHANES data.

III. RESULTS AND DISCUSSION

A total of 4,339 participants (n = 4339; 47.85% men and 52.15% women) were included in the US sample, and 1,672 (n = 1672; 47.79% men and 52.21% women) were included in the Croatian sample.

Higher total MediLite scores in the Croatian sample were primarily due to greater consumption of fruits, legumes, and olive oil, and lower consumption of meat and dairy (Table 1). These findings indicate meaningful differences in dietary patterns between Western and Mediterranean populations, which may reflect differences in cultural, environmental, and food system factors.

Table 1. Total MediLite and MediLite component scores for Croatia and the US

	US	**Croatia**	***p*-value**
Total MediLite score	6.82 (0.06)	7.35 (0.06)	<0.0001*
Fruit	0.34 (0.02)	1.48 (0.02)	<0.0001*
Vegetables	1.06 (0.03)	1.09 (0.02)	0.5254
Grains	1.86 (0.01)	0.52 (0.02)	<0.0001*
Dairy	0.63 (0.02)	1.20 (0.02)	<0.0001*
Meat	1.04 (0.03)	1.37 (0.02)	<0.0001*
Fish	0.46 (0.03)	0.42 (0.02)	0.2348
Legumes	0.47 (0.03)	0.60 (0.02)	0.0013*
Olive Oil	0.01 (0.003)	0.03 (0.004)	0.0001*
Alcohol	0.97 (0.01)	0.65 (0.01)	<0.0001*

Data are presented as mean (standard error). * Independent t-tests used to differences between countries ($p<0.05$).

Olive oil intake was significantly higher in Croatia, likely reflecting greater availability and affordability. In Croatia, olive oil is frequently used for preparing dishes, whereas in the US it is often more expensive and is therefore frequently substituted with cheaper, refined vegetable oils (Buckland & González, 2010; Xiong et al., 2014). However, olive oil intake was low in both countries, so future analyses could consider using an alternative variable to reflect fat intake, such as the monounsaturated to saturated fat ratio. Vegetable intake did not significantly differ between countries and may be partially explained by widespread public health messaging about the importance of incorporating vegetables into a healthy diet (Antonić Degač et al., 2002). However, preliminary analyses found that other plant-based foods – fruit and legumes – were significantly higher in Croatia than in the US. Grain scores were significantly higher in the US and may be driven largely by refined grain products common in UPFs rather than whole grains emphasized in the (Dunford et al. This finding may indicate a limitation of the MediLite scoring system, which does not distinguish between whole and refined grains.

In terms of animal-based foods, meat and dairy scores were significantly higher in Croatia, reflecting lower overall intakes. This contrasts with dietary patterns in the US, where higher consumption of dairy and meat – often in processed forms – is common (Daniel et al., 2011). Although not significant, fish intake was slightly higher in the US. Given that Croatia is a coastal country, this finding may reflect regional heterogeneity within Croatia (Marinac Pupavac et al., 2022) or limitations in dietary assessment methods.

Alcohol scores were higher in the US compared to Croatia. In the US, alcohol intake may be more evenly distributed at moderate levels, whereas in Croatia, consumption patterns may be more polarized, with a higher prevalence of abstention or heavier episodic drinking

(Mišević et al., 2020). MD scoring rewards moderate alcohol intake regardless of beverage or context, which may favor US patterns despite differences from traditional Mediterranean wine-with-meals practices. Thus, this finding may highlight limitations with MD scoring systems for alcohol intake.

Intake of UPFs may partially explain differences in MD adherence, which is substantially higher in the US (approx. 60% of total energy intake (Juul et al., 2022) compared to Croatia (approx. 20% of total energy intake) (Mertens, 2022). Higher UPF consumption is associated with poorer overall diet quality (Liu et al., 2022) and lower Mediterranean diet adherence (Ruggiero et al., 2025), as UPFs can displace whole foods central to the MD.

IV. CONCLUSIONS

In conclusion, adherence to the Mediterranean Diet was slightly higher in Croatia than in the United States, due to greater intake of plant-based foods and lower consumption of animal products. Differences in food access, processing, and cultural practices likely explain variation in diet components. Overall adherence was low in both countries, reflecting the spread of Western dietary patterns. These findings highlight the importance of targeted public health policies and community-based interventions that promote affordable access to minimally processed foods, nutrition education, and preservation of traditional dietary practices to improve adherence to healthy eating patterns in both Mediterranean and Western countries.

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The "Student Bag": A New Concept Based on the Mediterranean Diet to Improve the Diet of University Students in Croatia

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Abstract

Dietary and other health-related habits established during young adulthood, especially during university education period, may represent an important factor in health-related determinants and the prevention of chronic diseases. Student restaurants play an important role in shaping dietary habits, nutrition literacy, and promoting healthy and sustainable dietary patterns such as the Mediterranean diet. This study examined the opinions of university students in Croatia regarding meal proposals that could improve the offer in student restaurants and enhance resemblance of students' diets to the Mediterranean dietary pattern. The study used mixed methods (exploratory sequential design). In the qualitative phase, a focus group of student representatives from the University of Zagreb (n=8) generated proposals for new meals, considering sustainability, practicality, and Mediterranean diet principles. Based on the results of the focus group, a questionnaire was developed and completed by 1187 students from 70 higher education institutions across Croatia. The analysis showed that gender, age, and type of accommodation significantly influenced willingness to choose Mediterranean dietary options: female students, older students, and those living in private accommodation were more inclined to choose such options, while the region of study had no impact. Students expressed interest in practical and subsidized meal options such as salads, tortillas, nuts, olive oil, and ready-to-eat meals to go (the "student bag" concept). The survey confirmed the focus group findings, with tortillas and salads (as complete meals) highlighted as preferred options for the "student bag" content.

Keywords: *Mediterranean diet, student restaurants, "student bag", dietary habits*

I. INTRODUCTION

According to the 2019 Global Burden of Disease study (GBD 2019 Risk Factors Collaborators, 2020), poor diet quality is responsible for more than 11 million premature deaths and over 295 million disability-adjusted life-years (DALYs) annually. These findings highlight the urgent need to promote healthier and more sustainable dietary patterns, particularly the Mediterranean diet.

Among university students, academic stress negatively affects dietary choices and physical activity. Students often skip meals (Lee et al., 2017) and rely on highly processed food, rich in fats and sugars (Mikolajczyk et al., 2009). Male Croatian university students prefer red meat and fast food, while female students tend to consume more low-fat dairy products and whole grain foods (Šatalić et al., 2007). Analysis of Croatian student restaurant menus using MeDCIn showed low compliance with the Mediterranean dietary pattern. The menus lack dishes with eggs, whole grains, olive oil, nuts, and seeds, while offer of fruits, vegetables, and fish dishes is not diverse enough (Neto et al., 2024).

The aim of this study was to collect and analyze students' proposals for new Mediterranean options in student restaurants appropriate for the "student bag" concept, i.e., a sustainable and practical meal to go that would include food items typical of the Mediterranean diet.

II. MATERIALS AND METHODS

The study was conducted as a part of the international PRIMA project MedDietMenus4Campus, which aims to promote sustainable, Mediterranean-oriented nutrition in student restaurants. In the first of seven phases, a focus group was designed, including session organization, participant recruitment, and preparation of a focus group guide with predefined topics and questions. Proposals from the focus group were collected in the second phase, followed by transcription of the data in the third phase and initial data analysis in the fourth phase. Results from the focus group analysis were used to design the questionnaire in phase 5, which was administered in the sixth phase. The seventh and final phase involved qualitative analysis of the data collected through the questionnaire.

The study used an exploratory sequential mixed-methods design, combining qualitative and quantitative approaches to achieve a comprehensive understanding of students' dietary behaviors and needs. Qualitative methods explored students' perceptions, preferences, and proposed food choices in student restaurants, while quantitative methods allowed systematic examination of previously collected results on a larger sample.

The study was approved by the Ethics Committee of the University of Zagreb Faculty of Food Technology and Biotechnology.

Focus group participants were recruited according to the following inclusion criteria: (1) enrollment in undergraduate or graduate studies at the University of Zagreb, (2) eligibility for subsidized student meals, (3) enrollment in the relevant field of study, and (4) representation of both genders. The focus group included eight students: five undergraduate (four females and one male) and three graduate students (one female and two males). Participants represented eight faculties of the University of Zagreb.

Demographic data, student eating habits, and preferences for Mediterranean-style to-go options were collected using a 13-question long questionnaire, which included 12 closed-ended questions (multiple choice, yes/no, ranking) and one open-ended question for suggestions regarding the "student bag" option. The online questionnaire was completed by 1187 students from 70 higher education institutions across Croatia between 5th November 2024 and 7th February 2025. Most respondents live in private accommodation (43.8%), followed by those living with their families (29.4%) and those living in student dormitories (26.8%). Frequency of dining was influenced by place of residence: 28.1% of students reported consuming one meal per day, 26.5% consumed two to three meals per day, and 25.6% reported eating in student restaurants several times per week. Students were divided into four groups according to the region of their faculty, based on the National classification of statistical region at level 2: the City of Zagreb, Northern Croatia, Pannonian Croatia, and Adriatic Croatia. Overall, the sample was considered representative of the student population of Croatia.

An independent-samples *t*-test was used to examine gender differences in willingness to choose Mediterranean options in student restaurants. Participants were divided into four age groups (≤20, 21–23, 24–26, and ≥27 years). One-way ANOVA was conducted to assess differences in willingness to choose Mediterranean options across age groups, place of study, and type of household during the study period.

Qualitative data were analyzed using transcription, thematic analysis, and content analysis, while quantitative data from the questionnaire were analyzed using IBM SPSS Statistics (version 21.0).

III. RESULTS AND DISCUSSION

To support the study's aim of analyzing students' proposals for Mediterranean-style options suitable for the "student bag" concept, content analysis was used to complement thematic analysis by quantifying qualitative data from focus group transcripts (Holsti, 1968). A summative approach based on keyword frequency and context helped identify proposed

dishes that could address gaps in the student restaurant's offer. The most frequently mentioned terms were eggs (n=36), olive oil (n=23), nuts (n=19), and whole-grain products such as pancakes (n=19) and tortilla (n=18), which align with previously identified deficiencies in student nutrition (Neto et al., 2026).

The focus group transcript was analyzed using thematic analysis to identify key themes relevant to the research questions (Braun and Clark, 2006). Three main themes emerged: (1) selection of food products suitable for student restaurants, (2) price and subsidy, and (3) practicality and food safety of takeaway options. Participants preferred convenient foods similar to those available in bakeries and supermarkets, such as salads, sandwiches, tortillas, pizzas, and simple soups. Acceptance of new options depended largely on affordability and inclusion in subsidized menus. Practicality and food safety were emphasized, with a preference for individually packaged, easy-to-consume foods and the use of reusable or recyclable packaging.

Most student participants expressed willingness to include whole-grain bread and olive oil with their meals, as well as to purchase products for later consumption, particularly nuts, canned fish, and soup in a bag. Opinions were more divided regarding the purchase of olive oil for later use. Among focus group participants, nuts, salads, and tortillas were the most preferred options, whereas questionnaire respondents most frequently selected tortillas, salads, and sandwiches (Fig. 1).

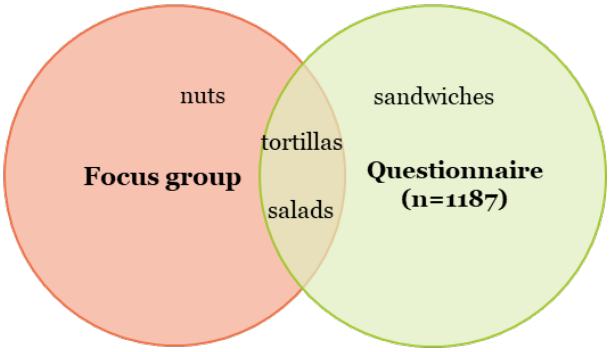

Figure 1. The three preferred options of the focus group participants and the survey respondents

Table 1 shows the influence of sociodemographic factors on the willingness to choose Mediterranean options in student restaurants.

Table 1. Willingness to choose Mediterranean options in student restaurants by gender, age group, region and place of residence

Gender	**n**	**Mean ± SD**
Male	300	3.73^{a} ± 1,58
Female	869	4.12^{b} ± 1,40
Age group	**n**	**Mean ± SD**
≤20	260	3.57^{a} ± 1,55
21-23	598	3.99^{b} ± 1,42
24-26	270	4.37^{c} ± 1,36
≥27	59	4.47^{bc} ± 1,32
Region	**n**	**Mean ± SD**
City of Zagreb	585	3.96^{a} ± 1,43
Northern Croatia	25	4.40^{a} ± 1,26
Pannonian Croatia	319	4.12^{a} ± 1,53
Adriatic Croatia	258	3.95^{a} ± 1,44
While studying and attending classes at the university, I live...	**n**	**Mean ± SD**
with my family	349	3.48^{a} ± 1,51
in a student dormitory	318	4.03^{b} ± 1,46
in private accommodation	520	4.36^{c} ± 1,31

Different letters a, b, c in each category indicate statistically significant difference between the groups, $p<0.001$.

Female students showed significantly higher willingness compared to male students. This finding is consistent with evidence from the HELENA study (Morreno et al., 2014) and Lombardo et al. (2025).

Older students were more inclined to select Mediterranean meals. Previous research suggested that younger individuals tend to prefer food with high energy and low nutritional density, potentially due to a weaker connection of prefrontal-limbic regions (Giuliani and Pfeifer, 2015; Van Meer et al., 2017).

Students living in private accommodation are most willing to choose Mediterranean options in student restaurants, likely due to greater independence and responsibility for meal planning. The ability to buy groceries and to-go Mediterranean options in student restaurants would make meal planning easier for them.

Despite initial expectations, willingness to choose Mediterranean options did not differ significantly by region of study, including Adriatic Croatia ($p<0.05$). This finding aligns with evidence of a generational shift away from the traditional Mediterranean diet toward more Western dietary patterns, even in Mediterranean regions. Previous studies indicate declining adherence among younger populations due to lifestyle changes, globalization, and increased consumption of processed foods (Missoni et al., 2016).

The findings indicate a clear need to improve the offer of student restaurants. Any changes must consider infrastructural and financial constraints, as well as student preferences, where taste, price, availability, convenience, and scheduling play key roles in food choice.

This study has several limitations. The questionnaire did not assess students' perceptions of food quality in student restaurants, their willingness to pay higher prices for new meals, or their specific interest in proposed options, which limits the evaluation of the market potential of the "student bag" to-go concept and its ability to attract more users. Future research should therefore examine price sensitivity in relation to students' financial capacity, interest in specific meal proposals during a pilot phase, and acceptable sustainable packaging solutions.

IV. CONCLUSIONS

This study aimed to propose new "student bag" options and identify the factors influencing students' selection of the Mediterranean option in student restaurants. The analysis showed that gender, age, and type of accommodation significantly influenced the willingness to choose Mediterranean dietary options.

Students show strong interest in new meal options offered in the student restaurant. The "student bag" concept, as a take-away option, is ideal for students' lifestyle and daily routine. Key desired features include practicality, ease of transport in suitable containers, and the possibility of later consumption.

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Association Between Dietary Patterns and Inspiratory Muscle Strength and Function in Patients with COPD

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Abstract

It is known that dietary patterns such as the Mediterranean diet can promote muscle strength, while the characteristics of the Western diet can have negative effects. However, there is a lack of information on how these dietary patterns may affect respiratory muscle strength and function. The aim of this study was to investigate the correlation between dietary patterns of patients with Chronic Obstructive Pulmonary Disease (COPD) and the inspiratory muscle strength and function. The three 24-hour recalls were used to determine the dietary patterns of 71 patients with COPD (55% men; 66.6 ± 8.3 years). Patients were recruited at the Special Hospital for Pulmonary Diseases (Zagreb, Croatia; September 2023 - May 2024). Assessment of dietary patterns and inspiratory muscle strength and function were performed during pulmonary rehabilitation according to standard protocols. For the analysis, all foods and beverages were categorized into 13 food groups. The patients had 1528 ± 405 kcal of daily energy intake. Of all 13 food groups, higher maximum inspiratory pressure (MIP) values were associated with a higher contribution of vegetables (r=0.340; p=0.001) and meat and fish products (r=0.270; p=0.036) to the daily energy intake, while lower MIP values were inversely associated with the relative contribution of legumes, seeds and nuts (r=-0.351; p=0.004). A negative association was found between diaphragm thickness at the end-expiration and the contribution of the alcohol group to daily energy intake (r=-0.257; p=0.032). These results underline the possible influence of specific dietary patterns on the inspiratory muscle strength and function. The results could help to develop nutritional strategies for pulmonary rehabilitation.

Keywords: *COPD, dietary patterns, inspiratory muscle strength, inspiratory muscle function*

I. INTRODUCTION

In nutritional epidemiology, dietary habits are most commonly categorized into two predominant patterns: the Western diet, regarded as nutritionally unfavorable, and the Mediterranean diet, which is considered well-balanced and associated with positive health outcomes (van Iersel et al., 2022). The Western dietary pattern is characterized by a high consumption of red and processed meats, refined grains, added sugars, and fried foods, and has been linked to an increased risk of developing chronic obstructive pulmonary disease (COPD) (Zheng et al., 2016), as well as an increased frequency of respiratory symptoms and impaired lung function (Sorli-Aguilar et al., 2016). Conversely, the Mediterranean diet is distinguished by a high intake of fruits, vegetables, fatty fish, and whole grains, and is associated with a reduced risk of COPD (van Iersel et al., 2022). The positive impact of the Mediterranean diet is further potentiated by higher levels of physical activity and superior physical fitness, indicating a synergistic interaction between healthy dietary patterns and lifestyle behaviors in preserving lung function (Gutiérrez-Carrasquilla et al., 2019).

In patients with COPD, sarcopenia may involve both peripheral and inspiratory musculature (Ma et al., 2022). The diaphragm represents the primary inspiratory muscle, and its dysfunction constitutes a significant systemic manifestation of COPD (Cao et al., 2022). Dietary patterns such as the Mediterranean diet have been shown to support peripheral muscle strength, whereas the nutritional characteristics of the Western diet may exert detrimental effects (Papadopoulou et al., 2023). However, despite growing evidence linking diet to skeletal muscle outcomes, data on the influence of dietary patterns on inspiratory muscle strength and function remains limited. Therefore, the present study aims to observe the association between dietary patterns of patients with COPD and the inspiratory muscle strength and function.

II. MATERIALS AND METHODS

A. Study Design and Participants

This cross-sectional study was conducted between September 2023 and May 2024 at the Special Hospital for Pulmonary Diseases in Zagreb, Croatia. Participants were recruited consecutively from the day clinic during pulmonary rehabilitation. Eligibility required a confirmed diagnosis of COPD according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria (GOLD, 2025). A detailed protocol for participant recruitment, including inclusion and exclusion criteria, was described elsewhere (Ranogajec, 2025). During the recruitment period, 102 patients were screened, of whom 71 met the eligibility criteria and had completed 24h recalls (aged 40–75 years).

Demographic and clinical data were collected through structured interviews conducted during pulmonary rehabilitation and extracted from the Hospital Information System (v. 212.0.000; IN2 Ltd., Zagreb, Croatia). All participants received detailed information about the study procedures and provided written informed consent. Participation was voluntary, and consent could be withdrawn at any time. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the School of Medicine, University of Zagreb (reference number: 251-59-10106-23-111/203; class: 641-01/23-02/01).

B. Dietary Assessment

Dietary intake was assessed using three nonconsecutive 24-hour dietary recalls collected by trained dietitians within the first two weeks of recruitment using a standardized multiple-pass approach. Portion sizes were estimated using household measures and portion sizes from packaged foods. Brand names of packaged foods and dietary supplements were recorded. For the analysis, all foods and beverages were categorized into 13 food groups based on their origin and type. To estimate daily energy intake and the contribution of each food group to daily energy intake, the Prehrana software (v. 1.0; Infosistem Plc., Zagreb, Croatia) was used. This software incorporates national food composition tables (Kaić-Rak and Antonić, 1990) and additional data from nutrition labels of packaged products and supplements.

C. Assessment of Inspiratory Muscle Strength

Maximal inspiratory muscle strength was evaluated by measuring the maximal inspiratory pressure (MIP) using a PowerBreathe device (PowerBreathe International Ltd., Southam, UK) connected to a computer. Each participant performed five maximal inspiratory maneuvers with short rest intervals, and the highest value achieved was retained for analysis, in accordance with established recommendations favoring the best effort over mean values (Sachs et al., 2009).

D. Ultrasonographic Assessment of Diaphragmatic Thickness

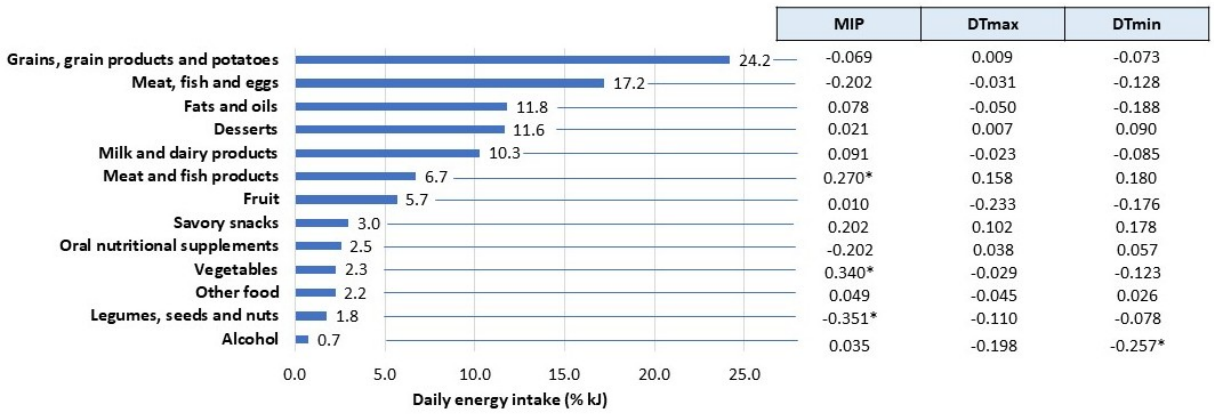
Diaphragmatic thickness was assessed by ultrasonography during quiet and deep breathing using a Mindray DC-8 ultrasound system (Mindray Medical International, Shenzhen, China) equipped with a 7.5–10 MHz linear transducer. Examinations were performed with participants in a supine position by a single experienced examiner to minimize inter-operator variability. Diaphragmatic thickness was measured at end-expiration (DTmin) and at end-inspiration (DTmax). Measurements were obtained perpendicular to diaphragmatic muscle fibers, from the midpleural to the midperitoneal line, and expressed in millimeters. To ensure measurement reliability, each inspiratory thickness assessment was repeated at least three times, and mean values were used for subsequent analyses (Boussuges et al., 2021).

E. Statistical Analysis

Statistical analysis was performed using SPSS software (IBM SPSS Statistics for Windows, version 23.0, Armonk, NY, USA: IBM Corp.). Descriptive data were presented as mean and standard deviation because their normal distribution was confirmed by the Shapiro-Wilk test. The associations between the relative contribution of the 13 food groups to the inspiratory muscle strength and function parameters were tested using the Pearson correlation coefficient. In all tests, the significance level was set at $\alpha = 0.05$.

III. RESULTS AND DISCUSSION

In the present study, patients with COPD (55% men; 66.6 ± 8.3 years) had an average daily energy intake of 1529 ± 405 kcal, which is significantly below the average requirements for middle-aged and elderly people with moderate activity (EFSA, 2019). This result is consistent with available data, as it has been estimated that about 85% of outpatients with COPD do not consume enough energy (Nguyen et al., 2019). The energy intake of the present cohort indicates that their diet does not quantitatively meet daily energy needs, which can lead to loss of body mass and nutritional deficits. Of all 13 food groups, the potato and cereal group (24.2%) contributes the most to the total daily energy intake, followed by the meat, poultry, fish, and eggs group and fats and oils, but also sugars, sweets, and snacks (Fig. 1).



MIP - maximum inspiratory pressure; DTmax - diaphragm thickness at the end-inspiration; DTmin - diaphragm thickness at the end-expiration; * Pearson correlation coefficients ($p<0.05$)

Figure 1. Food group contribution to daily energy intake and its relationship with inspiratory muscle strength and function in patients with COPD (n = 71)

Furthermore, in Fig. 1, the higher MIP values were associated with a higher contribution of vegetables ($r=0.340$; $p=0.001$) and meat and fish products ($r=0.270$; $p=0.036$) to daily energy intake, while lower MIP values were associated with the legumes, seeds and nuts food group ($r=-0.351$; $p=0.004$). Findings that higher MIP was associated with a greater relative contribution of vegetables to daily energy intake aligns with emerging evidence that dietary patterns with higher phytochemical intake may influence inspiratory muscle strength and function in COPD (Ranogajec et al., 2024). In addition, meta-analyses suggest that antioxidant supplementation can improve measures of muscle strength, including MIP, in COPD patients, further indicating a mechanistic link between nutrient-rich diets and respiratory muscle performance (He et al., 2025). The positive association between MIP and meat and fish intake is consistent with evidence that increased energy and protein intake can improve muscle strength and lean body mass in COPD, although direct evidence on inspiratory muscles has been limited (Bernardes et al., 2023). The observed negative association between the legumes, seeds, and nuts group can be explained in the context of overall low energy intake and a higher proportional contribution of lower-digestibility plant proteins that may displace more energy-dense or leucine-rich proteins needed to sustain inspiratory muscle strength (He et al., 2025).

Regarding diaphragmatic structure (Fig. 1), the only significant association in our study was the negative correlation between DTmin and alcohol's contribution to energy intake ($r=-0.257$; $p=0.032$). While there are no COPD-specific studies directly linking alcohol intake to diaphragmatic thickness, general evidence indicates that chronic alcohol consumption can exert deleterious effects on muscle structure and function, including myopathic changes and impaired protein synthesis, which may plausibly extend to respiratory muscles in COPD patients (Urbano-Márquez and Fernández-Solà, 2004).

IV. CONCLUSIONS

This study demonstrates a markedly insufficient energy intake in patients with COPD, placing this population at high risk of malnutrition, weight loss, and muscle dysfunction. Beyond total energy intake, these findings suggest that diet quality and the relative contribution of specific food groups may influence inspiratory muscle strength. Overall, nutritional strategies in malnourished COPD patients should prioritize both sufficient energy intake and an improved dietary composition to support respiratory muscle function and clinical outcomes.

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Association Between Hydration Status and Inspiratory Muscle Strength and Function in Patients with COPD

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Abstract

Alterations in body composition are common in patients with chronic obstructive pulmonary disease (COPD). One of the segments of body composition is hydration status, the disturbance of which is related to pulmonary function, but there is a lack of information on its effects on inspiratory muscle strength and function. Therefore, the aim of this cross-sectional study was to observe the hydration status of adult COPD patients and to assess whether its distribution is related to inspiratory muscle strength and function. In 48 patients with COPD (64.6% men; 66.5 ± 8.9 years) attending pulmonary rehabilitation at the Special Hospital for Pulmonary Diseases in Zagreb, hydration status was determined by bioelectrical impedance, and inspiratory muscle strength and function were assessed according to standard protocols using the PowerBreathe and ultrasound devices. On average, the patients had 50.2 ± 6.0% of total body water (TBW), and 66.7% of them had a sufficient amount of it. The extracellular body water (ECW) accounted for 45.1 ± 2.1% of TBW and intracellular (ICW) for 54.9 ± 2.1%, corresponding to a ratio (ECW/ICW) of 0.8 ± 0.1. The average phase angle (PhA) was 5.2 ± 1.8 degrees, while it was within an appropriate range in only 18.8% of the patients. The correlation analysis showed that lower %ECW (r=-0.327, p=0.023) and higher %ICW (r=0.327, p=0.023) were associated with a thicker diaphragm at end-expiration (DTmin). Moreover, a higher ECW/ICW ratio was associated with decreased DTmin. In addition, higher maximum inspiratory pressure (MIP) was related to higher PhA (r = 0.397; p = 0.005). In conclusion, hydration status may serve as a potential indicator for predicting inspiratory muscle strength and function in COPD patients.

Keywords: *COPD, hydration status, fluid distribution, maximum inspiratory pressure, diaphragm thickness*

I. INTRODUCTION

Chronic obstructive pulmonary disease (COPD) affects approximately 10.3% of the global population and is the fourth leading cause of death worldwide (Adeloye et al., 2022; WHO, 2024). COPD results from structural and functional changes in the airways and alveoli, leading to persistent airflow obstruction. It arises from a complex interaction between genetic and environmental factors, with smoking as the most significant risk factor. The most common symptoms are shortness of breath, cough, sputum production, and exacerbations (WHO, 2024). COPD is associated with depletion of patients' nutritional status, an important predictor of disease outcomes that plays a significant role in designing and implementing targeted pulmonary rehabilitation (Schols et al., 2014). Although nutritional status and muscle mass loss are considered the most important parameters, it is known that people with COPD can also have abnormalities in other body composition parameters, such as fluid distribution (Vermeeren et al., 2006). Just as malnutrition and obesity combined with loss of muscle mass have clinical consequences (Schols et al., 2014), changes in hydration status can reduce lung function (Jin et al., 2024). Hydration status and fluid distribution can be measured using various devices based on the bioelectrical impedance method, a non-invasive and readily

available technique. Furthermore, the phase angle is also an interesting parameter for predicting disease outcomes, especially in diseases with pronounced catabolism, such as COPD. It has been suggested that phase angle provides information about cell integrity, cell mass, and hydration status (de Benedetto et al., 2023). Previous studies suggest that a lower phase angle (<5°) increases the risk of more severe COPD outcomes and that patients with a lower phase angle have a higher risk of mortality (Xie et al., 2024). A lower phase angle is also associated with indicators of sarcopenia and reduced peripheral muscle function in patients with COPD (de Blasio et al., 2019).

To address the gap in knowledge about how hydration status and phase angle may serve as potential indicators of inspiratory muscle strength and function, this study aims to observe the hydration status, fluid distribution, and phase angle of adult COPD patients and assess whether these factors are related to inspiratory muscle strength and function.

II. MATERIALS AND METHODS

A. Study Design and Participants

Participants for this cross-sectional study were recruited from September 2023 to May 2024 at the Special Hospital for Pulmonary Diseases during pulmonary rehabilitation. All participants had a diagnosis of COPD for between 6 and 30 years, according to the Global Initiative for Chronic Obstructive Lung Diseases (GOLD) scale (GOLD, 2025). The exclusion criteria are detailed elsewhere (Ranogajec, 2025). From the total study sample (n = 76), the present study was conducted on a subsample of 48 (63.2%) patients who underwent assessment of body composition and inspiratory muscle strength and function. Each patient provided written informed consent to participate in the study after being informed of the study protocols and measurements. All measurements were performed during the hospital visit for pulmonary rehabilitation by hospital staff. General information about the patients was collected through the Hospital Information System software (version 212.0.000, IN2 Ltd., Zagreb, Croatia) and supplemented with missing data obtained through interviews. The Ethics Committee of the School of Medicine, University of Zagreb (reference number: 251-59-10106-23-111/203, class: 641-01/23-02/01) approved the study, which was designed and conducted in accordance with the Declaration of Helsinki.

B. Assessment of Hydration Status and Fluid Distribution

Assessment of hydration status and fluid distribution was included in the anthropometric and body composition analysis. Patients underwent the assessment wearing light clothing and barefoot. Body height was measured with a stadiometer (SECA 799, Hamburg, Germany) to the nearest 0.1 cm. Body weight and body composition were measured using a bioelectric impedance device with an integrated scale (TANITA MC-780MA P, Tanita Corp., Tokyo, Japan). The measurements reflecting hydration status and fluid distribution from the body composition analysis included total body water (TBW), intracellular body water (ICW), extracellular body water (ECW), and phase angle (PhA).

C. Assessment of Inspiratory Muscle Strength and Function

Assessment of inspiratory muscle strength and function included maximum inspiratory pressure (MIP) and diaphragm thickness at the end-inspiration (DTmax) and end-expiration (DTmin). MIP was measured according to the standard protocol using the PowerBreathe device (PowerBreathe International Ltd., Southam, England, UK) (Sachs et al., 2009). The device also calculates the expected MIP value based on standard formulas that account for the patient's age and sex (Rodrigues et al., 2017). Diaphragm thickness was measured using the Mindray DC-8 ultrasound device (Mindray Medical International Ltd., Shenzhen, Guangdong, China) with a linear probe frequency of 7.5–10.0 MHz. Patients were in the supine position in

B-mode, while the probe was placed above the apposition zone between the eighth and ninth intercostal spaces and between the anterior and middle axillary lines on the right side (Boussuges et al., 2021; Carrillo-Esper et al., 2016).

D. Statistical Analysis

Statistical analysis was performed using SPSS software (IBM SPSS Statistics for Windows, version 23.0, Armonk, NY, USA: IBM Corp.). Descriptive data were presented as mean and standard deviation because their normal distribution was confirmed by the Shapiro-Wilk test. The associations between muscle strength and function parameters and hydration status in patients were tested using the Pearson correlation coefficient. In all tests, the significance level was set at $\alpha = 0.05$.

III. RESULTS AND DISCUSSION

The study included 48 patients, 64.6% men and 35.4% women, with a mean age of 66.5 ± 8.8 years. Most patients had COPD at GOLD stage II (43.8%), followed by stage III (25.0%), stage I (18.8%), and stage IV (12.5%). Additionally, most patients were former smokers (59.6%) or current smokers at the time of the study (38.3%). This description of the study population aligns with global epidemiology trends, indicating that men, older individuals, and smokers or former smokers are more susceptible to developing COPD (Adeloye et al., 2022). Parameters of inspiratory muscle strength and function of the total study sample are shown in table 1.

In the present study sample, 66.7% had adequate TBW, which, according to the European Food Safety Authority, ranges from 45% to 65% depending on sex and body composition of adults (EFSA, 2010). On average, patients had 50.2 ± 6.0% TBW (39.2 ± 7.6 kg), consisting of 45.1 ± 2.1% ECW (17.6 ± 3.0 kg) and 54.9 ± 2.1% ICW (21.6 ± 4.7 kg). The available literature indicates that patients with COPD have TBW similar to that of healthy controls. However, patients with more severe COPD have lower levels of TBW, ECW, and ICW (Jin et al., 2024).

Table 1. Characteristics of inspiratory muscle strength and function of the study sample

Variables	**Total study sample (n = 48)**
MIP (cmH2O)	70.4 ± 20.0
DTmax (mm)	2.4 ± 0.6
DTmin (mm)	1.7 ± 0.5
DTmax/DTmin	1.5 ± 0.3

Data were presented as mean and standard deviation; MIP - maximum inspiratory pressure; DTmax - diaphragm thickness at the end-inspiration; DTmin - diaphragm thickness at the end-expiration

The findings from the present study (Table 2) suggested that inspiratory muscle strength and function were not associated with the percentage of TBW, while ECW and ICW expressed as %TBW were related only to DTmin, indicating that lower %ECW and higher %ICW were associated with a thicker DTmin. In addition, the COPD patients in the present study had an ECW/ICW ratio of 0.8 ± 0.1, which also indicates loss of ICW. Moreover, study results suggest that a higher ECW/ICW ratio is associated only with decreased DTmin, indicating lower inspiratory muscle function. Lower levels of ICW may reflect poorer nutritional status and have been linked to sarcopenia in COPD patients (Jin et al., 2024).

Furthermore, the average PhA was 5.2 ± 1.8 degrees, which aligns with the proposed range of 5° to 7° for healthy individuals (Zanella et al., 2025), and only 18.8% of the patients in this

study were within that range. Higher PhA was related only to greater MIP values (Table 2), indicating that higher PhA is associated with better inspiratory muscle strength and function. These results support previous study findings that lower phase angle is associated with reduced peripheral muscle mass and decreased functional capacity in COPD patients (Zanella et al., 2025; de Benedetto et al., 2023; de Blasio et al., 2019), as well as a higher frequency of exacerbations (Xie et al., 2024).

Table 2. Relationship between inspiratory muscle strength and function with hydration status in patients with COPD (n = 48)

Variables	**MIP** (cmH2O)		**DTmax** (mm)		**DTmin** (mm)		**DTmax/DTmin**	
	r	*p* Values	r	*p* Values	r	*p* Values	r	*p* Values
TBW (% kg)	-0.113	0.444	0.093	0.528	0.143	0.331	-0.110	0.547
ECW (% TBW)	-0.171	0.246	-0.250	0.087	-0.327	0.023	0.214	0.144
ICW (% TBW)	0.171	0.246	0.250	0.087	0.327	0.023	-0.214	0.144
ECW/ICW	-0.169	0.251	-0.247	0.090	-0.324	0.025	0.219	0.135
PhA (°)	0.397	0.005	0.227	0.120	0.037	0.805	0.217	0.139

MIP - maximum inspiratory pressure; DTmax - diaphragm thickness at the end-inspiration; DTmin - diaphragm thickness at the end-expiration; TBW - total body water; ECW - extracellular water; ICW - intracellular water; PhA - phase angle; * Pearson correlation coefficients ($p<0.05$)

The results of this study should be interpreted with caution, as the cross-sectional design does not imply causal relationships. Additionally, the study was conducted on a small sample of COPD patients, primarily with mild stages of the disease.

IV. CONCLUSIONS

In patients with COPD, lower total body water and a higher extracellular water to intracellular water ratio have been observed. Additionally, the phase angle was near the lower limit recommended for a healthy population. All parameters were significantly associated with muscle strength and/or inspiratory muscle function. These findings confirm the practical value of measuring hydration status, fluid distribution, and phase angle for nutritional assessment to provide better insight into the health outcomes of COPD.

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Is There a Link Between Food Safety Culture and Internal Audit Results in Retail Settings?

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ABSTRACT

Companies with a strong food safety culture (FSC) are generally associated with fewer food safety non-conformities and incidents. However, several research studies indicate that FSC assessments should be conducted alongside observations of actual food safety practices to validate FSC results. In this study, the link between FSC in a retail chain in Croatia and internal audit results was examined. Additionally, employee motivation was assessed, and its relationship to FSC and audit results was described.

A structured employee questionnaire based on the European Commission guidelines (2022/C 355/01) was used to assess FSC, targeting staff from various regions. Internal audit results were evaluated using the GFSI (Global Food Safety Initiative) checklist, while employee motivation was measured through perceptions of workload, work atmosphere, and long-term interest in employment with the company.

The results indicated a high overall level of FSC (mean=4.51). No significant correlation was found between audit results and either FSC or motivation, while motivation showed a strong positive correlation with FSC ($r=0.528$, $p<0.05$). Regional differences were observed, with employees in Zagreb and Central Croatia having lower average FSC and motivation scores.

For the observed retail chain, it is recommended to develop a system of motivational incentives to encourage proactive employee behavior in food safety and to invest in improving resource availability. The assessment of food safety culture is based on employees' subjective perceptions, while audits provide more objective and relevant indicators; therefore, combining both offers the most comprehensive picture of actual safety practices.

Keywords: *food safety culture (FSC), retail, audit, motivation*

I. INTRODUCTION

Food safety is a key element in protecting public health and maintaining consumer confidence in the food sector. Although legal frameworks and technical standards such as the HACCP (Hazard Analysis and Critical Control Points) system have been established for a long time, frequent incidents related to food contamination show that technical solutions alone are insufficient without a strong organizational Food Safety Culture (FSC).

Research studies show that organizations with a stronger FSC achieve better audit results, fewer non-conformities, and less frequent microbiological incidents (Baeza and Kluse, 2024; De Boeck et al., 2015). The concept of FSC, which encompasses employees' values, beliefs, and attitudes toward food safety, was legally recognized in Regulation (EU) 2021/382, which obliges all food business operators to establish and maintain it.

The retail sector is characterized by high employee turnover, especially in operational roles, making it difficult to maintain FSC continuity and implement long-term educational programs (Liggans and Kim, 2024). Other characteristics of retail – high levels of customer interaction, diverse products, and complex structure – make the assessment and maintenance of FSC a complex process that may require both subjective employee perceptions and objective indicators such as audits (Baeza and Kluse, 2024).

Therefore, in this study, the link between FSC in a retail chain in Croatia and internal audit results was examined. Additionally, employee motivation was assessed, and its relationship to FSC and audit results was described.

II. MATERIALS AND METHODS

The research was conducted in 15 large-format stores of a retail chain in Croatia, located in the East, West, Zagreb, and Central regions. The sample included 117 employees from fresh food departments (butchery, fish counter, delicatessen, bakery, gastronomy, fruit and vegetables, dairy). A survey questionnaire based on Annex 3 of the European Commission Notice (European Commission, 2022) was used to assess the FSC, with three additional statements on motivation.

The questionnaire covered five FSC categories (communication, importance of hygiene, resources, risks, leadership) and included a motivation section measured through perceptions of workload, work atmosphere, and long-term interest in employment with the company. The motivation assessment claims were based on a validated questionnaire developed for research on an expanded model of food safety culture, which included psychosocial factors such as burnout, motivation, and workplace stress (De Boeck et al., 2017).

Internal audit results according to GFSI criteria (GFSI, 2018) were also collected in parallel. According to the Codex Alimentarius, an internal audit assesses the effectiveness of the food safety system, including the implementation of HACCP and prerequisite programs such as hygiene, cleaning, pest control, maintenance, and staff training. The audit is conducted through document review, on-site observation, and employee interviews to verify compliance and proper implementation.

The mean values of FSC, employee motivation and audit results were calculated. The mean values of FSC, motivation and audit for the 15 facilities represented new variables used in further correlation analyses. Data were processed in Excel and SPSS, using Spearman correlation.

III. RESULTS AND DISCUSSION

The results indicated a high overall level of FSC (mean = 4.51) in a retail chain. High scores are common in food establishments (Tomasevic et al., 2020; Vidacek Filipec et al., 2023).

Fig. 1 shows the mean values of five FSC categories for 117 employees. Four categories had similarly high values, while the lowest score was in the resources category, which is consistent with other studies where resources was the lowest-scored category (Tomasevic et al., 2020; Vidaček Filipec et al., 2023).

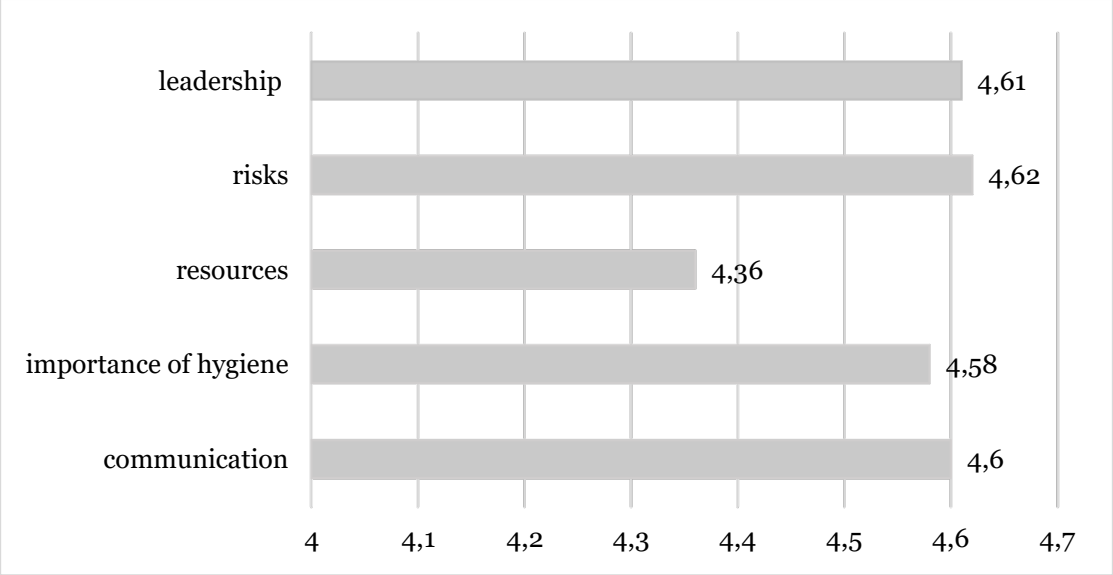

Figure 1. Mean values of 5 FSC categories (n=117)

Results on motivation showed that 89% of the 117 employees (104) wanted to stay at the current company for a longer period, and 85% (99) felt positive about their workplace. The lowest scores were for workload perception: 22% (26) felt overloaded, 14% (16) were neutral, and 63% (73) did not feel overloaded with work. According to De Boeck et al. (2017), employees' psychological states can block the impact of a good organizational FSC, and organizations should not only invest in education and communication but also actively manage psychosocial working conditions (e.g. workload, support, stress recognition) to improve actual employee behavior in practice.

Table 1. shows mean values of FSC, motivation and audit for each of the 15 stores, grouped into three regions. Regional differences were observed, with employees in the Zagreb/Central region having lower average FSC and motivation scores. There were no statistically significant differences in audit results among the regions.

Table 1. Mean values of FSC, motivation and audit (different letters in each raw a, b, c indicate statistically different values among regions, $p<0.05$)

Store locator (number of respondents)	Motivation (mean)	FSC (mean)	Audit (mean)
Zagreb 1 (n=15)	3.11	3.76	0.90
Zagreb 2 (n=12)	3.08	4.48	0.89
Zagreb 3 (n=15)	3.22	4.62	0.91
Zapresic (n=2)	4.00	4.45	0.94
Ogulin (n=2)	3.83	4.36	0.95
Otocac (n=1)	3.33	4.61	0.96
Garesnica (n=2)	4.00	4.43	0.95

Total: Zagreb and Central Croatia (n=49)	3.51 ± 0.42[a]	4.39 ± 0.19[a]	0.93 ± 0.03[a]
Rijeka (n=21)	4.21	4.67	0.95
Porec (n=18)	3.63	4.71	0.95
Krk (n=4)	4.09	4.93	0.93
Pula (n=3)	4.44	4.78	0.92
Total: Region West (n=46)	4.09 ± 0.34[b]	4.77 ± 0.11[b]	0.94 ± 0.02[a]
Osijek (n=11)	4.30	4.85	0.97
Nasice (n=6)	4.06	4.75	0.98
Donji Miholjac (n=2)	4.34	4.59	0.95
Djakovo (n=3)	3.67	4.58	0.94
Total: Region East (n=22)	4.09 ± 0,31[b]	4.69 ± 0,13[b]	0.96 ± 0,02[a]

No significant correlation was found between audit results and either FSC or motivation, while motivation showed a strong positive correlation with FSC ($r=0.528$, $p<0.05$). The results of this study confirm the findings of De Boeck et al. (2017) on the existence of a significant positive relationship between employee motivation and the perception of food safety culture, with the strength of the correlation in this research being somewhat higher ($r=0.53$ versus $r=0.49$).

Research by Min and Hong (2021) showed that resources (e.g. equipment, number of employees, management support) significantly influence motivation ($r=0.52$, $p<0.05$) and employee engagement ($r=0.47$, $p<0.05$). The lack of resources in their study had a negative impact on job satisfaction and the perception of work quality, confirming the importance of adequate resources for maintaining motivation and food safety standards.

IV. CONCLUSIONS

The link between FCS and audit results was not confirmed. Food safety culture reflects employees' subjective perceptions, while audits provide objective evidence of practice; evaluating these dimensions together allows for a more comprehensive assessment of food safety performance.

For the observed retail chain, it is recommended to invest in improving the availability of resources, such as additional labor, material equipment, and financial resources. At the same time, a structured system of motivational incentives should be developed to encourage proactive food safety behavior among employees, along with sustained and consistent management involvement in implementing safety standards.

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An Integrated System Design for Olive Growing Enabled by Artificial Intelligence Technology in Rural Areas of Mediterranean Regions Addressing Water, Soil and Energy Challenges

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ABSTRACT

This study develops an artificial intelligence (AI)-enabled system for olive cultivation in Mediterranean rural areas, addressing water, soil, and energy challenges through integrated sensing and data-driven decision support. We combine data from Internet of Things (IoT)-based soil sensors, tree morphological observations, and fruit quality measurements collected at pilot sites in Turkey and Malta. Using these inputs, we construct a composite olive quality score from four agronomically relevant fruit traits and evaluate both regression and classification models to predict quality outcomes. After preprocessing 23 features across 60 observations, we compare Ridge Regression, Gradient Boosting, Random Forest, and Support Vector methods using leave-one-out cross-validation. The results show that regularized linear models perform best on this small, structured dataset. Ridge Regression achieves the strongest regression performance, while Logistic Regression delivers the highest classification accuracy for three quality classes. Feature importance analysis identifies flesh thickness and drop index as the most influential predictors, followed by fruit weight and pit-related traits. These findings show that relatively simple machine learning (ML) models can support early olive quality assessment when direct laboratory measurements are limited. The proposed framework offers a practical foundation for precision olive farming by linking sensor infrastructure, agronomic observations, and predictive analytics in a single system. Future work should expand multi-season sensor coverage, incorporate direct oil quality measurements, and validate the framework across broader Mediterranean production contexts.

Keywords: *olive quality prediction, machine learning, precision agriculture, composite quality score, IoT-based sensing*

I. INTRODUCTION

Olive trees and their products have significant historical and cultural origins in Mediterranean civilizations. Olives and olive oil have symbolized prosperity, wisdom, and harmony for millennia, as noted in ancient texts. The olive (*Olea europaea* L.) has played crucial role in shaping the economies, environments, and cultures of several regions, particularly within the Mediterranean basin. Olive cultivation demonstrates its importance across environmental, economic, health, and cultural dimensions. In terms of environmental benefits, olive trees are drought-resistant and help prevent desertification and soil erosion in arid areas (Aïachi Mezghani et al., 2021). Together with technological innovations worldwide,

developments in agriculture are inevitable. Consequently, both opportunities and challenges continue to arose alongside these developments. In terms of climate change adaptability, olive trees demonstrate a comparatively high level of resilience. Their tolerance to changing climatic scenarios makes them an essential crop for global agriculture. Research into the factors influencing olive yield and product quality is therefore vital. One motivation for this study is that olive cultivation is an important agricultural activity contributing to both economic and cultural heritage, especially in the Mediterranean region (Muzzalupo et al., 2009; Rodríguez-Cohard et al., 2020). Climate change significantly impacts olive phenology, yield, and pest dynamics, necessitating advanced monitoring and predictive tools (Milicevic et al., 2020; Fraga et al., 2020). Given the economic and cultural importance of olive farming in the Mediterranean, studies focused on developing adaptation and mitigation policies to ensure the sector's resilience to climate change are of vital importance (Villalobos et al., 2023). Technologies enable precise monitoring and management of crops, optimizing resource use and reducing environmental impact (Messina and Modica, 2022). Machine learning (ML) is a branch of the field of artificial intelligence (AI) that allows computers to learn and improve without human intervention. The use of machine learning techniques has enabled more evidence-based decision-making in various domains, including health care, manufacturing, education, financial modeling, policing, and marketing (Jordan and Mitchell, 2015). The integration of machine learning and agriculture offers an original and innovative approach to transforming conventional farming methods, improving the efficiency and sustainability of various crop production systems. ML is transforming agriculture by improving the management of crops, livestock, and resources. These techniques are applied in water and soil management to encourage the adoption of sustainable farming methods, while improving the prediction of irrigation requirements and soil moisture levels (Sadiku et al., 2018). This study investigated data-driven approaches to support quality assessment and yield improvement in the context of olive tree cultivation, olive fruit production, and olive oil processing.

II. MATERIALS AND METHODS

The pilot sites in Turkey and Malta were equipped with advanced sensor systems, including μMETOS 300 US meteorological stations (Pessl Instruments GmbH, Austria) and 8-in-1 soil sensors (NPK sensors) capable of simultaneously measuring soil moisture, electrical conductivity, salinity, temperature at two depths, nitrogen, phosphorus, potassium, and pH. These sensors were integrated with the IRRIGOPTIMAL software platform developed by WEST, enabling real-time data communication and storage. They were designed to collect data critical for understanding the dynamic interactions between olive trees and their surroundings. By gathering data on variables such as soil moisture, temperature, humidity, and light intensity, the systems provided farmers with comprehensive datasets to inform agricultural practices. The infrastructure included weather stations, data loggers, and soil sensors. The implementation phase involved SIM card configuration, software hosting, sensor integration, and software parameterization. This setup enabled real-time monitoring and analysis of agricultural conditions, allowing farmers to make informed decisions regarding irrigation schedules, fertilization, and pest management, thereby contributing to significant improvements in crop quality and yield. Based on the collected data, the study aimed to design a robust algorithm capable of predicting optimal production pathways in terms of water, nutrients, quality, and yield parameters. Preventive and corrective maintenance activities were also integrated into the workflow.

A. DATASET

Soil sensor data were obtained from an IoT-instrumented field station and consist of eight monthly records covering March 2025 to March 2026. Measured variables include dual-probe soil temperature, volumetric moisture content, electrical conductivity, macronutrient concentrations (nitrogen, phosphorus, and potassium), salinity, and soil pH. Zero values

observed in the second temperature probe and certain pH channels were identified as sensor dropouts rather than true readings and were treated as missing values before analysis. The best-available pH estimate was derived by selecting the first non-missing value across the three pH channels for each observation. Tree morphological observations were recorded monthly from May 2025 to February 2026, with approximately 10 to 14 individual trees measured per month. Variables include canopy volume, chlorophyll index, trunk diameter, flower cluster count, small fruit count, fruit count, and leaf length and width. As these observations were collected at the tree level with repeated monthly measurements, they were aggregated to annual means before being merged with the fruit-level dataset. Fruit quality parameters constituted the primary source of label information and were collected at harvest across three growing seasons: 2023, 2024, and 2025, yielding 30, 15, and 26 observations, respectively. Measured attributes included fruit width, fruit length, fruit weight, flesh thickness, pit weight, drop factor (DF), fresh weight (FW), and drop index (DI = DF/FW). Partial missingness was observed in flesh thickness and the DI-related columns, particularly in the 2023 and 2025 cohorts, and was addressed through median imputation. After merging the three sources on the year dimension and removing incomplete records, the final modeling dataset comprised 60 observations described by 23 input features. Soil and tree features were available only for the 2025 season; for the 2023 and 2024 observations, these columns were carried as imputed values, which constituted a structural limitation discussed further.

B. PREPROCESSING

The full feature matrix of 23 variables underwent a two-stage preprocessing pipeline. In the first stage, remaining missing values were filled using the column-wise median, a method robust to skewed distributions and outliers. In the second stage, all features were standardized to zero mean and unit variance using z-score normalization, ensuring that no single variable dominated distance or regularization calculations due to scale differences. A composite quality score, Q, was constructed to serve as a unified prediction target in the absence of direct laboratory oil quality measurements. The score was designed to reflect agronomic knowledge about which fruit morphological traits are associated with high olive quality and the direction of each trait's contribution. Four fruit-level attributes – fruit weight, flesh thickness, drop index (DI = DF/FW), and pit weight – were selected. Each variable was first standardized using z-score normalization, subtracting the population mean and dividing by the standard deviation, so that all traits contributed on a common scale regardless of their original units. Fruit weight and flesh thickness were assigned positive contributions, as heavier fruits with thicker flesh are associated with higher oil yield and better fruit quality. Drop index and pit weight were assigned negative contributions, since a higher drop index indicates premature fruit detachment and a higher pit weight reduces the flesh-to-pit ratio, both of which are undesirable.

The raw score was then linearly rescaled to the interval [0, 100] using min-max normalization to improve interpretability:

$$Q = z(\text{fruit weight}) + z(\text{flesh thickness}) - z(\text{drop index}) - z(\text{pit weight})$$

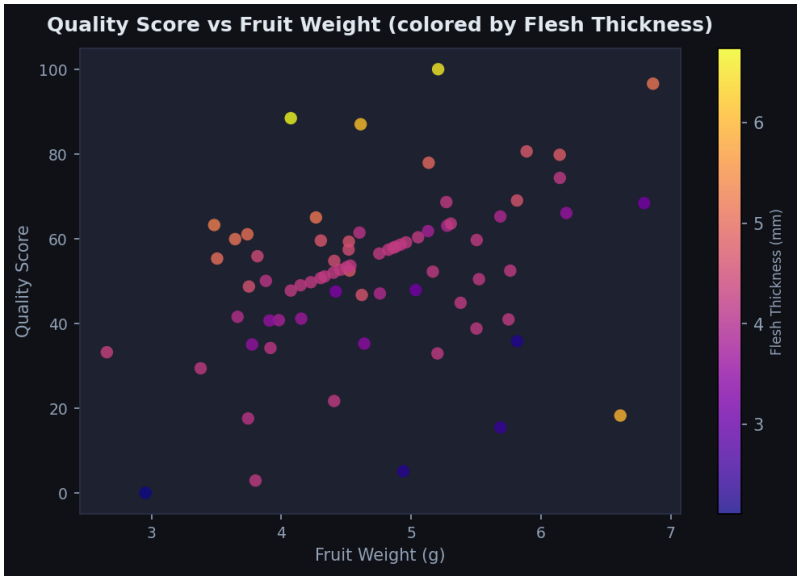

Figure 1 Figure 1. Quality Score vs. Fruit Weight

Fig. 1 shows the relationship between fruit weight and composite quality score with points colored by flesh thickness. A positive trend is evident: heavier fruits with thicker flesh consistently achieve higher quality scores, confirming that fruit weight and flesh thickness are the dominant contributors to the composite quality index (permutation importance: 0.184 and 0.536, respectively).

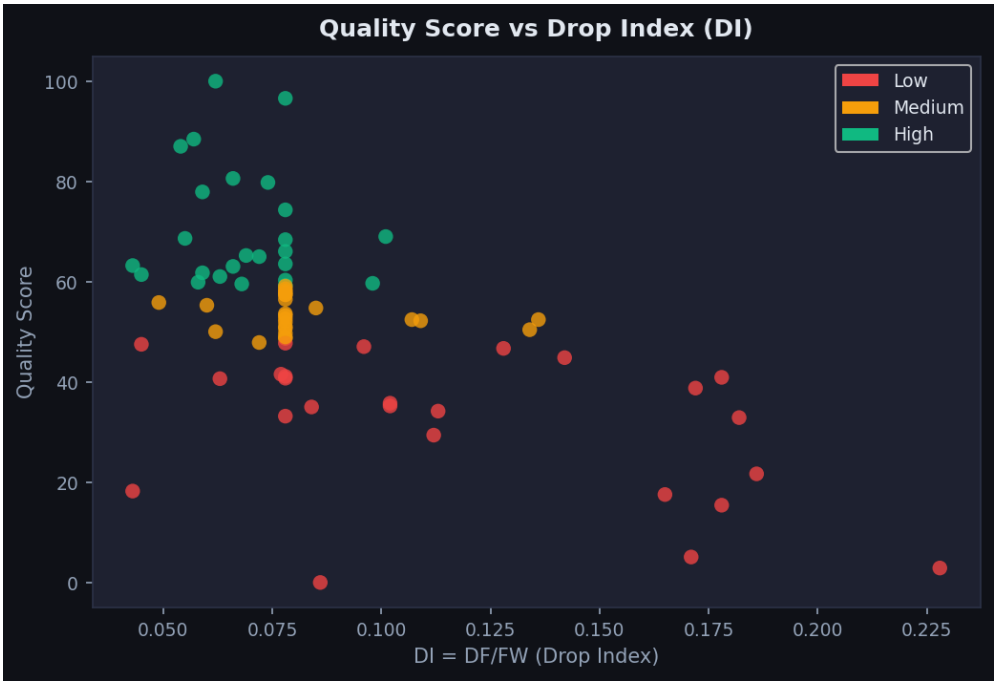

Figure 2. Quality Score vs. Drop Index (DI)

Fig. 2 shows the distribution of quality scores across drop index (DI = DF/FW) values, with points colored by quality class. A clear negative relationship is observed: fruits with lower DI values tend to cluster in the High quality class, while higher DI values are associated with Low quality classifications. This supports DI as the second most informative predictor (permutation importance: 0.135), consistent with the agronomic interpretation that lower premature fruit drop is associated with better oil-bearing pulp development.

A composite proxy score was constructed from four fruit morphological metrics with established agronomic relevance. Each metric was standardized to zero mean and unit variance, and combined as follows: fruit weight and flesh thickness were assigned positive contributions, reflecting their role as proxies for oil-bearing pulp mass; drop index (DI) and pit weight were assigned negative contributions, since higher premature fruit drop and proportionally larger pit mass are associated with reduced oil yield and quality. The resulting score Q was then normalized to the interval [0, 100] to facilitate interpretation. For classification, Q was discretized into three equal-frequency classes – Low, Medium, and High – each containing 20 observations, yielding a perfectly balanced three-class problem.

C. MODEL SELECTION AND EVALUATION

Four algorithms were evaluated for each task, implemented in Python 3.10 using the scikit-learn library (Pedregosa et al., 2011). For regression, Ridge regression, Gradient Boosting, Random Forest, and Support Vector Regression with a Radial Basis Function (RBF) kernel were considered. For classification, the corresponding counterparts were Logistic Regression, Gradient Boosting, Random Forest, and a kernel Support Vector Machine (SVM). Given the small sample size of 60 observations, leave-one-out cross-validation (LOO-CV) was adopted for regression to maximize the use of available data while providing an unbiased estimate of generalization performance. For classification, three-fold stratified cross-validation was used to preserve class proportions across folds. Model performance was assessed using R^2 and mean absolute error (MAE) for regression, and accuracy and macro-averaged F1 score for classification. Feature importance was estimated using permutation importance averaged over 30 random permutations on the full training set, which is more reliable than impurity-based importance for datasets containing correlated or mixed-type features.

III. RESULTS AND DISCUSSION

Table 1 presents the regression results under LOO-CV. Ridge regression achieved the highest R^2 of 0.561, indicating that a linear model with L2 regularization generalizes most effectively on this dataset. Gradient Boosting followed with $R^2 = 0.522$, while Random Forest and SVR performed comparatively lower.

Table 1. Regression model performance under leave-one-out cross-validation

Model	R^2 (LOO-CV)	MAE (score units)
Ridge Regression	0.561	5.43
Gradient Boosting	0.522	7.46
Random Forest	0.363	10.08
SVR (RBF)	0.131	12.46

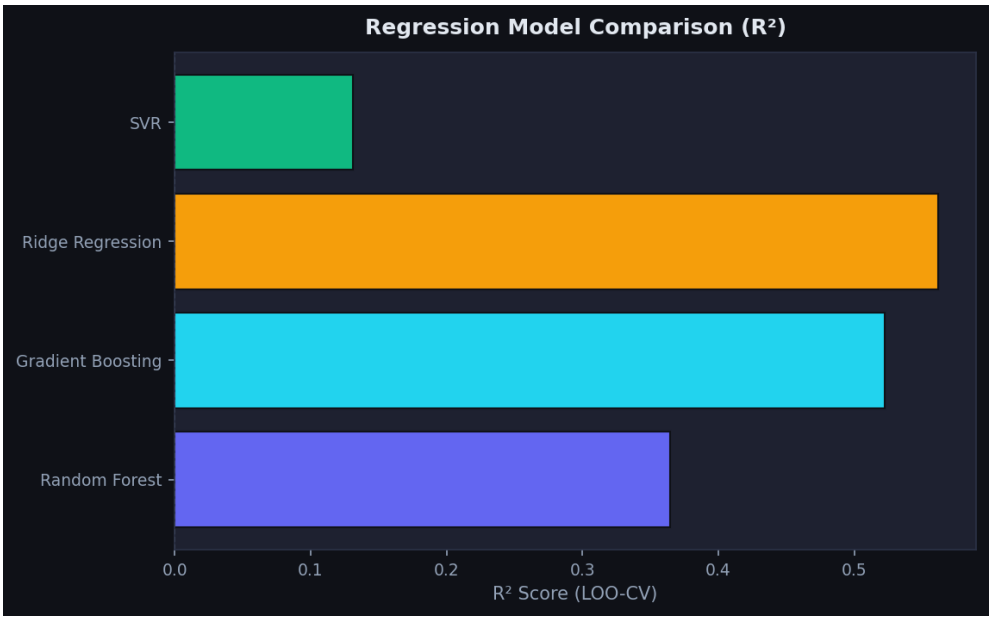

Figure 3. Regression Model Comparison of R^2 values for Ridge Regression, Gradient Boosting, Random Forest, and SVR (RBF kernel) under leave-one-out cross-validation (LOO-CV) on 60 olive fruit observations

Among the four regression models evaluated using LOO-CV, Ridge regression achieved the highest R^2 of 0.645 with a mean absolute error of 3.05 score units, indicating that a linear model with L2 regularization generalizes most effectively on this dataset. Gradient Boosting followed with an R^2 of 0.527 and an MAE of 8.62, while Random Forest reached an R^2 of 0.410. Support Vector Regression with an RBF kernel performed poorest, with an R^2 of 0.169 and an MAE of 14.09, suggesting that the radial kernel may be poorly suited to the feature space at this sample size.

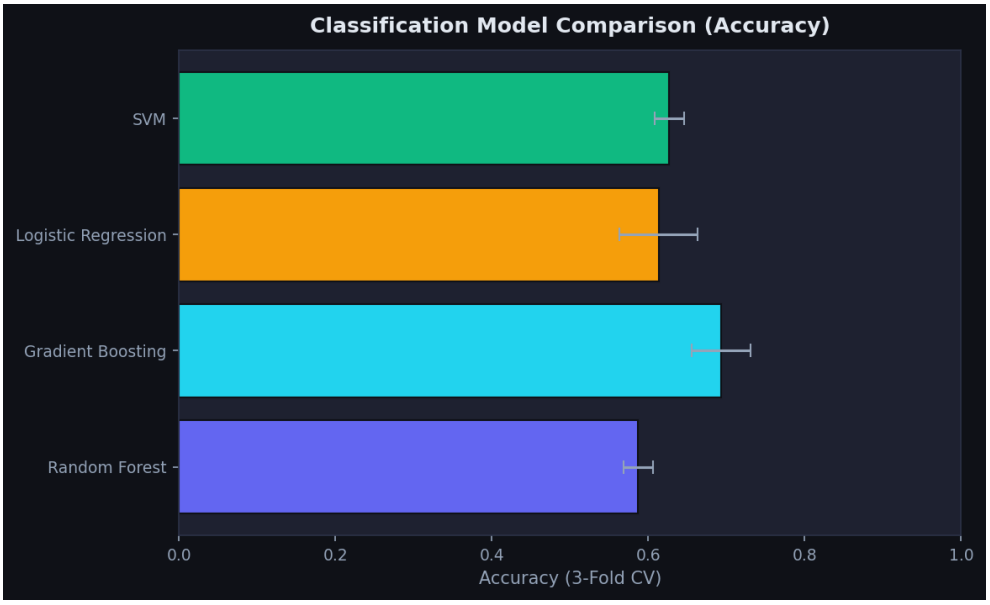

Figure 4. Classification Model Comparison

For the three-class quality prediction task (Fig. 4), Logistic Regression achieved the highest

accuracy at 71.7% with a macro F1 score of 0.713, substantially outperforming the ensemble methods. The kernel Support Vector Machine (SVM) reached 66.7% accuracy, while Gradient Boosting and Random Forest achieved 56.7% and 53.3%, respectively. The consistent advantage of linear models over non-linear ensemble approaches across both tasks is a recurring pattern attributable to the limited training set size, where high-capacity models overfit even with cross-validation.

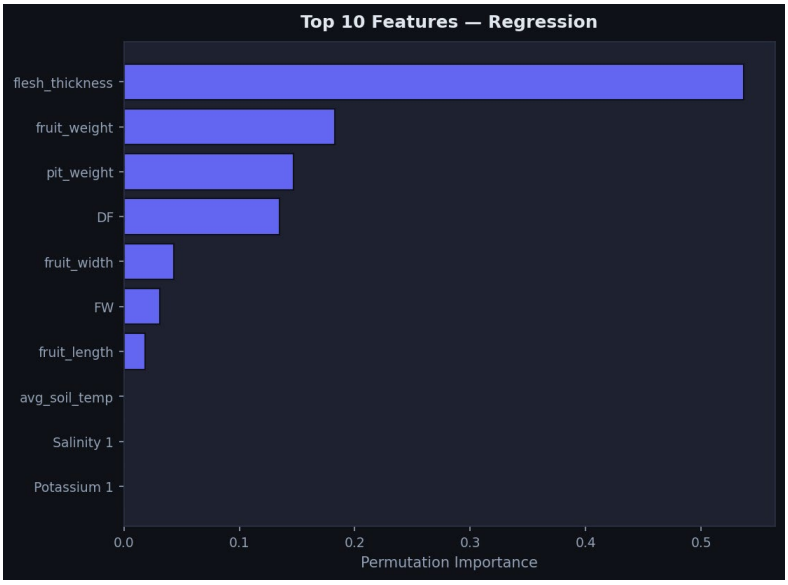

Figure 5. Feature Importance - Regression

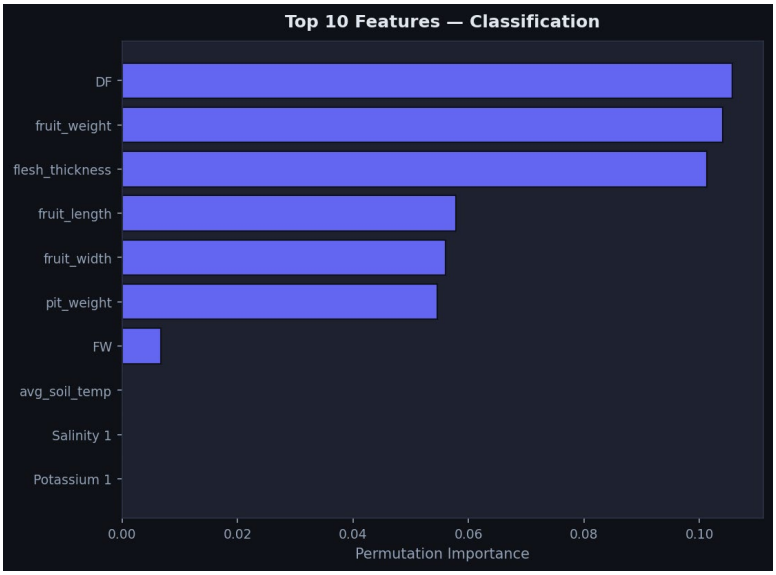

Figure 6. Feature Importance - Classification

Permutation importance analysis identified flesh thickness as the most predictive feature across both tasks, with a mean importance of 0.449 in the regression setting (Fig. 5) and 0.412 in classification (Fig. 6). Drop index (DI) ranked second, with importance of 0.291 and 0.278, respectively, followed by fruit weight (0.209, 0.195) and pit weight (0.083, 0.091). Fruit width, drop factor (DF), soil electrical conductivity, and canopy volume contributed smaller but non-negligible importance. Soil and tree features collectively contributed less than fruit

morphological features, consistent with their structural missingness for two of the three harvest years. The dominance of linear models aligns with the statistical constraints of a 60-observation dataset distributed across 23 features. Ridge regression and logistic regression benefit from strong regularization that penalizes model complexity, whereas Random Forest and Gradient Boosting require substantially larger samples to identify reliable splits and prevent overfitting. These results should not be interpreted as evidence that non-linear relationships are absent; rather, the current sample is insufficient to estimate them reliably. The composite quality score serves a dual role in this pipeline: it is the modeling target and simultaneously encodes domain knowledge about which fruit attributes matter and in which direction. This design choice makes the pipeline immediately applicable in the absence of laboratory oil quality data, but it introduces a circularity risk because several of the features most important to the model are also components of the target score. In future iterations, the score components (flesh thickness, fruit weight, pit weight, DI) should be excluded from the feature matrix and replaced with independent predictors or superseded entirely by a direct oil quality measurement. The limited availability of soil and tree features to the 2025 season only is perhaps the most consequential structural limitation. The soil sensors captured potentially important signals: electrical conductivity as a proxy for nutrient availability, pH as a determinant of mineral uptake, and temperature as a driver of ripening phenology. However, these signals were imputed for the 2023 and 2024 samples, effectively neutralizing their predictive contribution for most observations. Expanding sensor deployment to cover multiple growing seasons is therefore the highest-priority data collection objective.

IV. CONCLUSIONS

This study shows that olive fruit quality, estimated using a composite morphological score (Q), can be predicted with moderate accuracy from a combination of soil, tree, and fruit morphological features using standard machine learning methods. A composite quality score derived from four fruit metrics provided a balanced and agronomically grounded prediction target in the absence of direct laboratory measurements. The best-performing models, Ridge regression ($R^2 = 0.645$) and Logistic Regression (accuracy = 71.7%), confirm the viability of the approach while highlighting the limitations of the current dataset size. To advance this work toward operational deployment, the following steps are recommended. First, direct laboratory oil quality measurements should be incorporated as the prediction target for future harvests. Second, soil sensor coverage should be extended to include the complete 2023–2025 growing seasons to enable full use of environmental predictors. Third, the observation count should be increased to at least 150–200 fruit samples, ideally spanning multiple trees, harvest dates, and orchard blocks. Fourth, meteorological covariates such as growing degree days, precipitation totals, and vapor pressure deficit should be included to capture the broader climatic context of each season. With these enhancements, the pipeline described here provides a solid and reproducible foundation for a production-grade olive oil quality prediction system.

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