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Unlocking the potential of acorns as a functional and sustainable food in Turkey: a value chain and policy analysis

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Acorns, though traditionally consumed across Mediterranean and East Asian regions, remain underutilized in Turkey despite ecological abundance, cultural relevance, and emerging evidence of nutritional and functional potential. This study evaluates the sustainability and market prospects of Turkey's acorn-based food value chain using an integrated PESTEL (Political, Economic, Social, Technological, Environmental, Legal) and SWOT (Strengths, Weaknesses, Opportunities, Threats) approach. Drawing on desk research and 15 semi-structured interviews with stakeholders spanning the supply side of the value chain (forest villagers, intermediaries, processors linked to valonia utilization, forestry officials, and food researchers), we identify system-level drivers and translate empirical themes into strategic implications. Findings indicate strong potential linked to low-input forest-based production and rising interest in functional and gluten-free ingredients, while major barriers include regulatory ambiguity around commercialization pathways, limited processing and quality standardization, weak price transparency and bargaining power on the supply side, and early-stage demand formation. By explicitly mapping stakeholder narratives and documentary evidence into PESTEL domains and deriving an evidence-linked SWOT, the analysis produces traceable policy-relevant insights beyond a conventional SWOT or descriptive value-chain narrative. Recommendations emphasize regulatory clarification, basic standards development, inclusive market formation mechanisms, and support for cooperative aggregation and small-scale processing to enable equitable and sustainable acorn valorization.

KEYWORDS

acorns, circular bioeconomy, food system innovation, forest-based foods, rural development, sustainable food systems, underutilized plant ingredients

1 Introduction

As food systems worldwide face mounting challenges including climate change, biodiversity loss, and socio-economic inequality, there is increasing interest in alternative food sources that offer both ecological and cultural value and that can support sustainability transitions in practice (Eakin et al., 2017; Hebinck et al., 2018; Gaitán-Cremaschi et al., 2019). Acorns, the fruit of oak trees (*Quercus spp.*), have historically served as staple or supplementary food resources in Mediterranean, East Asian, and North American cultures. In Turkey, home to more than 18 native oak species, acorns have traditionally played a role in rural subsistence diets and forest-based economies (Aktaş, 2010; Cingöz and Inatçı, 2025). Yet, their integration into contemporary food value chains remains fragmented, undervalued, and largely informal,

echoing broader challenges observed in other forest economies where non-timber forest products (NTFPs) struggle to transition from informal use to structured commercial systems despite high local significance (Masso-Ardila et al., 2025), particularly in rural regions shaped by uneven development and structural economic constraints.

At the same time, acorn flour and related extracts are increasingly recognized as promising bioactive-rich ingredients for functional and gluten-free food products. Owing to their high levels of antioxidants, polyphenols, and dietary fiber, acorn-based ingredients can improve nutritional and technological properties while supporting circular food systems by valorizing underutilized forest resources (Acquaticci et al., 2024; Beltrão Martins et al., 2020; Inácio et al., 2024; Levent and Aktaş, 2024; Mokhtari et al., 2019; Polimac et al., 2016; Stankov Jovanović et al., 2025; Suo et al., 2025) within a broader context of expanding global demand for functional and bioactive food ingredients (Li et al., 2025). Beyond nutritional functionality, oak-derived materials have also been investigated for broader bioactive potential, including antiproliferative effects reported for *Quercus* species extracts (Gezici, 2019). In addition to food-oriented functionality, *Quercus* fruit extracts have also been investigated in experimental health-related contexts, including studies examining metabolic outcomes in diabetic models (Taş and Özmen, 2024).

Acorns also require no irrigation, fertilizers, or tillage, supporting regenerative and climate-resilient production strategies (Özcan and Bayçu, 2005) and aligning with broader regenerative and circular bioeconomy narratives in which biodiversity-based, low-input resources are increasingly valued (Amante et al., 2025; Anikwe and Ife, 2023; Borrello et al., 2023; Singhal et al., 2024). Emerging initiatives in Turkey and other Mediterranean countries further demonstrate the feasibility of acorn-based products through artisanal and small-scale production systems, including flour and beverage substitutes (Sacchelli et al., 2021; Zocchi et al., 2022).

Despite this promise, several constraints impede the scale-up of the acorn food value chain in Turkey. These include regulatory ambiguities, limited technical infrastructure, and weak market development strategies (Özdemir and Karadag, 2023). Evidence from other wild and forest food value chains similarly suggests that successful integration into mainstream markets depends not only on product quality but also on consumer trust, governance arrangements, and coordinated value-chain development (D'Amato et al., 2022; Meinhold and Darr, 2022; Stavi et al., 2022). These observations point to the need for analytical approaches that can connect actor experiences and market organization challenges to wider institutional and regulatory conditions shaping commercialization pathways.

Research on NTFP commercialization consistently emphasizes that market outcomes depend not only on ecological availability or product functionality, but also on governance structures, institutional clarity, and market coordination mechanisms. Transitions from subsistence or informal use toward structured commercial value chains are often constrained by unclear harvesting rights, limited standardization and quality infrastructure, fragmented market channels, and asymmetric bargaining power between collectors and downstream buyers, resulting in low-investment equilibria despite resource abundance

(Hinrichs, 2014). Complementary work on underutilized foods and sustainability transitions similarly highlights that market emergence is rarely driven by nutritional or ecological value alone; consumer awareness, cultural legitimacy, product standardization, and regulatory recognition strongly influence whether underutilized foods can transition into formal markets (García-Martín et al., 2021). In parallel, value-chain governance research underscores how power asymmetries between primary producers and downstream buyers shape market participation and value distribution, especially in seasonal and yield-variable chains where producers face financial and infrastructural constraints.

To address these interacting governance, market, and innovation dimensions in an emerging sector, this study uses an integrated analytical approach that combines macro-environmental scanning with strategic diagnosis. Specifically, the analysis employs PESTEL (Political, Economic, Social, Technological, Environmental, Legal) to organize system-level drivers and uses an evidence-grounded SWOT (Strengths, Weaknesses, Opportunities, Threats) to translate empirically derived themes into strategic and policy-relevant implications. While both tools are widely used, they are often applied in parallel rather than integrated in ways that make the pathway from evidence to strategic interpretation transparent. Here, qualitative stakeholder interviews and desk research are used to identify empirical themes, which are mapped to PESTEL domains to interpret system-level drivers; SWOT categories are then derived from these mapped themes so that strengths, weaknesses, opportunities, and threats reflect observable conditions rather than abstract strategic speculation (Chagomoka et al., 2013; El Bilali, 2019). Integrated applications in Turkey similarly suggest that combining macro-environmental scanning with strategic tools can strengthen decision-making under systemic uncertainty (Uztürk and Büyüközkan, 2023). In addition, stakeholder-informed approaches are widely recognized as essential in sustainability planning contexts characterized by complexity, limited formal data, and multi-actor governance (Willaarts et al., 2018).

Building on this literature and the identified need to better understand how governance structures, market coordination mechanisms, and regulatory frameworks shape the commercialization potential of underutilized forest-based foods, this study focuses on the emerging acorn food value chain in Turkey. The study is guided by four research questions:

RQ1. What are the key governance, institutional, and market barriers and enablers shaping the development of the acorn-based food value chain in Turkey?

RQ2. How do these barriers and opportunities differ across value chain stages, including harvesting, aggregation, processing, governance, and research and innovation?

RQ3. How do stakeholders perceive demand-side potential and consumer market formation, and how do these perceptions align with available documentary and market evidence?

RQ4. Based on triangulated empirical evidence, which policy and institutional interventions appear most feasible for supporting sustainable and inclusive acorn value chain development?

To address these questions, the study combines desk research with semi-structured interviews across key supply-side and institutional actors. Findings are analyzed through thematic coding,

mapped into PESTEL domains, and translated into an evidence-grounded SWOT to support policy-relevant synthesis. Interviews are geographically concentrated mainly in Uşak and Denizli; transferability is addressed in the Limitations section.

2 Materials and methods

2.1 Study design and analytical framework

This research employed an exploratory qualitative case study design to examine the emerging acorn food value chain in Turkey. The study combined desk-based document review with semi-structured stakeholder interviews to capture both (i) macro-level institutional, regulatory, and market conditions and (ii) actor-level experiences shaping value chain development. Given the early-stage nature of food-oriented acorn markets and the limited availability of reliable market statistics, a stakeholder-informed qualitative approach was considered appropriate for identifying constraints, opportunity windows, and leverage points for policy and intervention design (Willaarts et al., 2018).

To structure analysis and ensure traceability between evidence and strategic interpretation, the study integrated PESTEL (Political, Economic, Social, Technological, Environmental, Legal) with an evidence-grounded SWOT (Strengths, Weaknesses, Opportunities, Threats). PESTEL has been used in agri-food and sustainability research to map how policy, economic trends, socio-cultural dynamics, technological capacity, environmental pressures, and legal regimes shape value chain development (El Bilali et al., 2021; Iagăru et al., 2023; Madureira et al., 2024). SWOT has similarly been used to assess viability and constraints in agri-food systems and value chains (Chagomoka et al., 2013; El Bilali, 2019). Their integration supports a structured evidence pipeline—macro-level scanning (PESTEL) combined with strategic translation (SWOT)—which has also been applied in Turkey to support planning under systemic uncertainty (Uztürk and Büyüközkan, 2023).

Empirical themes were identified through qualitative coding of interviews and systematic extraction from documentary sources. Themes were mapped to PESTEL domains to interpret system drivers, and SWOT categories were derived from the PESTEL-mapped themes using explicit translation rules so that strengths, weaknesses, opportunities, and threats reflected observable conditions rather than abstract strategic claims (El Bilali, 2019). Major themes were labeled by evidence source as interview-derived, document-derived, or triangulated.

2.2 Data sources and collection

A document review was conducted to contextualize the acorn value chain and to identify relevant institutional, regulatory, and market conditions. Sources included peer-reviewed literature and gray literature accessed through Scopus, Web of Science, Google Scholar, and institutional repositories, as well as relevant national policy documents, NGO reports, and sector documents related to NTFP governance, rural development, food regulation/standards, and acorn-related initiatives. Documentary content was extracted

into an evidence matrix aligned with PESTEL domains (e.g., forest governance instruments under Political/Legal; processing and R&D capacity under Technological; market narratives and incentives under Economic/Social). This matrix informed the interview guide and supported triangulation during analysis.

Primary data consisted of 15 semi-structured interviews and one focus group conducted during fieldwork between March and May 2024. Interviews followed a semi-structured guide covering harvesting practices and access arrangements; market channels and price formation; processing practices, technology constraints, and quality considerations; regulatory experiences (e.g., permits, commercialization pathways, food safety and standards); perceptions of demand potential and consumer market formation; and policy support needs and institutional gaps. Interviews typically lasted approximately 45–75 min and were recorded and/or documented via detailed notes depending on consent and field conditions. All participants provided informed consent. To reduce legal and ethical risk, participant identities and organizational details are anonymized, and potentially sensitive claims are reported in aggregated form.

2.3 Sampling strategy and participants

Sampling was purposive and supplemented through snowball referrals to ensure coverage across value chain roles and institutional perspectives rather than statistical representativeness. Participants included forest villagers involved in harvesting and informal processing (one focus group and five interviews) in the Uşak region; two intermediaries involved in procurement and trading; one actor linked to a major processing plant within the broader acorn ecosystem (primarily associated with valonia-related industrial use); five forestry officials from the Ministry of Forestry in Denizli and Uşak; and two researchers working on acorn uses in the food industry. The focus of the study is primarily supply-side and institutional, reflecting the early-stage development of consumer markets for acorn-based foods in Turkey. The characteristics of interview participants and value-chain coverage are summarized in Table 1.

Interviews are geographically concentrated mainly in Uşak and Denizli, reflecting access to active actors and relevant forest-resource contexts. Transferability to other forest regions is addressed explicitly in Section 2.5.

2.4 Data analysis and evidence integration

Analysis followed a staged workflow to support transparency and replicability. First, notes/transcripts were reviewed and summarized, and analytic memos documented emerging issues. Second, inductive open coding identified recurring themes. Third, codes were clustered into higher-order themes and mapped to PESTEL domains. Fourth, SWOT categories were derived from the PESTEL-mapped themes using explicit rules: strengths and weaknesses represent internal capabilities or constraints in the current value chain configuration, while opportunities and threats represent external trends and structural risks shaping development.

TABLE 1 Interview sample characteristics and value-chain coverage.

Respondent ID	Actor type	Region	Value chain stage	Interview period	Data collection format
FG1 (<i>n</i> = 5)	Forest villagers (collectors/informal processors)	Uşak	Harvesting/Primary handling	Mar 2024	Focus group
R1	Forest villager	Uşak	Harvesting	Mar 2024	Interview
R2	Forest villager	Uşak	Harvesting/informal processing	Mar 2024	Interview
R3	Middleman/intermediary	Uşak region	Aggregation/trade	Apr 2024	Interview
R4	Middleman/intermediary	Uşak region	Aggregation/Trade	Apr 2024	Interview
R5	Processing sector stakeholder (valonia-related industrial use context)	Manisa	Industrial processing interface	Apr 2024	Interview
R6	Forestry official	Denizli	Governance/regulation	Apr 2024	Interview
R7	Forestry official	Denizli	Governance/regulation	Apr 2024	Interview
R8	Forestry official	Uşak	Governance/field implementation	May 2024	Interview
R9	Forestry official	Uşak	Governance/field implementation	May 2024	Interview
R10	Forestry official	Ankara	Governance/policy implementation	May 2024	Interview
R11	Researcher (food science/product development)	Denizli	R&D/innovation	May 2024	Interview
R12	Researcher (acorn food applications/value addition)	Denizli	R&D/innovation	May 2024	Interview

Interviews and the focus group were conducted during fieldwork between March and May 2024. Respondent identities are anonymized to protect confidentiality.

Each major theme and derived finding was labeled by evidence source (interview-derived, document-derived, or triangulated) to improve traceability and reduce ambiguity.

Credibility was strengthened through triangulation between interviews and documentary sources, noting convergence and divergence. The structured coding workflow, explicit translation rules, and evidence labeling were used to reduce interpretive drift and clarify the basis for claims. Where interviewees raised potentially sensitive issues (e.g., perceptions of buyer power or market concentration), these were reported explicitly as stakeholder perceptions unless corroborated by documentary evidence.

2.5 Limitations and analytical considerations

This study has several limitations. First, although actor roles are diverse, the geographic scope is concentrated mainly in Uşak and Denizli, which may limit transferability to other forest regions in Turkey with different ecological conditions, governance arrangements, or market structures. Second, demand-side evidence is limited because consumer markets for acorn-based foods remain nascent; demand-related statements are therefore treated cautiously and labeled by evidence source. Third, the study is qualitative and does not quantify market concentration, price dynamics, or ecological yields; such quantitative validation is outside the scope of this manuscript and is recommended for future

research. A follow-up consumer and market study is underway to complement the present findings.

3 Results

3.1 Cross-domain overview and value-chain context

Findings indicate that Turkey's acorn ecosystem currently functions as a multi-use forest product system in which the largest and most organized flows are linked to industrial uses (notably valonia extraction for leather tanning), while food-oriented uses remain small-scale, informal, or experimental. Across stakeholder groups, the constraints shaping a transition toward a food value chain clustered around three interacting conditions: (i) governance and regulatory uncertainty, (ii) limited food-grade processing and storage capacity, and (iii) weak market formation mechanisms (price transparency, stable procurement relationships, demand signaling).

These constraints reinforce one another. Stakeholders reported that unclear commercialization pathways and standards reduce incentives to invest in food-grade processing, while perceived buyer power and unstable pricing reduce incentives for collectors to sort, store, or upgrade quality. At the same time, respondents consistently emphasized that acorns represent an ecologically low-input resource aligned with climate resilience and circular

TABLE 2 Evidence-based mapping of empirical themes across PESTEL domains.

Empirical theme	Value chain stage	Evidence source	Evidence source	PESTEL domain	SWOT category	Key implication
Regulatory ambiguity	Governance	Interviews with foresters, processors, researchers	Political	Political	Weakness	Unclear commercialization pathways increase perceived risk for food entrepreneurs and limit investment in acorn food processing.
Limited processing infrastructure	Processing/storage	Interviews with collectors, middlemen, processors	Technological	Technological	Weakness	–
Buyer concentration and price negotiation	Aggregation/sales	Interviews with collectors, middlemen	Economic	Economic	Weakness	Lack of food-specific infrastructure impedes quality control and market expansion beyond informal or artisanal uses.
Low consumer awareness	Consumption demand	Interviews with researchers, villagers	Social	Social	Weakness	Limited understanding of nutritional benefits constrains market demand and slows product acceptance.
Ecological sustainability	Harvesting/Sourcing	Interviews with foresters, researchers	Environmental	Environmental	Strength	Low-input, biodiversity-friendly production offers resilience advantage, reinforcing sustainability branding narratives.
Climate variability	Harvesting/yield stability	Interviews with foresters, villagers	Environmental	Environmental	Threat	–
Unstandardized food certification	Interviews with researchers, processors	Interviews with researchers, processors	Processing/ market entry	Legal	Threat	Lack of clear legal/food safety guidelines creates hurdles to standardized certification needed to enter formal markets.
Emerging functional food trends	Consumption Demand	Interviews with researchers, processors	Social	Social	Opportunity	–

This table synthesizes empirical themes identified through interviews during the period March–May 2024, mapping them to PESTEL domains and categorizing them via SWOT; (Strengths, Weaknesses, Opportunities, Threats); analysis to distill key implications for the acorn food value chain in Turkey.

bioeconomy strategies, suggesting a substantial opportunity window if institutional and coordination barriers are addressed.

3.2 Political and governance factors

3.2.1 Access arrangements and administrative implementation

Acorn collection occurs largely on public forest land and is therefore shaped by forest governance rules, local implementation practices, and the administrative capacity of collectors and intermediaries to comply with access arrangements. Stakeholders described how collection activity is feasible but often embedded in informal practices and seasonal routines, with limited institutional support mechanisms that enable transition from opportunistic collection toward structured food-grade supply arrangements. Similar governance dynamics affecting forest villagers' livelihood strategies and NTFP commercialization were also reflected in stakeholder interviews and the reviewed policy documents in this study.

3.2.2 Public planning and institutional attention to oak resources

A supportive policy signal is provided by the Ministry of Agriculture and Forestry's Acorn Exploitation Action Plan and Report (2022–2026), which frames acorns as a multi-use forest resource and outlines strategic directions including revising exploitation plans, supporting oak management sites, improving vegetation management for oak productivity, increasing acorn production, incentivizing research, and training resource managers and collectors. Stakeholders emphasized that such policy recognition can support legitimacy and create a coordination baseline for future interventions across harvesting, processing, and market development.

3.2.3 Limited alignment with rural entrepreneurship and investment support mechanisms

Despite the existence of forest-focused rural support programs, stakeholders described limited alignment between forest governance and entrepreneurship-oriented funding streams needed to develop food-grade processing and market channels. In particular, respondents highlighted that investment programs such as IPARD tend to prioritize agriculture and livestock-oriented investments, while forestry-related supports are more often oriented toward improving forest villager living conditions and basic tools rather than enabling value-added forest-food enterprises, cooperative processing, or product innovation. This perceived funding gap was repeatedly associated with underinvestment in processing and the absence of structured rural enterprise models for acorn-based foods.

3.2.4 Perceived bargaining asymmetry and the absence of transparent market organization mechanisms

Collectors and intermediaries described an environment where prices are negotiated informally with limited transparency and where downstream demand linked to established industrial uses can shape local price expectations. In Eldeniz village (Sivasli district, Uşak), collectors described perceived inconsistencies in purchasing prices across nearby procurement points and between intermediaries. Because the study does not quantify market concentration, such claims are treated as stakeholder perceptions; however, their consistency across interviews suggests that the absence of inclusive market organization mechanisms (e.g., cooperative aggregation, transparent procurement standards, or reference pricing systems) may reduce incentives for quality upgrading and food-oriented value addition.

3.3 Economic and market factors

3.3.1 Market orientation and emerging food-related niches

Economic activity around acorns was described as dominated by established non-food applications and informal exchange, while food-oriented value addition remains small-scale and niche. Stakeholders emphasized that food-grade demand is currently inconsistent and limited, with emerging interest associated with functional and gluten-free markets, artisanal experimentation, and small-scale product development.

3.3.2 Low entry barriers for collection but weak incentives for upgrading

Collectors and intermediaries emphasized that acorn harvesting is low-input and labor-based, enabling rapid collection during peak season. One intermediary described that a household of three could collect up to approximately one ton per day under favorable conditions, suggesting that raw material supply can be substantial during harvest windows. However, weak and inconsistent demand signals for food-grade acorns, combined with limited storage and processing infrastructure, were reported to constrain incentives for sorting, quality differentiation, and stable supply relationships.

3.3.3 Price volatility, outlet diversity, and perceived buyer power

Stakeholders described price volatility linked to seasonal supply and variable yields. Collectors repeatedly highlighted dependence on limited outlet options in certain localities and described informal price setting with limited transparency. Several respondents claimed that purchasing prices could vary substantially between intermediaries and between nearby procurement points. Without quantitative market data, these

descriptions are treated as perceptions; nevertheless, they suggest a vulnerability mechanism in which limited transparency and inconsistent pricing reduce incentives for longer-term investment in food-grade processing practices.

3.3.4 Investment constraints and the role of support programs

Economic constraints were also linked to limited investment support tailored to forest-food value chain development. Stakeholders highlighted that available rural funding mechanisms often prioritize agriculture and livestock activities and do not easily accommodate forest-based food processing, cooperative aggregation, or product development. This was frequently framed as a reason for the continued dominance of informal trade patterns and for limited scaling of food-oriented enterprises.

3.4 Social and cultural factors

3.4.1 Stigma, heritage, and shifting perceptions

Stakeholders noted that acorns have historically been associated with scarcity and sometimes perceived as “famine food” or animal fodder, creating lingering stigma in some contexts. However, interviewees and documentary sources indicate a gradual perception shift among health-conscious and sustainability-oriented consumers and among actors interested in heritage foods. This provides a potential foundation for repositioning acorns as culturally rooted and nutritionally valuable ingredients.

Fieldwork conducted in Eldeniz village revealed extensive traditional ecological knowledge related to both food uses and broader ecosystem interactions associated with acorn harvesting and oak forest systems. Villagers described long-standing practices of feeding acorns to sheep and goats and reported that this practice is believed to improve meat flavor and quality. In addition, older generations were reported to consume acorns directly for perceived health benefits, including traditional uses associated with blood sugar regulation and diabetes-related folk practices.

Beyond direct food and feed uses, respondents also described ecosystem-related applications of acorn by-products. One respondent reported a practice of grinding cupula (acorn cups) and incorporating the material into irrigation water, which was believed locally to support soil quality. Collectors also described post-harvest detoxification practices, including burying acorns underground for approximately two months to reduce bitterness and tannin content prior to consumption or processing. Furthermore, one collector mentioned the presence of truffle mushrooms growing beneath oak trees, highlighting potential complementary livelihood opportunities linked to oak forest ecosystems.

Taken together, these practices indicate the presence of a strong and multifaceted local knowledge base that may support product storytelling, locally grounded innovation, and the development of sustainability-oriented value chain strategies for acorn-based food products.

3.4.2 Livelihood contribution and inclusivity

Stakeholders described acorn collection as a seasonal income source with low entry barriers and inclusive participation (including older family members). Beyond income, acorn collection was described as embedded in social cooperation and intergenerational knowledge transmission, an important social asset for community-based enterprise development.

Socially, the chain benefits from deep local knowledge and cultural embedment, but scaling food markets likely requires active repositioning and consumer education to overcome stigma and build legitimacy.

3.5 Technological and innovation factors

3.5.1 Applied research capacity and Turkey-based scientific work on acorns

Research and applied experimentation were repeatedly referenced as a strength, particularly within Turkish universities and research networks exploring acorn-based foods. Researchers highlighted increasing scientific attention to acorn flour and extracts as functional ingredients (Fadiloglu and Ergezer, 2024), including work on antioxidant and polyphenol-rich properties and trials incorporating acorn-derived ingredients into food products (Güneş et al., 2025). Turkey-based applied experimentation has explored acorn flour integration into product formulations and processing methods relevant to food industry adoption, contributing to a growing evidence base for product safety, nutritional functionality, and technological performance. Complementary experimental research has also explored physiological effects of *Quercus* fruit-derived extracts, reinforcing broader interest in their bioactive potential (Taş and Özmen, 2024). Beyond food formulations, Turkey-based applied studies also illustrate broader bio-based valorization pathways for acorn-derived materials, including product development in personal care applications such as toothpaste (Sahin et al., 2021).

3.5.2 Processing bottlenecks: food-grade infrastructure for detoxification, drying, milling, and storage

Despite research interest, stakeholders emphasized that the binding technological constraint is the limited availability of accessible food-grade processing infrastructure. Converting acorns into consistent food-grade ingredients requires multiple steps, including drying, shelling, tannin reduction/detoxification, milling, and controlled storage. Forest villagers described informal detoxification knowledge (including burying acorns underground for approximately two months to reduce bitterness), but such methods were also framed as difficult to standardize at scale. Limited access to controlled drying and storage was described as a major barrier to stabilizing supply, maintaining quality, and enabling year-round market participation.

3.5.3 Innovation transfer and institutional support gaps

Stakeholders described weak mechanisms for transferring scientific knowledge into rural enterprise models, including limited applied extension capacity and limited multi-actor innovation platforms. Several respondents noted that research incentives often favor globally prominent topics over locally valuable forest-food innovation and described barriers to patenting and intellectual property protection as discouraging product development. The [ITU, Acorn Food Workshop \(2024\)](#) was described as a positive platform for raising awareness and connecting actors across research and practice, but stakeholders emphasized that sustained institutional support is needed to translate episodic initiatives into stable innovation ecosystems.

3.5.4 Digitalization and traceability potential

Some stakeholders suggested that traceability systems and certification pathways could support premium market formation for acorn foods; however, cost and infrastructure constraints limit adoption in the current stage. Stakeholders emphasized that basic processing standardization and quality assurance mechanisms are prerequisites before digital traceability becomes feasible at scale.

3.6 Environmental and resource factors

3.6.1 Ecological sustainability and low-input production advantages

Across stakeholder groups, acorns were consistently described as an ecologically sustainable forest resource. Forest villagers, forestry officials, and researchers emphasized that acorn production requires no irrigation, fertilizer input, or land conversion, which distinguishes it from many conventional agricultural crops. Stakeholders highlighted that acorn harvesting is compatible with existing forest ecosystems and can support biodiversity conservation when conducted under regulated and sustainable harvesting practices.

Forestry officials noted that oak forests represent stable and widely distributed ecosystems across Turkey, providing a potentially resilient resource base under changing climate conditions. Respondents emphasized that acorns could contribute to climate-resilient food system strategies due to their ability to be harvested from naturally regenerating forest systems rather than cultivated monocultures.

3.6.2 Climate variability and yield uncertainty

Despite ecological advantages, stakeholders reported variability in acorn yields across years due to climatic conditions, including drought stress, irregular precipitation, and temperature variability. Forest villagers noted that yield fluctuations can significantly affect seasonal income and reduce predictability of supply for potential food processors.

Researchers and forestry officials emphasized that mast cycles (natural variability in oak seed production) create natural supply variability that would need to be managed through storage, aggregation, and potentially diversified sourcing if acorn-based food supply chains were scaled.

3.6.3 Sustainable harvesting and ecosystem management considerations

Forestry officials and researchers highlighted the importance of regulated harvesting to prevent over-collection and to maintain forest regeneration capacity. Some stakeholders noted that if acorn demand increased significantly, monitoring and sustainable harvesting guidelines would become increasingly important.

However, respondents emphasized that current harvesting levels are generally low relative to total ecological production potential, suggesting that moderate expansion of acorn-based food use would likely remain within ecological limits if properly regulated.

Environmental findings suggest that ecological constraints are not currently the primary limiting factor for acorn value chain development. Instead, ecological sustainability represents a major long-term strength, while climate-driven yield variability reinforces the need for storage infrastructure and supply coordination mechanisms.

3.7 Legal and regulatory factors

3.7.1 Regulatory classification ambiguity between forest product and food product

Stakeholders consistently identified legal and regulatory uncertainty as one of the most significant barriers to acorn food commercialization. Respondents reported that acorns are primarily governed under forest product regulations, while food system regulatory pathways for acorn-based food products are perceived as less clearly defined.

Several stakeholders noted uncertainty regarding classification under food safety standards, certification requirements, and product labeling rules. This ambiguity was reported to increase perceived regulatory risk for potential food entrepreneurs and processors.

3.7.2 Administrative complexity and multi-institutional oversight

Interviewees described acorn commercialization as potentially requiring interaction with multiple regulatory authorities, including forestry administration and food safety authorities. Stakeholders noted that navigating multiple regulatory systems may be particularly challenging for small-scale producers and rural cooperatives with limited administrative capacity.

Forestry officials emphasized that while harvesting permissions are relatively structured, downstream commercialization pathways

are less standardized, particularly for novel or underutilized forest food products.

3.7.3 Food safety standards and product certification barriers

Stakeholders reported that uncertainty around food-grade standards for acorn flour and related products may discourage investment in processing. Researchers emphasized that standardization of detoxification and processing protocols could help support regulatory clarity and product safety certification.

Some stakeholders suggested that developing clear technical guidelines for acorn food processing could reduce regulatory uncertainty and support market development.

3.7.4 Legal risk perception and market entry decisions

Several stakeholders emphasized that perceived legal uncertainty affects business decisions even in the absence of explicit regulatory prohibitions. Small processors and potential entrepreneurs reportedly prefer to avoid entering markets where regulatory interpretation is unclear or may change.

Legal and regulatory findings indicate that the primary constraint is not prohibition of acorn food commercialization, but rather the absence of clearly articulated and operationalized commercialization pathways linking forest governance and food regulatory systems. This regulatory uncertainty interacts with economic and technological constraints, reinforcing low investment and slow market development.

To synthesize these findings and improve traceability between empirical evidence, system-level drivers, and strategic implications, the key themes identified across interviews and documentary sources are mapped across PESTEL domains and corresponding SWOT categories in [Table 2](#).

4 Discussion

The findings suggest that the limited integration of acorns into formal food value chains in Turkey is shaped primarily by institutional and coordination constraints rather than by ecological or technological feasibility limitations. Although acorns are widely available across Turkish forest ecosystems, require minimal external inputs, and are increasingly supported by scientific research demonstrating nutritional and functional potential, stakeholders consistently identified regulatory uncertainty, limited food-grade processing capacity, and weak market coordination as the most significant barriers to value chain development.

These results are consistent with broader research on non-timber forest product commercialization, which demonstrates that resource abundance alone rarely results in structured markets without supportive governance frameworks, standards, and coordination mechanisms. In the Turkish context, relatively well-developed forest governance systems coexist with less clearly

defined food commercialization pathways. While harvesting and resource protection are regulated, the transition from forest product to food ingredient remains institutionally ambiguous. This uncertainty increases perceived investment risk and discourages actors from investing in processing, certification, and market development.

Importantly, the constraints identified in this study do not operate independently. Regulatory ambiguity discourages investment in processing infrastructure, while limited processing and storage capacity reinforces seasonal supply variability and weak demand signaling. At the same time, perceived price instability and limited outlet diversity reduce incentives for collectors to engage in quality differentiation or supply stabilization practices. These reinforcing dynamics contribute to a low-investment equilibrium in which acorns remain underutilized as food resources despite strong ecological and functional potential.

At the policy level, Turkey already possesses an important institutional foundation for acorn resource governance. The Acorn Exploitation Action Plan (2022–2026) demonstrates growing recognition of acorns as a multi-use forest resource and highlights potential roles in rural development, research, and resource management. However, stakeholder perspectives indicate that this policy recognition has not yet translated into clearly operationalized food commercialization pathways. Clarifying regulatory classification, processing standards, and commercialization procedures for acorn-based food products would likely reduce uncertainty and support investment, particularly for small and medium enterprises seeking to enter emerging functional food markets.

Economic findings highlight the importance of market organization mechanisms alongside regulatory clarity. Stakeholder perceptions of price inconsistency and limited bargaining power suggest that collectors face structural vulnerabilities that may discourage participation in higher-value food markets. At the same time, acorn harvesting provides low-barrier income opportunities in rural areas and contributes to household economic diversification. Strengthening cooperative aggregation models, improving price transparency, and supporting collective marketing mechanisms could therefore improve rural livelihood stability while simultaneously supporting food value chain development.

Investment support structures represent another critical dimension. Stakeholders repeatedly emphasized that existing rural investment mechanisms are often more closely aligned with agricultural and livestock sectors than with forest-food value chains. Programs such as IPARD were frequently described as difficult to access for forest-based food processing or cooperative innovation models. Aligning investment support criteria with forest-food entrepreneurship, or establishing dedicated instruments for NTFP food innovation, could address a key barrier to scaling food-grade processing capacity and entrepreneurial entry.

From a technological perspective, the findings suggest that Turkey possesses growing scientific capacity related to acorn-based food applications, including work on functional properties, product formulation, and processing methods. However, stakeholders described limited translation of scientific knowledge into commercial value chains. Weak innovation transfer mechanisms, limited applied funding, and barriers to

intellectual property protection were repeatedly identified as constraints. Initiatives such as the ITU Acorn Food Workshop demonstrate the potential value of cross-sector innovation platforms, but stakeholders emphasized that sustained institutional support is needed to translate episodic initiatives into stable innovation ecosystems.

Processing infrastructure remains a particularly important bottleneck. While traditional knowledge provides detoxification and preparation methods, stakeholders emphasized that standardized, food-grade detoxification, drying, milling, and storage infrastructure is necessary to ensure product consistency, food safety compliance, and supply stabilization. Targeted support for small-scale or shared processing infrastructure could therefore generate disproportionate benefits for value chain development.

Social findings indicate that cultural familiarity with acorns provides an important foundation for market development, but that historical associations with subsistence or scarcity foods may limit consumer acceptance. At the same time, emerging functional food and sustainability-oriented market trends create opportunities for repositioning acorns as heritage-based, health-oriented, and environmentally sustainable ingredients. Stakeholders suggested that consumer education and product innovation will likely play key roles in shifting perception and supporting demand formation. Evidence from other wild food markets, including game meat, suggests that consumer acceptance, product positioning, and trust-building strategies play a central role in market expansion, even where supply potential exists (Riedl et al., 2024).

Environmental findings reinforce the long-term relevance of acorns within climate-resilient and low-input food system strategies. Acorns are harvested from naturally regenerating forest ecosystems without irrigation or chemical inputs, making them compatible with biodiversity conservation and circular bioeconomy approaches and broader bio-based transition pathways. However, natural yield variability linked to climate and mast cycles reinforces the importance of storage infrastructure and supply coordination mechanisms for stable market development.

Several policy-relevant implications emerge from these findings. Reducing regulatory ambiguity around food classification and processing standards would likely represent one of the most immediate enabling interventions. At the same time, strengthening cooperative aggregation mechanisms and improving procurement transparency could reduce perceived collector vulnerability and support supply stabilization. Expanding investment support mechanisms to better accommodate forest-food enterprises, including processing and cooperative infrastructure, could further accelerate value chain development. Finally, strengthening research-to-practice transfer through multi-actor innovation platforms could help translate growing scientific knowledge into commercial and rural development outcomes.

The study has several limitations. The interview sample is geographically concentrated and primarily reflects supply-side and institutional perspectives. Consumer demand research remains an important area for future work. In addition, the qualitative design does not quantify market concentration or pricing dynamics. Future research should expand regional coverage, incorporate consumer research, and evaluate pilot policy and infrastructure interventions.

5 Conclusion

Acorns represent a historically rooted yet currently underutilized forest-based food resource with significant potential to contribute to sustainable food system transitions in Turkey. Despite strong ecological availability, low-input production characteristics, and increasing scientific interest in acorn-based functional food applications, their integration into formal food value chains remains limited. The findings indicate that this limitation is not primarily driven by resource scarcity or technological infeasibility, but rather by governance, coordination, and market formation constraints that shape incentives across the value chain.

The analysis demonstrates that regulatory ambiguity surrounding food classification and commercialization pathways, combined with limited access to food-grade processing and storage infrastructure, currently constrains investment and entrepreneurial entry. At the same time, weak market coordination and perceived price instability reduce incentives for collectors and intermediaries to engage in quality differentiation and supply stabilization practices required for food market participation. These factors interact across institutional, economic, and technological domains, reinforcing a low-investment equilibrium that limits the transition from informal or industrial acorn uses toward structured food value chains.

At the same time, the study highlights several enabling conditions that could support future development. Turkey possesses strong ecological resource availability, extensive traditional ecological knowledge, and a growing scientific research base related to acorn functional properties and food applications. Policy initiatives such as the Acorn Exploitation Action Plan (2022–2026) demonstrate increasing institutional recognition of acorns as a multi-use forest resource. However, translating this recognition into food value chain development will likely require stronger integration between forest governance systems, food regulatory frameworks, rural investment mechanisms, and innovation support structures.

The findings suggest that reducing regulatory uncertainty around food commercialization, improving access to processing and storage infrastructure, strengthening cooperative aggregation mechanisms, and improving alignment between rural investment programs and forest-food entrepreneurship could represent important leverage points. In addition, strengthening research-to-practice transfer and supporting consumer awareness and product innovation could help support demand formation for acorn-based foods, particularly within functional and sustainability-oriented market segments.

Several limitations should be acknowledged. The study is geographically concentrated and primarily reflects supply-side and institutional perspectives. Consumer demand dynamics remain underexplored due to the early-stage nature of the acorn food market. Future research should expand regional analysis across Turkey's diverse forest ecosystems, incorporate consumer behavior and willingness-to-pay studies, and evaluate pilot policy and infrastructure interventions designed to support forest-based food value chain development.

Overall, the results suggest that acorns have the potential to contribute to more resilient, biodiversity-supportive, and locally grounded food systems in Turkey. Realizing this potential will depend less on ecological or technological breakthroughs and more on institutional coordination, market organization, and targeted support for early-stage forest-food value chain development.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Istanbul Teknik Üniversitesi Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CU: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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