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Canning for Shelf-Life Extension of Agricultural Products in Afghanistan: A Narrative Review of Technical, Postharvest, and Economic Considerations

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ABSTRACT

Canning is an established method of thermal preservation, but its industrial feasibility in Afghanistan cannot be inferred from general claims about shelf-life extension or reductions in postharvest loss. This narrative review examines food-engineering literature and Afghanistan-specific institutional and commodity-level evidence. Sources were assessed for their relevance to thermal-process design, product acidity, microbiological safety, packaging, shelf-life assessment, infrastructure, logistics, markets and financing. The review separates general engineering knowledge from Afghanistan-specific contextual evidence and project-level information that must be measured or obtained through current quotations. Thermal-process adequacy depends on the product, package, heat-penetration behavior, critical factors and target microorganisms. Shelf-life claims require defined storage conditions and supporting product-specific evidence. The available Afghanistan-related literature identifies postharvest, infrastructure and market constraints but does not establish the profitability of an unspecified industrial canning facility. Payment arrangements, supply-chain reliability, utilities, packaging procurement, raw-material seasonality and verified market demand are material feasibility variables. No national loss-reduction rate, universal processing schedule or investment return can be derived responsibly from the reviewed sources. Canning warrants commodity- and location-specific investigation in Afghanistan. A defensible feasibility study should integrate validated product and thermal-process specifications with measured supply, utility, packaging, market and financial information. The contribution of this review is a three-layer evidence framework distinguishing established technical principles, Afghanistan-specific operating conditions and project-specific primary data. This approach clarifies what can be concluded from the present literature and what must be established before an investment decision. The framework is intended to guide transparent appraisal and prioritization of subsequent field measurements and pilot trials.

Keywords: Afghanistan; Canning; postharvest loss; shelf life; thermal processing;

INTRODUCTION

Food loss is a reduction in the quantity or quality of food along the supply chain before retail. Food and Agriculture Organization of the United Nations (FAO) reports that losses can arise at the farm, during storage, in transit and during processing because of factors such as harvesting practices, inadequate storage, weak infrastructure, technical malfunction and human error. The same report stresses that interventions should be selected after identifying the critical loss points in a specific supply chain (Food and Agriculture Organization of the United Nations, 2019).

For Afghanistan, Azam-Ali (2008) prepared a two-volume FAO/Ministry of Agriculture manual on postharvest handling, storage and processing of fruits and vegetables. The manual provides Afghanistan-specific evidence that postharvest management and processing are relevant topics, although it is primarily a training manual for home-based and small-scale processing rather than an industrial canning feasibility study.

Canning is one preservation option within this broader postharvest system. Holdsworth and

Simpson (2016) describe thermal processing of packaged foods as the establishment of time-temperature conditions needed to achieve adequate sterilization or pasteurization. The required process depends on the food and package, so canning cannot be represented by one universal processing condition (Holdsworth & Simpson, 2016).

Although the scientific principles of food canning are well established, limited integrated evidence is available on their application under Afghanistan-specific agricultural, infrastructure, and market conditions. This review therefore aims to examine the technical principles of canning, assess relevant postharvest and industrial conditions in Afghanistan, and identify the information required for future feasibility studies. The main contribution is a three-layer evidence framework that distinguishes established engineering principles, Afghanistan-specific conditions, and project-level data requirements. This framework provides a basis for future commodity selection, pilot testing, and techno-economic assessment.

REVIEW METHODOLOGY

This narrative review selected sources for direct relevance to thermal processing, shelf-life evaluation, microbial spoilage, packaging, postharvest loss, emerging in-container thermal technologies and Afghanistan's agricultural and business context. Priority was given to peer-reviewed literature, established food-engineering texts and institutional publications from FAO, the World Bank and the U.S. Food and Drug Administration (FDA).

Evidence was used only within its scope: food-engineering sources support general technical principles; Afghanistan-specific sources support local contextual statements; and regulatory sources are presented as external technical examples, not Afghan law. The review is descriptive and analytical rather than systematic and does not claim exhaustive database coverage or meta-analysis.

Because Afghanistan-specific industrial canning data are limited, the review does not estimate national loss reduction, plant profitability or employment effects. Unsupported numerical claims are treated as data requirements rather than findings.

AGRICULTURAL AND POSTHARVEST CONTEXT IN AFGHANISTAN

Afghanistan's agricultural sector produces a range of perishable fruits and vegetables, but postharvest losses remain an important concern for producers, traders, and consumers. These losses may occur at different stages of the supply chain, including harvesting, sorting, packaging, transportation, storage, and marketing. The Food and Agriculture Organization emphasizes that food-loss patterns vary considerably between commodities and supply chains (Food and Agriculture Organization of the United Nations, 2019). Therefore, the selection of an appropriate intervention requires an understanding of where losses occur, their causes, and the condition of the product at each stage.

Yusufi and Yamada (2017) investigated preharvest and postharvest grape losses in Mirbachakot, Shakardara, and Kalakan districts of Kabul Province. Their study involved interviews with 60 participants from the grape supply chain during August and September 2016. The authors reported preharvest losses of 14%, 13%, and 12% for large, medium, and small grape growers, respectively. They also reported losses of 9.0% at the contractor level, 10.3% at the wholesaler level, and 12.0% at the retailer level. The study identified insect attacks, diseases, fruit dropping, improper packaging, and transportation problems among the factors contributing to losses. These results demonstrate that losses occur at several stages of grape production and marketing. However, the percentages represent observations within the investigated supply chain and should not be interpreted as national estimates or added together to calculate a total national loss.

A separate field study by Gulab et al. (2020) examined tomato production, trade, and postharvest handling in eastern Afghanistan. The researchers collected information from agricultural organizations, producers, traders, consumers, and university professors. Their findings highlighted the importance of

agricultural inputs, including hybrid seeds and fertilizers, for tomato yield and quality. They also identified postharvest handling practices as relevant to reducing losses. Although the study provides useful information about tomato production and marketing in eastern Afghanistan, it does not establish the quantity of tomatoes available for industrial canning or demonstrate the financial feasibility of a tomato-processing facility.

The findings of these local studies should be interpreted according to their geographical and commodity-specific scope. Grapes and tomatoes differ in their physical properties, composition, processing requirements, market conditions, and potential preserved products. Therefore, observations from grape marketing in selected districts of Kabul Province cannot be directly applied to tomato supply chains in eastern Afghanistan or to other agricultural commodities. Similarly, evidence of postharvest losses does not automatically demonstrate that canning is the most suitable preservation method. The FAO (2019) recommends identifying critical loss points before selecting interventions, since the effectiveness of loss-reduction measures depends on the commodity and the stage of the supply chain.

An important distinction must be made between losses that can potentially be reduced through processing and losses that require other interventions. Damage caused by harvesting methods, pest infestation, disease, or unsuitable transportation conditions may occur before agricultural products reach a processing facility. Such problems may require improvements in harvesting practices, pest management, sorting, protective packaging, and transportation. Processing cannot restore raw materials that have already become unsafe or unsuitable for food production. In contrast, timely processing of sound, suitable raw materials may reduce deterioration associated with limited fresh-market demand or short storage life. Canning may therefore be considered one possible intervention, but its effectiveness depends on the condition of the incoming material, the intended product, and the availability of appropriate processing facilities (FAO, 2019; Azam-Ali, 2008).

The grape and tomato studies provide a useful starting point for identifying commodities that deserve further investigation in Afghanistan. For grapes, future research should examine the suitability of specific grape varieties for preserved products, the availability of acceptable raw materials, processing yields, and consumer demand. For tomatoes, investigations could examine seasonal supply, raw-material quality, sorting losses, processing characteristics, and the market for canned tomato products. These are proposed research directions rather than findings established by the cited local studies.

Before industrial canning is recommended for either commodity, field investigations should determine seasonal production volumes, the proportion of raw materials suitable for processing, existing marketing channels, and the causes of losses at each stage. Pilot-scale trials should then assess processing yield, product quality, thermal-processing requirements, packaging suitability, and shelf-life performance. Economic evaluation should consider raw-material prices, utilities, packaging, transportation, plant utilization, and market demand. This commodity-specific approach would help determine whether canning provides a technically suitable and economically justified preservation option under local conditions.

SCIENTIFIC PRINCIPLES OF FOOD CANNING

Thermal processing of packaged foods is an integrated system involving the food, package and heating process. Holdsworth and Simpson (2016), Awuah et al. (2007), and Jimenez et al. (2024) describe the relationships among heat transfer, microbial inactivation, heat penetration and process evaluation. These principles explain why a scheduled thermal process must be established for the particular product and package rather than selected from a generic flow diagram.

The scheduled thermal process for canned food is established using heat-penetration studies conducted under defined product and operating conditions. Its adequacy depends on the temperature history at the slowest-heating

region of the food. Container dimensions influence the distance over which heat must penetrate. For conduction-dominated heating, the characteristic heating time is proportional to the square of the characteristic heat-transfer distance when other properties remain constant. Thus, increasing the relevant container dimension may substantially increase the time required for the product to reach the desired temperature. Food consistency also affects the heating mechanism. Liquid products may be heated mainly by natural convection, whereas highly viscous products may exhibit conduction-dominated heating. Changes in viscosity, particle size, or the solids-to-liquid ratio can therefore alter both the heating rate and the location of the slowest-heating region (Holdsworth & Simpson, 2016; Zechman & Pflug, 1994).

Fill conditions and formulation introduce further variations. Changes in fill weight, headspace, initial product temperature, or the proportion of solid ingredients can modify the temperature distribution and heating rate. Product formulation may also affect thermal diffusivity, viscosity, and microbial resistance characteristics. Since accumulated thermal lethality depends on the actual product-temperature history, the same retort temperature and processing duration do not necessarily provide equivalent lethality after these changes. Consequently, a scheduled process is valid only within its established critical-factor limits. Modifications that may affect heat penetration must be evaluated by a qualified process authority, with additional heat-penetration testing and reassessment of the scheduled process where required (Holdsworth & Simpson, 2016; U.S. FDA, 21 CFR §113.83).

Microbial spoilage is also product-specific. Snyder et al. (2024) show that different bacterial and fungal groups cause spoilage in different foods and that control strategies can act on raw materials, the processing environment, products and packaging. Therefore, statements that canning prevents all spoilage or gives the same shelf life to all foods would not be scientifically justified.

CANNING PROCESS AND UNIT OPERATIONS

Canning is not one uniform process for all agricultural products. The required preservation treatment depends on the food, package, and heat-transfer conditions. Holdsworth and Simpson (2016), Mishra and Sinha (2018), and Jimenez et al. (2024) show that thermal-process design must consider the heating behaviour of the packaged food and the resistance of the relevant microorganisms. Container dimensions are important because changes in diameter or height alter the distance and pathways through which heat reaches the slowest-heating region. Food consistency also influences heat penetration. In liquid products, natural convection may contribute significantly to heating, whereas thick or highly viscous products are more likely to exhibit conduction-dominated heating. Changes in viscosity, particle size, or the proportion of solids and liquids may therefore modify the heating rate and the location of the slowest-heating region. Similarly, variations in fill weight, headspace, initial product temperature, and formulation can affect heat transfer and the temperature history achieved during processing. These changes may alter the accumulated thermal lethality even when the retort temperature and processing duration remain unchanged. Consequently, a scheduled thermal process established for one product and container cannot automatically be transferred to another. Changes in critical product, packaging, or filling conditions must be evaluated, and additional heat-penetration studies and reassessment of the scheduled process may be necessary to ensure that the required preservation treatment is consistently achieved (Holdsworth & Simpson, 2016; Jimenez et al., 2024).

Product acidity is particularly important because it influences microbial risk and process design. The review therefore treats equilibrium pH and water activity as product-specific engineering inputs rather than as generic descriptors (Holdsworth & Simpson, 2016).

A commercial canning line integrates raw-material preparation, filling, closure, thermal processing, cooling and storage. Because the

food, package and process interact, each operation must be specified for the selected product rather than copied from a generic flow diagram (Holdsworth & Simpson, 2016). The principal operations and their technical purposes are summarized in Table 1.

Conventional retort processing is established, while newer in-container technologies are being investigated for faster or more resource-efficient heating. Their relevance is considered separately in Section 9 (Bhunia et al., 2024).

Filling and closure affect process reproducibility and post-process protection. Fill quantity, headspace, closure integrity and container geometry should therefore be controlled as part of the scheduled process (Holdsworth & Simpson, 2016).

A commercial thermal process should be supported by microbial-resistance data, heat-penetration and heat-distribution evidence, and documented critical factors for the defined product and package (Holdsworth & Simpson, 2016; Pflug, 1987; Stumbo et al., 1975; Soni et al., 2022).

Table 1. Main canning operations and their technical purpose

Operation	Technical purpose	Primary source
Raw-material selection and sorting	Remove unsuitable material and select product appropriate for processing.	FAO (1998); Holdsworth & Simpson (2016)
Washing and preparation	Reduce soil and foreign material and prepare the commodity for filling.	FAO (1998)
Blanching where applicable	Inactivate enzymes and prepare selected vegetables before further processing.	FAO (1998)
Filling and exhausting	Place the prepared product in the selected container and manage entrapped air/headspace as required by the process.	FAO (1998)
Hermetic closure	Protect the processed product against recontamination after closure.	Holdsworth & Simpson (2016)
Thermal processing	Apply a defined time-temperature process to achieve the required preservation objective.	Holdsworth & Simpson (2016)
Cooling, labelling and storage	Terminate heating appropriately and protect the packaged product during subsequent handling and storage.	FAO (1998); Holdsworth & Simpson (2016)

Source: synthesized from FAO (1998) and Holdsworth & Simpson (2016).

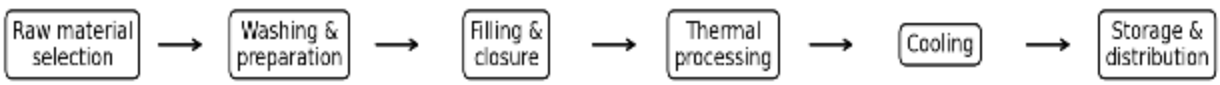


Figure 1. Conceptual sequence for thermal processing of packaged food. Source: developed by the authors from the thermal-processing framework described by Holdsworth and Simpson (2016). This is not a product-specific operating procedure.

Quantitative thermal-process framework

Thermal-process adequacy can be evaluated using the decimal reduction time (D-value), thermal resistance constant (z-value), and accumulated lethality (F-value). At a specified temperature, the D-value represents the time required to reduce the viable population of a target microorganism by one $\log_{10}$ cycle (90%), under defined conditions. The z-value represents the temperature increase required to reduce the D-value by a factor of ten. These parameters describe the temperature dependence of microbial inactivation and provide a basis for evaluating thermal treatments (Holdsworth & Simpson, 2016; Pflug, 1987; Soni et al., 2022).

During thermal processing, the temperature inside the packaged food changes continuously and may differ considerably from the retort temperature. Heat-penetration studies therefore measure the product-temperature history at the critical slowest-heating location under defined processing conditions. Each recorded temperature contributes a different amount of microbial lethality. This contribution is expressed as the instantaneous lethal rate, which represents the microbial inactivation effect at the measured product temperature relative to a selected reference temperature. For a specified reference temperature T_{ref} and z-value, the instantaneous lethal rate is calculated as follows:

$$L(T) = 10^{\frac{(T-T_{ref})}{z}}$$

where L(T) is the dimensionless instantaneous lethal rate, T is the measured product temperature (°C), T_{ref} is the selected reference temperature (°C), and z is the temperature change (°C) required for a tenfold change in the D-value. At the reference temperature, L(T) equals 1. At temperatures below the reference temperature, the lethal rate decreases, while at higher temperatures it increases.

The accumulated thermal lethality is obtained by integrating the instantaneous lethal rate over the measured product-temperature history, including the relevant heating and cooling periods.

$$F_{T_{ref,\,z}} = \int_0^{t_p} 10^{\frac{(T-T_{ref})}{z}}\, dt$$

Where:

- $F_{T_{ref,\,z}}$ = accumulated lethality, expressed as equivalent minutes at the reference temperature.
- T(t) = measured product temperature at time (t).
- T_{ref} = reference temperature.
- z = temperature sensitivity parameter.
- t_p = duration of the evaluated temperature history.

For temperature measurements recorded at discrete time intervals, the calculation can be approximated by:

$$F_{T_{ref,\,z}} \approx \sum_{i=1}^{n} 10^{\frac{(T_i-T_{ref})}{z}}\, \Delta t_i$$

Here, T_i represents the product temperature associated with time interval Δt_i. The approximation assumes the temperature is represented adequately over each interval.

The resulting F-value expresses the total treatment as an equivalent holding time at the selected reference temperature. However, an F-value calculation alone does not establish the safety of a commercial canning process. Process safety also depends on appropriate target-organism selection, microbial resistance data, representative heat-penetration and heat-distribution studies, control of critical processing factors, container integrity, and validation of the scheduled process (Holdsworth & Simpson, 2016; Pflug, 1987).

For low-acid canned-food calculations, F_0 conventionally denotes equivalent lethality at T_{ref} = 121.1 °C with z = 10 °C; it is an equivalent time at the reference temperature, not the retort holding time itself (Holdsworth & Simpson, 2016).

A simple illustration shows the calculation. At 111.1 °C with z = 10 °C and T_ref = 121.1 °C, the exponent (T - T_ref)/z equals -1 and therefore L = 0.1. If the product temperature remained at 111.1 °C for 10 minutes, that interval would contribute 1 equivalent minute at 121.1 °C. At the reference temperature, L = 1. In an actual process, product temperature changes continuously during heating and cooling, so lethality is integrated over the measured time-temperature history.

The quantitative framework must be tied to heat-penetration and heat-distribution evidence. F or F_0 calculations are meaningful only when the product-temperature history, reference conditions and critical process factors are defined. For shelf-stable low-acid canned foods with a finished equilibrium pH above 4.6 and water activity above 0.85, control of proteolytic Clostridium botulinum is a central public-health consideration in scheduled thermal processing (Brown et al., 2012; Holdsworth & Simpson, 2016; FDA, 2025).

No universal F_0 target is assigned here. The required scheduled process depends on the specific product and container, including formulation, equilibrium pH, water activity, package, fill, initial temperature, heating behavior, critical factors and the relevant target microorganism (Holdsworth & Simpson, 2016; Pflug, 1987; Stumbo et al., 1975).

Product acidity and the pH 4.6 boundary

The pH boundary is important because it changes process classification. Under the U.S. FDA framework, low-acid canned food generally has a finished equilibrium pH above 4.6 and water activity above 0.85, subject to stated exclusions; acidified food is low-acid food acidified to an equilibrium pH of 4.6 or below while water activity remains above 0.85 (FDA, 2025). The microbiological importance of the pH 4.6 boundary in relation to Clostridium botulinum is also discussed by Odlaug and Pflug (1978). These definitions are used here as technical references and are not presented as Afghan law.

For engineering purposes, this classification affects process design and control. A product remaining above the low-acid boundary requires a preservation process appropriate to that status; when acidification is used, equilibrium pH and the acidification procedure become critical controls.

Raw-material preparation and filling must be specified for the selected commodity. The Afghanistan processing manual describes washing, preparation, filling and related small-scale operations for fruits and vegetables (Azam-Ali, 2008). For industrial work, these operations need measurable acceptance criteria, including raw-material condition, fill quantity, headspace or other package variables that can affect processing and product consistency.

Closure and post-process handling are equally important because thermal treatment is only effective if the package continues to protect the food. Holdsworth and Simpson (2016) treat the package as part of the thermal-processing system, while Zheng et al. (2023) review chemical contaminants associated with canned and can-packaged foods. A feasibility study should therefore specify the container and closure system, supplier quality requirements and inspection or testing needed to demonstrate package integrity.

MICROBIAL SAFETY AND THERMAL PROCESS DESIGN

Thermal processing is only one part of food-safety management in canning operations. The microbiological safety and shelf stability of canned foods depend on a series of connected controls, beginning with raw-material selection and continuing through hygienic preparation, thermal processing, container sealing, cooling, and storage. Snyder et al. (2024) describe how microbial spoilage varies among food products and how control measures can be applied at different stages of food production. Brown et al. (2012) and Holdsworth and Simpson (2016) further provide the microbiological and

engineering principles relevant to thermally processed packaged foods. These considerations indicate that the safety of a canned product cannot be evaluated solely from the processing temperature or duration. It also depends on the condition of the food before processing, the adequacy of the scheduled thermal treatment, and the prevention of contamination after processing.

Raw-material quality and initial microbial contamination.

Agricultural products may carry microorganisms originating from soil, irrigation water, harvesting equipment, transportation containers, and handling surfaces. Their microbiological condition can vary according to maturity, physical damage, storage duration, and handling practices. Damaged or decayed fruits and vegetables may introduce additional spoilage microorganisms into the processing line. Sorting, grading, washing, and removal of unsuitable materials are therefore important preliminary operations. These measures reduce contamination and improve the uniformity of materials entering the process, although they cannot reliably eliminate all microorganisms, particularly heat-resistant bacterial spores. Raw-material characteristics also influence thermal processing indirectly. Variations in firmness, particle size, soluble solids, and composition may change the consistency of the finished product and consequently affect heat penetration. Raw-material quality control therefore contributes both to reducing microbial contamination and to maintaining the product characteristics assumed during thermal-process design (Brown et al., 2012; Holdsworth & Simpson, 2016).

Hygienic preparation and processing conditions.

Following raw-material acceptance, contamination must be controlled during washing, peeling, cutting, blanching, mixing, filling, and container closing. Each operation creates opportunities for microorganisms to enter the product through equipment surfaces, processing water, personnel, or contact with contaminated materials. Inadequate equipment cleaning, accumulation of food residues, and prolonged holding of prepared products may increase microbial contamination before the final thermal treatment. Hygienic processing therefore requires suitable cleaning and sanitation procedures, appropriate water quality, control of food-contact surfaces, and prevention of cross-contamination between raw and prepared products. The time and temperature of intermediate holding operations should also be controlled to limit microbial growth. Although blanching can reduce vegetative microorganisms and inactivate certain enzymes, it does not replace the scheduled thermal process required for the packaged product. Hygienic preparation and thermal processing consequently serve different but complementary purposes: the former limits contamination before heating, while the latter provides the microbial inactivation required for preservation (Snyder et al., 2024; Brown et al., 2012; Holdsworth & Simpson, 2016).

Thermal-process design and validation.

The scheduled thermal process must be established according to the microbiological characteristics of the food, its formulation, container properties, and heat-transfer behavior. Its purpose is to deliver the required microbial inactivation throughout the packaged product, including the region that receives the least effective thermal treatment. Heat-distribution studies assess the performance of the processing equipment, while heat-penetration studies determine how the temperature inside the food changes during heating and cooling. The measured product-temperature history can then be used to calculate accumulated thermal lethality using appropriate microbial resistance parameters. However, calculated lethality alone does not establish the adequacy of a commercial process unless the selected target microorganisms, heat-resistance data, processing conditions, and critical product factors are appropriate. Changes in container dimensions, filling temperature, fill weight, product consistency, or formulation may alter heat penetration and require reassessment of the scheduled process.

Once established, the process must be implemented under controlled operating conditions, with monitoring and records to demonstrate that the specified critical factors have been maintained (Holdsworth & Simpson, 2016; Brown et al., 2012).

Container closure integrity and prevention of recontamination.

The effectiveness of thermal processing depends on maintaining the microbiological barrier provided by the container after treatment. Hermetic closures are intended to prevent microorganisms from entering the product during cooling, handling, storage, and distribution. Defective double seams in metal cans, improperly sealed glass containers, damaged closures, or leakage may allow contamination even when the required thermal treatment has been achieved. Container closure quality must therefore be controlled through appropriate sealing-equipment adjustment, inspection, and verification procedures suited to the packaging material. This requirement is particularly important because thermal-process validation addresses microbial inactivation during treatment, whereas closure integrity determines whether the treated food remains protected afterward. A correctly processed product may consequently become unsafe or spoil if its container loses integrity (Brown et al., 2012; Holdsworth & Simpson, 2016).

Post-process handling, cooling, and storage.

Following thermal processing, containers must be handled in a manner that preserves closure integrity and limits exposure to contamination. Cooling is an important stage because containers may come into contact with water while internal temperature and pressure are changing. Where water is used for cooling, its microbiological quality must be appropriately controlled to reduce the risk of contamination through defective or compromised closures. Mechanical damage during conveying, stacking, transportation, or storage may also affect container integrity. Appropriate handling, inspection, and storage practices are therefore necessary to protect the finished product. In addition, storage temperature and duration influence the stability and quality of canned foods and should be considered when establishing their intended shelf life. Post-process controls do not compensate for inadequate thermal treatment, but they help preserve the safety and stability achieved by a properly established process (Holdsworth & Simpson, 2016; Snyder et al., 2024).

These stages form an interdependent food-safety system. Raw-material selection and hygienic preparation reduce contamination and help maintain consistent product characteristics before processing. Thermal-process validation establishes the treatment required to achieve the intended preservation outcome, while routine process control ensures that the established conditions are followed during production. Container closure integrity and hygienic post-process handling subsequently protect the treated product against recontamination. Failure at one stage cannot necessarily be corrected by satisfactory performance at another. For example, a hermetically sealed container cannot compensate for inadequate thermal processing, and sufficient thermal lethality cannot prevent spoilage if microorganisms enter through a defective closure after treatment. Therefore, the safety and shelf stability of canned agricultural products must be evaluated through the combined performance of raw-material control, hygienic operations, validated thermal processing, packaging integrity, and post-process handling rather than through thermal treatment alone (Brown et al., 2012; Holdsworth & Simpson, 2016).

SHELF LIFE, NUTRITIONAL QUALITY AND SENSORY QUALITY

Shelf life should be evaluated for a defined food under stated storage conditions and against stated acceptance criteria. Kilcast (2000) describes sensory evaluation as an important component of shelf-life assessment and discusses the design and interpretation of sensory shelf-life tests. Accordingly, a fixed storage period should not be assigned to canned foods in general without product-specific evidence.

Thermal-process design must also consider product quality. Awuah et al. (2007) review the relationship between thermal processing, safety and quality, while Ling et al. (2015) review the kinetics of food-quality changes during thermal treatment. Rickman et al. (2007) further show that nutritional effects of canning vary by nutrient and commodity. A more severe heat treatment is therefore not automatically a better process; the process must achieve its safety objective while limiting unnecessary quality deterioration.

Predictive shelf-life approaches are developing as well. Shi et al. (2024) review artificial-neural-network approaches used to predict food shelf life from storage and product data. Their review demonstrates that shelf-life prediction can use multiple measured variables, but it does not provide a ready-made model for Afghan canned products. Table 2 summarizes the evidence needed to support a product-specific shelf-life claim.

Table 2. Evidence required for a defensible shelf-life claim

Evidence element	Why it is required	Supporting source
Defined product and package	Shelf life is specific to the product and its protection system.	Kilcast (2000); Holdsworth & Simpson (2016)
Defined storage conditions	Temperature and other storage conditions influence deterioration.	Kilcast (2000)
Acceptance criteria	The end of shelf life requires an explicit quality or safety criterion.	Kilcast (2000)
Sensory assessment where relevant	Appearance, texture, aroma and flavor can determine acceptability.	Kilcast (2000)
Measured or validated prediction data	Predictive models require appropriate input data and validation.	Shi et al. (2024)

Source: synthesis of the cited shelf-life and thermal-processing literature.

PACKAGING AND CONTAINER INTEGRITY

The package is a functional part of the food preservation system, and its selection must be based on the characteristics of the intended food and the conditions under which it will be processed, stored, and distributed. Metal cans, glass jars, and retortable flexible packages differ in their heat-transfer behavior, mechanical strength, sealing requirements, and compatibility with food products. The acidity, salt content, moisture, fat composition, and physical consistency of the food are important considerations because they influence the interaction between the product and the packaging material. For example, acidic or salt-containing products may increase the risk of corrosion in inadequately protected metal containers, while fatty foods may require particular attention to the compatibility and migration characteristics of food-contact coatings. Product consistency and the presence of solid particles also influence heat penetration and must be considered when selecting container dimensions and establishing the thermal process. Therefore, packaging selection should begin with the intended food rather than treating the container as an independent component of the production system (Holdsworth & Simpson, 2016; Lestido-Cardama et al., 2022).

Processing conditions provide a second basis for container selection. The package must withstand the temperature, pressure, processing duration, and cooling conditions required to achieve the intended preservation outcome. Rigid metal cans, glass containers, and flexible retort pouches respond differently to heating and pressure changes. Metal cans generally provide good mechanical resistance but require suitable seam construction and internal

protection against product-container interactions. Glass jars require attention to thermal shock, closure performance, and pressure differences during heating and cooling. Retort pouches must maintain the integrity of their laminated structure and heat seals under the specified processing conditions. Container dimensions and geometry also affect the rate of heat penetration; therefore, a thermal process established for one package size or configuration cannot automatically be applied to another. Packaging specifications and thermal-process design must consequently be developed together to ensure that the selected container can tolerate processing conditions while allowing the required thermal treatment to reach the food (Holdsworth & Simpson, 2016).

Closure integrity is equally important because an adequate thermal process cannot prevent contamination if microorganisms enter the package after processing. The closure method must be appropriate for the selected packaging material and capable of maintaining a hermetic seal throughout processing, cooling, storage, and distribution. Metal cans typically rely on mechanically formed double seams, glass jars use compatible caps or closure systems, and retort pouches depend on properly formed heat seals. Each closure system has different critical operating parameters and inspection requirements. For example, double-seam quality depends on correct seam formation and mechanical adjustment, while pouch-seal integrity depends on suitable sealing temperature, pressure, time, and the absence of food particles or other contamination in the sealing area. Closure verification should therefore be incorporated into packaging specifications and production quality control. The package must also resist damage during cooling, handling, stacking, and transportation because deformation, impact, or seal damage may compromise hermetic integrity even when the thermal process has been correctly applied (Holdsworth & Simpson, 2016).

Packaging selection must also consider the expected storage environment and the chemical safety of food-contact materials. Temperature fluctuations, humidity, transportation conditions, and storage duration can affect container performance and product quality. In humid environments, external corrosion may be a concern for metal containers, while prolonged storage and elevated temperatures may influence chemical migration from certain coatings and polymer-based packaging materials. Zheng et al. (2023) review chemical contaminants associated with canned and can-packaged foods, while Lestido-Cardama et al. (2022) examine food and beverage can coatings, migration, and related risk-assessment considerations. Ni et al. (2023) further discuss bisphenol A and its structural analogues in canned foods. These studies indicate that packaging evaluation should include not only mechanical strength and closure integrity but also the suitability of food-contact materials for the specific product and its expected storage conditions. Supplier qualification should therefore address container dimensions, material specifications, coating compatibility, closure performance, resistance to processing conditions, and applicable food-contact safety requirements. The final packaging choice should provide a suitable combination of microbiological protection, thermal-process compatibility, chemical safety, and durability throughout the intended shelf life (Zheng et al., 2023; Lestido-Cardama et al., 2022; Ni et al., 2023; Holdsworth & Simpson, 2016).

PRESERVATION OPTIONS AND EMERGING THERMAL TECHNOLOGIES

Conventional retort processing is widely used to produce shelf-stable canned foods, but its energy and water requirements depend on the heating medium, equipment design, processing duration, product characteristics, and opportunities for heat and water recovery. Bhunia et al. (2024) identify steam generation, retort heating, venting, and cooling as important considerations in the resource efficiency of conventional thermal processing. Emerging microwave-assisted thermal pasteurization and sterilization technologies aim to improve heating efficiency and reduce unnecessary thermal exposure while achieving the required microbial inactivation. However,

their performance must be evaluated using quantitative results obtained under specified product and operating conditions rather than assuming that all microwave processes are more efficient than conventional retorting.

Experimental studies provide examples of these potential benefits. Cho and Chung (2020) investigated microwave pretreatment of vegetable food products, including peeled potatoes and a spicy sauce containing vegetables. A microwave treatment lasting 3 min reduced total bacterial counts by approximately 3–4 log CFU/g and heat-resistant microorganisms by approximately 2 log CFU/g. The authors also reported that microwave treatment required approximately 70–80% of the energy used for steam treatment under their experimental conditions. These findings demonstrate the potential of microwave pretreatment to reduce microbial contamination and energy demand. However, the treatment was investigated as a preliminary processing step and should not be interpreted as a validated replacement for commercial sterilization.

Product-quality comparisons also indicate that the effects of advanced thermal processing depend on the food and packaging system. In an experimental study of garlic mashed potatoes, microwave-assisted thermal sterilization was designed to deliver approximately 6 min of F_0 lethality. Vitamin C losses were reported as 13–16% in microwave-processed samples packaged in high-barrier polymer pouches, compared with 18% in conventionally retorted samples packaged in aluminium-foil-based pouches. The study also found that oxygen and water-vapour transmission rates of the polymer pouches increased after processing, demonstrating that improved nutrient retention must be considered alongside packaging-barrier performance. Because the packaging systems differed, the reported quality differences cannot be attributed exclusively to the heating technology.

These findings indicate that microwave-assisted processing can offer advantages in particular applications, but the magnitude of improvement depends on the product, process configuration, packaging, and evaluation method. Furthermore, published reductions in treatment duration or improvements in nutrient retention do not independently establish reductions in total factory energy or water consumption. Direct comparisons should report energy consumption per kilogram of finished product, water withdrawal and consumption per kilogram, processing throughput, achieved microbial lethality, and relevant quality indicators under comparable operating conditions. For Afghanistan, such measurements would be necessary before selecting advanced thermal technologies for locally available fruits and vegetables. Table 3 summarizes the technical differences between conventional retorting and emerging in-container technologies, while the quantitative results above illustrate their reported performance under specific experimental conditions (Bhunia et al., 2024; Cho & Chung, 2020).

Table 3. Conventional canning and emerging in-container thermal processing

Criterion	Conventional thermal canning	Emerging microwave-based in-container processing
Industrial maturity	Long-established and widely used.	Newer systems are being developed and applied for pasteurization and sterilization.
Heating approach	Heat is transferred from an external heating medium through the package and food.	Microwave energy provides volumetric heating under controlled systems.
Resource considerations	Conventional systems can have relatively low energy efficiency and substantial water use.	Reviewed microwave systems may improve water and energy efficiency.

Decision for Afghanistan	Requires product-specific engineering and local utility assessment.	Requires separate assessment of equipment availability, support, cost and technical capacity.

Source: Bhunia et al. (2024), interpreted together with Holdsworth and Simpson (2016).

Technology choice should not be driven by novelty alone. Bhunia et al. (2024) review microwave-based in-container pasteurization and sterilization and discuss potential improvements in heating performance and resource efficiency. These systems deserve consideration, but their suitability for Afghanistan depends on equipment availability, technical support, maintenance capability, utility quality, production scale and total cost. Conventional and emerging options should therefore be compared against the same product and operating assumptions.

The utility comparison should also reflect the local energy supply. Conventional thermal processing commonly relies on boilers to generate pressurized steam; Bhunia et al. (2024) identify natural gas, coal and oil as boiler fuels used in food plants. Microwave-based systems, by contrast, are electrically powered and can reduce water and energy use relative to conventional thermal processing. For an Afghanistan-specific feasibility study, the local availability, delivered price and reliability of the applicable boiler fuel and electricity supply should therefore be entered as project-specific variables rather than assumed from international averages (Bhunia et al., 2024).

Resource demand should be quantified from the selected equipment rather than described generically. The feasibility study should use vendor-specified or measured steam, fuel, electricity, cooling-water and other utility demands, together with local tariffs, delivered fuel prices and backup requirements. This converts infrastructure constraints into measurable engineering and economic variables.

TECHNICAL AND INFRASTRUCTURE REQUIREMENTS FOR AFGHANISTAN

Industrial canning depends on reliable utilities, product handling, cooling, storage, maintenance and quality-control capacity in addition to the retort or heating equipment (Holdsworth & Simpson, 2016). A feasibility study should quantify these requirements for the selected line and operating schedule.

Human capability is part of the technical system. Staffing should be derived from the equipment layout, shift pattern, maintenance plan and process-control responsibilities rather than from a generic employment ratio. The Afghan processing manual also illustrates the importance of practical training, although its scope is smaller-scale than industrial retort operation (Azam-Ali, 2008).

ECONOMIC AND MARKET CONSIDERATIONS

Economic feasibility cannot be inferred from technical feasibility alone. A canning facility may be technically capable of producing safe and shelf-stable products but remain financially unviable if raw-material supply is irregular, processing costs are high, or market demand is insufficient. Therefore, an economic assessment should begin with a clearly defined agricultural commodity, processing location, finished product, packaging format, production capacity, operating schedule, and target market. Capital expenditure, operating expenditure, working capital, processing yield, capacity utilization, and expected sales should be estimated using dated and project-specific information. In the Afghan context, particular attention is required to the seasonal availability of fruits and vegetables, the reliability of utilities, packaging procurement, transportation conditions, and the purchasing capacity of target consumers.

Raw-material price and seasonal availability are important variables because they influence both production cost and the number of days a processing facility can operate. A plant designed for a particular daily capacity may experience low annual utilization if suitable agricultural products are available for only a limited harvesting period. This can increase the fixed cost allocated to each unit of finished

product. Processing yield is another important variable because losses during sorting, peeling, trimming, blanching, and filling determine the quantity of saleable product obtained from the purchased raw material. A lower yield increases the raw-material cost per unit of finished product and may reduce profitability even when the purchase price remains unchanged. Future feasibility studies should therefore examine alternative raw-material prices, seasonal supply volumes, processing yields, and annual operating days using commodity-specific field data.

Packaging costs, utility requirements, and logistics should also be evaluated because they directly affect operating expenditure. The cost of metal cans, glass jars, closures, labels, and secondary packaging depends on the selected packaging system, supplier conditions, transportation requirements, and procurement quantities. Where packaging materials or processing equipment are imported, exchange-rate changes may affect their local-currency costs. Energy and water requirements depend on the selected thermal-processing technology, production throughput, and operating efficiency. Transportation costs may vary with the distance between farms, processing facilities, distribution centres, and consumer markets. These variables should be examined individually and, where appropriate, in combination because their effects may occur simultaneously.

Market-related variables are equally important. The selling price, achievable sales volume, product acceptance, distribution margins, and competition from imported or locally processed alternatives determine the revenue available to cover production and investment costs. A higher selling price does not necessarily improve financial performance if it reduces demand or leaves finished products unsold. Similarly, producing at full capacity does not guarantee profitability when the market cannot absorb the output. Future market assessments should therefore distinguish between installed processing capacity, achievable production, and realistic sales volumes. Working-capital requirements should also be considered because seasonal raw-material purchases, packaging inventories, finished-product storage, and delayed customer payments may create substantial financing needs before sales revenue is received.

A future project-specific financial model should test these uncertainties through sensitivity and scenario analysis. Sensitivity analysis can examine the effect of changing one variable at a time, such as raw-material price, processing yield, packaging cost, capacity utilization, or selling price, while holding other assumptions constant. Scenario analysis can evaluate combinations of conditions, such as favorable supply and sales conditions, expected operating conditions, and adverse conditions involving higher input costs, lower utilization, and weaker market demand. These scenarios are proposed as a framework for future investigation and do not represent calculated financial results of the present review. Once reliable project-specific data are available, the resulting cash-flow model may be used to estimate payback period, net present value (NPV), and internal rate of return (IRR), with explicit assumptions concerning investment costs, operating expenses, working capital, project life, and discount rate. Until such evidence is obtained, numerical profitability claims would be premature.

Table 4. Proposed project-specific economic data requirements and sensitivity tests for future canning feasibility studies in Afghanistan

Variable	Evidence required	Why it matters	Proposed sensitivity test
Raw-material purchase price	Farm-gate and delivered prices by commodity, season, and location	Determines the principal input cost	Higher and lower purchase-price cases
Seasonal raw-material availability	Harvest calendar, supply volume, procurement duration	Determines operating days and feasible capacity	Short, normal, and extended supply seasons
Processing yield	Measured input mass, preparation losses, finished-product output	Determines saleable production per tonne of raw material	Lower, expected, and improved yield
Plant capacity utilization	Rated capacity, operating days, downtime, production records	Determines fixed-cost recovery per unit	Low, expected, and high utilization
Packaging cost	Supplier quotations for containers, closures, labels, and cartons	Determines unit packaging cost and procurement exposure	Alternative package prices and formats
Energy and water costs	Measured or estimated consumption, tariffs, fuel prices	Determines utility expenditure	Changes in consumption and utility tariffs
Exchange rate	Currency of imported inputs and applicable exchange rates	Influences imported equipment and packaging costs	Alternative exchange-rate assumptions
Transportation and distribution	Freight quotations, route distances, handling and storage charges	Affects delivered input cost and market access	Higher and lower logistics-cost cases
Selling price and sales volume	Market surveys, distributor information, competing-product prices	Determines revenue and inventory turnover	Lower-price, expected, and higher-price cases, with realistic demand
Capital investment	Equipment, installation, building, utilities, and commissioning quotations	Determines initial investment and financial returns	Base investment and cost-overrun cases
Working capital	Inventory requirements, payment terms, receivables, and cash cycle	Determines financing required during operations	Alternative inventory and payment-cycle assumptions

Note: The scenarios are proposed tests, not modelled results. Numerical ranges should be established from field surveys, supplier quotations, operational measurements, and market evidence. They should not be treated as universal assumptions for Afghan canning facilities.

Table 4 identifies the principal variables, required evidence, and proposed sensitivity tests for a future commodity-specific canning feasibility study in Afghanistan. It is intended as a practical data-collection and financial-modelling framework rather than a presentation of completed economic results.

Afghanistan-specific market and financing constraints

The Afghan feasibility model must also reflect the country's current payment and trade structure. In the World Bank Private Sector Rapid Survey Round 3, among firms reporting business-related international payments, hawala was cited for 57% of import payments and 28% of export payments. Across the wider survey, 43% identified hawala and 19% cash as their current preferred international-payment channels. The survey also reported that 76% of interviewed firms faced difficulties making or receiving international payments (World Bank, 2024). These are survey results for the sampled firms, not universal rates for every Afghan transaction.

These conditions have direct modelling implications. Quotations for imported equipment, cans, closures, instrumentation and spares should record currency, payment route, quotation validity, delivery terms and lead time. No universal hawala fee should be assumed; transaction cost should come from project-specific evidence.

Trade-route risk should be modelled separately from payment risk. The World Bank reports that in 2024 Afghanistan shifted some import trade away from Pakistan amid regulatory changes and periodic border closures; Pakistan's share of Afghan imports declined while Iran and the UAE gained share. The same update reports that food exports grew in 2024 and that reopening key trade routes with Pakistan in the second half of the year supported that performance (World Bank, 2025). This evidence shows both disruption risk and the capacity of routes to reopen; it should not be simplified into an assumption of permanent closure.

The practical response is scenario analysis: a base case should use current supplier lead times and trade routes, while stress cases test longer delivery periods, higher safety stock or viable alternative routes. These are modelling scenarios, not predictions.

Table 5. Afghanistan-specific structural factors for feasibility modelling

Structural factor	Required treatment in the model	Evidence basis
International payment constraints	Record payment route, currency, validity and documented transaction costs for imported inputs.	World Bank (2024)
Hawala/cash reliance	Use project-specific transaction evidence; do not assume a universal hawala charge.	World Bank (2024)
Border/transit disruption	Test lead-time, safety-stock and temporary interruption scenarios.	World Bank (2025)
Changing trade routes	Document current route and destination assumptions and test viable alternatives.	World Bank (2025)

Source: World Bank (2024, 2025); modelling implications are the authors' analytical application of the cited evidence

.Table 5 connects the identified structural constraints with practical modelling implications.

Market evidence must be separated from production capability. Installed capacity indicates what equipment can process, not what can be sold. The model should identify customer, package size, channel, realistic sales volume and price source, then link these to the same production and cost scenario.

The framework improves traceability between claim and evidence: established engineering principles come from technical literature; Afghanistan-context statements require local

evidence; and plant-specific quantities require measurements, quotations or design data. This claim-evidence mapping is the paper's principal methodological contribution.

The revised framework can be read as three evidence layers. This distinction prevents universal engineering principles from being treated as Afghanistan-specific findings and prevents contextual evidence from being treated as plant-level feasibility data. The three evidence layers are summarized in Table 6.

Table 6. Three-layer evidence framework for canning feasibility

Evidence layer	Examples in this review	Permitted inference
Universal engineering principles	*C. botulinum* spores as the principal public-health target in shelf-stable low-acid canned foods; pH 4.6 boundary; D, z and F_0; heat penetration and package integrity	Defines the technical variables and validation logic that a safe process must address.
Afghanistan structural realities	Postharvest constraints; payment-channel difficulties; route and transit volatility; infrastructure and supplier constraints	Defines contextual risks and variables that should enter local feasibility analysis; does not establish plant profitability.
Project-specific primary data	Supplier quotations; raw-material seasonality and usable yield; utility tariffs and fuel prices; market demand; freight and working capital	Supports plant sizing, cash-flow modelling, sensitivity analysis and any project-specific investment conclusion.

Source: authors' synthesis from the evidence framework developed in this review.

RESEARCH GAPS, EVIDENCE REQUIREMENTS AND IMPLICATIONS FOR AFGHANISTAN

Table 7. Principal evidence gaps for Afghanistan

Evidence gap	Why it matters	Recommended next evidence
Commodity-specific postharvest loss data	Determines whether processing targets a verified loss point.	Commodity and location-specific loss assessment
Industrial canning process data	Needed for process design, utility demand and product quality.	Pilot trials and engineering design
Packaging supply and quality data	Affects closure integrity, food-contact safety and recurring cost.	Supplier qualification and package specification
Shelf-life data for selected Afghan products	Needed to support product claims.	Controlled shelf-life study with defined criteria
Current market evidence	Needed to estimate realistic sales and price.	Structured market survey and buyer data
Plant-level cost data	Required for financial feasibility.	Current quotations, tariffs and operating assumptions

Table 7 summarizes the principal evidence gaps and the measurements needed to address them.

The central gap is not a lack of general canning theory, but a lack of linked Afghanistan-specific evidence from commodity selection through process design to market and finance. Published sources justify investigation of postharvest improvement and value addition

and identify agricultural, infrastructure and market constraints, but they do not establish the performance or profitability of a particular industrial canning plant (Azam-Ali, 2008; World Bank, 2014, 2018; FAO, 2026).

Source: authors' synthesis of the evidence reviewed in this paper.

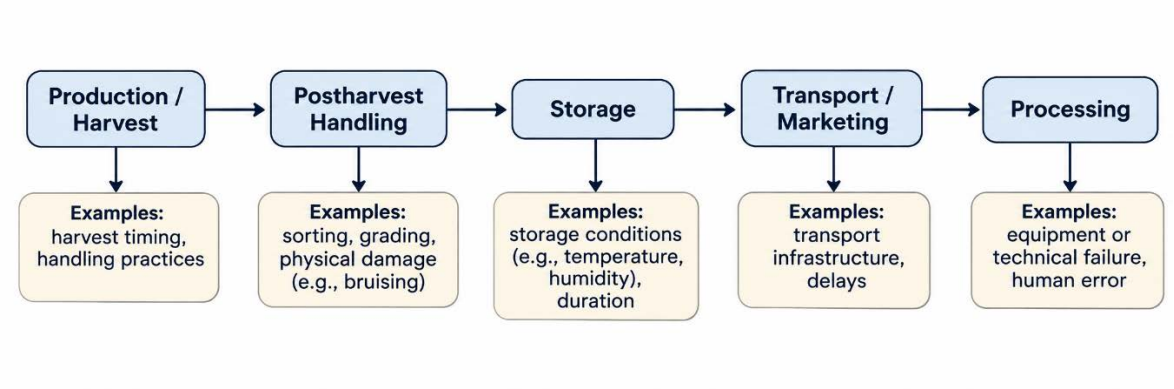


Figure 2. Examples of food-loss causes along the supply chain. Source: adapted from FAO (2019), The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. No loss percentages are inferred from this schematic.

A defensible next study should: (1) select a commodity and location from documented supply, seasonality, loss and market evidence; (2) define and validate the product, package and thermal process; (3) collect current plant-level cost, payment, logistics and market data; and (4) integrate these data in a cash-flow model with sensitivity analysis. Profitability or wider economic effects should be reported only when supported by these data.

The framework may also be useful in other fragile or data-constrained settings. Its transferable element is the separation of engineering knowledge, local contextual evidence and project-specific primary data; Afghanistan-specific findings should not be generalized without local verification.

Current Afghan regulatory requirements for industrial canning were not established from the reviewed sources. FDA material is used only to illustrate the pH/water-activity classification and scheduled-process concept. Implementation work must separately establish the applicable Afghan authorities, standards, licenses and laboratory obligations.

CONCLUSION

Canning is an established preservation method, but process adequacy is product- and package-specific. A defensible assessment connects microbial resistance, measured product-temperature history, heat penetration, package integrity, pH/water activity where relevant, and shelf-life evidence rather than relying on a generic process description (Holdsworth & Simpson, 2016).

For Afghanistan, available evidence supports investigation of improved postharvest handling and agro-processing, but it does not establish the profitability of an unspecified canning plant. Feasibility requires verified raw-material supply, utilities, packaging, process design, market demand, payment arrangements, logistics and current costs (World Bank, 2024; World Bank, 2025).

The paper's contribution is an evidence-disciplined feasibility framework rather than an investment verdict. Because Afghanistan-specific industrial canning evidence remains sparse, its practical value is to distinguish claims that are presently supportable from those that require project-specific primary data.

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The authors confirm that this manuscript is original, has not been published previously, and is not under consideration for publication in any other journal.

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