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Identifying Loss and Waste Hotspots and Data Gaps throughout the Wheat and Bread Lifecycle in the Fars Province of Iran through Value Stream Mapping

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Abstract: Reducing wheat and bread loss and waste is crucial for ensuring global food security and sustainability. The importance of reducing wheat and bread loss is particularly significant in Iran, where wheat is a staple crop and a vital component of the country's food security. A value stream mapping study was conducted to identify loss and waste hotspots and critical data gaps along the wheat and bread lifecycle (WBL). In October 2018, 14 experts were surveyed in Fars province, Iran's second-largest wheat producer. The study presents a detailed cradle-to-grave overview of WBL and identifies farms, foodservice, and households as the loss and waste hotspots. The results revealed significant data gaps regarding on-farm wheat loss and household bread waste. Additionally, although data exist in other segments of WBL, they are not readily accessible nor utilized to report loss and waste, highlighting the need for transparency within the WBL system and further research to compile existing data and analyze wheat and bread loss and waste. Other researchers can employ the holistic approach of the present study to investigate loss and waste throughout the lifecycle of other food items in different geographical contexts. The methodology adopted in this study offers advantages for defining the scope of research in lifecycle assessment and circular economy studies.

Keywords: food loss and waste; holistic approach; lifecycle assessment; lifecycle analysis; missing data; cereals; developing country

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1. Introduction

1.1. Problem Statement and Objectives of the Study

Reducing food loss and waste (FLW) is crucial to achieve sustainable development goals and can address food security, mitigate climate change, improve economic growth, and preserve natural resources [1–8]. Among all food items, reducing waste and loss of wheat and bread is particularly important due to their essential role in providing sustenance to a significant portion of the world's population. Wheat is among the four main crops that account for half of the global production of primary crops [9]. Wheat is an important source of protein, fiber, and other essential nutrients that are necessary for maintaining good health, providing a significant source of calories and nutrients for millions of people [10]. In addition to the nutritional benefits, wheat and bread play an important cultural and social role in many societies [11]. Moreover, wheat has important industrial implications, such as in manufacturing food additives and as a feedstock for green chemistry [12].

According to the Food and Agriculture Organization (FAO) [13], in 2020, global wheat production reached over 760.9 million tonnes, accounting for over 8% of the total global crop production. The global wheat flour market is forecasted to expand from

USD 160.66 billion in 2021 to USD 210.77 billion by 2028 [14]. Moreover, wheat and bread production has a considerable carbon footprint, and reducing their loss and waste can help mitigate the greenhouse gas emissions associated with their production and transportation, making it an essential step toward combating climate change. Safa and Samarasinghe [15] found that total CO_2 emissions from wheat production in Canterbury, New Zealand were 1032 kg CO_2/ha. In a study in southern Italy, Bux and Amicarelli [16] found that the primary production of durum wheat is responsible for the emission of 399–441 kg CO_2/ha and 339–374 kg CO_2/ha in conventional and organic farming, respectively. A lifecycle assessment (LCA) study on 21 different types of bread consumed in the European Union found that the global warming potential of 1 kg of bread ranges from 0.5 kg CO_2eq/kg to 6.6 kg CO_2eq/kg [17]. A study conducted by Chiriacò et al. [18] revealed that the carbon footprint of 1 kg of wholemeal bread was between 1.18 kg to 1.55 kg CO_2eq.

Iran is a major wheat producer, providing income and employment to millions in its agricultural sector. The wheat production of Iran in 2020 reached 15 million tonnes (ranking 13th globally), which comprised around 20% of its total crop production of 74.4 million tonnes, whereas the country imported 1,181,600 tonnes of wheat and did not export any [13]. This underscores the critical role of wheat in sustaining Iran's domestic food supply and supporting its agricultural sector. Around 43% of the agricultural lands in Iran are occupied for wheat production, accounting for over 55% of the arable lands used for the production of annual plants [19]. The total greenhouse gas emissions of rainfed wheat production in Kohgilouye Boyer-Ahmad province in southwestern Iran was estimated at 280.57 kg CO_2eq/ha by [20]. A study in Bojnourd in northeastern Iran revealed that the production of 1 kg of irrigated and rainfed wheat is responsible for 1.22 and 0.72 kg CO_2eq, respectively [21].

Wheat and bread are subject to significant levels of loss and waste throughout the food supply chain. After fruits and vegetables, cereals (including wheat), with around 30%, have the highest share in global FLW [22]. However, data on FLW are often scarce, incomplete, or inconsistent, especially in developing countries [23,24]. The availability of accurate data on FLW is essential to develop effective strategies and measure their impact [25,26], as well as to raise awareness among stakeholders and consumers [27]. In a country such as Iran, where the reliance on wheat as an essential staple commodity is high, and its production has a significant environmental impact, there is an urgent need for accurate quantification of loss and waste along the wheat and bread lifecycle (WBL) to plan more effective measures to reduce them and increase production efficiency. It is, therefore, necessary to first recognize the structure of WBL through a holistic approach, pinpoint where loss and waste occur the most, and identify gaps in available data and knowledge.

Fars province is one of Iran's major wheat production regions and is essential to the country's overall wheat and bread industry. Located in southwest Iran, Fars province has a favorable climate and fertile soil well-suited for wheat cultivation. Fars province is responsible for producing a significant portion of Iran's wheat. Despite being ranked 11th in terms of the area under wheat cultivation, Fars is the second-largest wheat producer across Iran's 31 provinces, with an annual production of about 1.2 million tonnes, accounting for over 8% of the total wheat production [19]. Therefore, understanding the extent and causes of wheat loss and waste in Fars province can help inform targeted interventions and policies aimed at reducing these losses and promoting more sustainable wheat production practices. With its significant contribution to wheat production in Iran, Fars province holds great potential to influence the country's food security; hence, a thorough examination of loss and waste throughout the WBL in this region is essential.

This study adopts a qualitative approach to map the WBL in Fars province with a cradle-to-grave perspective, aiming to identify gaps in data and knowledge. By examining various stages of the WBL, including production, processing, distribution, consumption, and disposal, the study aims to identify areas where loss and waste occur, as well as to explore their underlying causes. Furthermore, the present study intends to investigate how material flow data at each WBL stage are recorded, as well as to evaluate their potential availability for calculating loss or waste at each stage. This study implements value stream mapping (VSM) methodology to provide a detailed understanding of the complexities of the WBL in Fars province to address the research objectives. The study's findings are expected to provide valuable insights into which areas necessitate additional research and where quantification of loss and waste amounts is required.

1.2. The Background and Implications of Value Stream Mapping

In order to prevent the omission of significant food industry stakeholders, it is crucial to adopt a holistic perspective of the food lifecycle and implement mapping approaches that address FLW in a comprehensive and integrated manner [28]. VSM is a lean manufacturing tool used to visualize the flow of materials and information within a production system, providing a holistic yet detailed perspective [29]. However, in recent years, the application of VSM has been extended beyond the realm of manufacturing to include the analysis of supply chains and products' lifecycles [30,31].

VSM approaches are also increasingly used in LCA studies to evaluate the environmental and economic impacts of FLW. Vinodh et al. [32] and Hartini et al. [33] have proposed practical frameworks for integrating LCA and VSM to identify activities and sources of problems in terms of economic, environmental, and social aspects. Salvador et al. [34] presented a similar model that prioritizes action measures based on environmental preference, economic feasibility, and ease of implementation. VSM provides vital information required for goal definition, scope design [35], and the assessment of environmental impacts in LCA studies [36]. Moreover, integrating VSM and LCA provides decision-makers with an accurate perspective, allowing them to prioritize action measures to adopt more environmentally friendly and economically viable practices [34].

VSM has implications in circular economy studies as well. Circular economy studies focus on reducing, reusing, and recycling materials to maximize efficiency, minimize waste, and promote sustainability [37]. Using VSM, researchers can identify areas where materials are being wasted or inefficiently used, allowing for targeted interventions to improve the circularity of a system [38]. For example, Galvão et al. [39] implemented VSM to propose a circular business model framework that connects value streams within circular business models and their ecosystems. Mangers and Plapper [40] introduced a novel VSM model that takes a holistic approach to assess interrelated processes and identify barriers to achieving a circular flow of resources.

Adopting VSM in agri-food studies and FLW research carries significant implications. A holistic view of the food lifecycle through VSM recognizes the complexity of FLW that involves multiple actors, stages, and factors [41], enabling coordinated and collaborative efforts from different stakeholders [42]. In a systematic review, Steur et al. [43] found that VSM is a tool well-suited to identify and reduce FLW at different stages of food supply chains. An extended version of VSM was suggested by Bait et al. [44] to aid in the development of simulations for assessing management decisions on waste reduction. Kazancoglu et al. [45] utilized VSM to observe the material flow in turkey meat production in Türkiye to explore loss and waste drivers. In a study in Zimbabwe, Goriwondo et al. [46] demonstrated how VSM can be used to reduce bread waste.

Implementing VSM can help identify the different stages, causing factors, and their interactions that contribute to FLW, as well as the most effective entry points for interventions [43]. Portraying various stages of the food lifecycle through VSM allows for identifying areas where data is missing or incomplete [47] and prioritizing research efforts to fill these gaps. Furthermore, the ability of VSM to depict the intricacies of the food lifecycle enables improved development of FLW scope and definitions based on standardized global classifications [48]. This mitigates the issue of data incomparability, which primarily arises from variations in food lifecycle structures across different geographical contexts [49].

2. Materials and Methods

2.1. Sampling Strategy and Survey Development

The survey was conducted in October 2018, and judgmental sampling was used to select information-rich individuals who were actively engaged as actors in WBL. This sampling strategy was chosen because it allows for selecting individuals with the most relevant expertise and knowledge in the subject of study and also helps ensure that the key actors involved at every stage of the process, in this case, WBL, are included [50]. A total of 14 participants attended the interviews voluntarily and were informed at the onset that their data would be treated confidentially and that the results would be reported anonymously. Nonetheless, none of the practitioners employed at milling factories were willing to participate in this survey. The study intended to include the bakeries that produce the most commonly consumed wheat bread in Iran, chosen based on the food guidelines of the Iranian National Standardization Organization (INSO) [51,52]. The bread types are classified into two groups: traditional bread, with lavash and sangak being the most widely consumed types [11,53], and non-traditional bread, which include bulky oven bread types such as baguette, hamburger bun, sandwich, bread roll or broetchen, toast, and non-traditional barbari. Detailed characteristics and specifications of these bread types are provided by Ghaziani et al. [53], INSO [51,53], and Karizaki [11]. Table 1 anonymously lists the participants based on their role in WBL. Hereafter, the participants will be identified by their IDs from Table 1 to maintain confidentiality. For instance, the participant who held the chief executive officer (CEO) position at the local agricultural cooperative will be referred to as Co-op CEO.

Table 1. List of participants according to their professional roles.

Participant's ID	Role
Seed producer	The owner of a plant breeding and seed production company.
Farmer 1	A farmer with large-sized (over 70 ha) land.
Farmer 2	A farmer with small-sized (10 ha) land.
Farmer 3	A farmer with small-sized (10 ha) land.
Farmer 4	A farmer with small-sized (20 ha) land.
Co-op CEO	The chief executive officer (CEO) at a local agricultural cooperative and a farmer with medium-sized (50 ha) land.
GCCS inspector	The technical inspector of Grain Company and Commercial Services (GCCS) of Fars province.
Agri. Mins. Officer	A high-ranking officer at the Ministry of Agriculture.
Foodservice 1	The owner of a fast-food restaurant.
Foodservice 2	The head chef at a hotel.
Baker 1	The manager of a traditional bread (sangak) bakery.
Baker 2	The manager of a traditional bread (lavash) bakery.
Baker 3	The manager of a traditional bread (sangak) bakery.
Baker 4	The owner of a non-traditional bread bakery.

The framework presented in Figure 1 provided a step-by-step guide for conducting interviews to gather detailed information about WBL. The interview framework was developed following the cradle-to-grave approach recommended in the FAO's 2013 report on the environmental impacts of FLW [22] to ensure comprehensive coverage of all stages of WBL. Additionally, the questions were conceptualized through consultations with a senior agronomy scientist from the region and the director of the Department of Cereal Production at the Agricultural Organization of Fars.

As the first step of the interview framework, VSM was applied to map WBL based on a contextual modification of the diagramming method described by Pretty et al. [54]. Accordingly, participants were given drawing supplies to interactively develop a value stream map representing the WBL in Fars. The map was created on a large sheet of paper, and participants were encouraged to use different colors to highlight the various stages of WBL. Specifically, the drawing exercise aimed to illustrate the processes and material flow involved in the cultivation, harvest, transport, storage, milling, baking, distribution, and consumption of wheat and bread in Fars. Follow-up questions were also asked to clarify and complement the information regarding the structure of WBL. The final value stream map presented in Section 3 was the result of merging the individual diagrams.

Value stream mapping

Q: Please expand on your understanding of the entire wheat and bread lifecycle.

Q: Where does the wheat material come from before your lifecycle segment?

Q: What happens to products after your lifecycle segment?

Loss and waste hotspots

Q: At which points of the lifecycle is wheat lost, or is bread wasted the most?

Q: What are the main reasons for loss and waste at these points?

Material flow inventory

Q: At which points of the wheat supply chain are material flow inputs and outputs measured/ recorded?

Q: Are you obliged to report the material flow inventory to any organizations or authorities?

Q: How and where are the material flow inventory data stored?

Waste management

Q: How do you manage wheat or bread loss and waste?

Q: What do you know about what would eventually happen to the lost wheat material or wasted bread?

Figure 1. Interview framework; Q = question.

Furthermore, open-ended questions were asked to identify loss and waste hotspots, as well as to collect information about the material flow throughout WBL. Specifically, the questions were intended to determine how material inputs and outputs were recorded at each WBL stage and evaluate the potential availability of data for calculating loss and waste. Additionally, the questions aimed to investigate how the loss or waste materials were handled and to uncover the destination of materials designated for disposal. In this study, the term 'material' is defined as referring specifically to wheat and bread and excludes any other substances or matters. Examples of questions asked at different steps of the interviews are provided in Figure 1. The interviewers encouraged active engagement from the participants during the discussions, allowing them to argue and elaborate on their responses.

2.2. Data Analysis

The qualitative open-ended survey data analysis explained by Fielding et al. [55] was implemented to systematically code and analyze the interview transcripts using MAXQDA software [56]. MAXQDA is designed to aid researchers in analyzing qualitative data, such as interview transcripts, survey responses, and open-ended survey questions. The software offers various functionalities and benefits, including the creation of codes, categories, and themes to identify patterns and relationships within the data. By utilizing both manual codings by the researcher and automated codings via natural language processing algorithms, MAXQDA enabled an efficient and effective analysis of qualitative data, uncovering essential patterns and themes related to WBL. The participants' statements during the interviews were considered a direct representation of their understanding of the questions. Any quantitative information provided by the interviewees was excluded from the study with the assumption that the sample is not representative of the stakeholders in WBL. The interviews were transcribed and translated from Persian to English by the first author, and structural coding was applied to the participants' answers based on the interview framework (see Figure 1). The creation of sub-codings continued as long as no new classification could be found.

3. Results and Discussion

3.1. Overview

In this section, the outcomes of the interviews are presented within the survey framework and discussed against the existing research on wheat production and FLW. The results are presented as an interpretation of the participants' statements, along with direct quotations of their answers. The procedures explained in this chapter summarize the participants' responses. Complementary information is cited from the literature. The first subsection provides detailed information about the WBL and material flow in Fars province. The following subsections expand on the hotspots of wheat loss and waste, material flow data inventory, and the availability of loss and waste data at different segments of the WBL in Fars.

3.2. Wheat and Bread Lifecycle

Figure 2 demonstrates a schematic overview of material flow and production process throughout the WBL in Fars province. The following subsections present a cradle-to-grave description of WBL, explaining the details of Figure 2.

The Agricultural Research, Education, and Extension Organization (AREEO), a subbranch of the Ministry of Agriculture, is responsible for seed certification and supplying seeds to wheat producers [57]. AREEO produces the nucleus breeds for private breeding companies to cross-breed and produce hybrid cultivars and, eventually, certified seeds [58]. The seeds obtained from the propagation of hybrid cultivars are called certified seeds and are the last class of seeds in the seed certification program [59].

> *"Until 12 years ago, AREEO used to produce certified seeds. Nowadays, AREEO focuses only on research and producing nucleus breeds and delegates the rest of the breeding program to private companies . . . . We recently received breed 2, from which we produced 60 kg of breed 3 and, finally, 200 kg of the maternal line. Certified seeds are produced by [propagating] maternal seeds."* (Farmer 1)

Certified seeds are available to farmers in large quantities for the mass production of bread wheat [59]. Bread wheat refers to the product that is eventually used to produce bread. The supply of certified seeds is essential for ensuring high productivity, particularly in small-scale farms [60].

> *"We plant certified seeds supplied by AREEO. We purchase the seeds from the local AREEO subsidiary."* (Farmer 4)

The private breeding companies outsource part of the seed production program to selected farms with facilities suitable for seed production. This procedure is commonly known as contract seed production and is used to ensure that the seeds are produced in large quantities and meet the certification standards [61]. One of the potential benefits of contract seed production is the emergence of participatory plant breeding (PPB), a system that involves the direct engagement of farmers in the breeding procedure [62].

> *"The seed-producing companies sign contracts with some farmers. They give maternal seeds to farmers, and farmers produce certified seeds. The certified seed is used to produce bread wheat."* (Co-op CEO)

Contract seed production provides farmers with outstanding performance with the opportunity to earn extra money. Additionally, PPB leads to increased efficiency and societal benefits [63,64]. By working together with farmers and incorporating their feedback, breeders can create new varieties that are well-suited to local conditions and fulfill the requirements of both farmers and consumers [65]. The farmers produce seeds by propagating hybrid cultivars and sell them back to breeding companies or AREEO at a higher price than bread wheat.

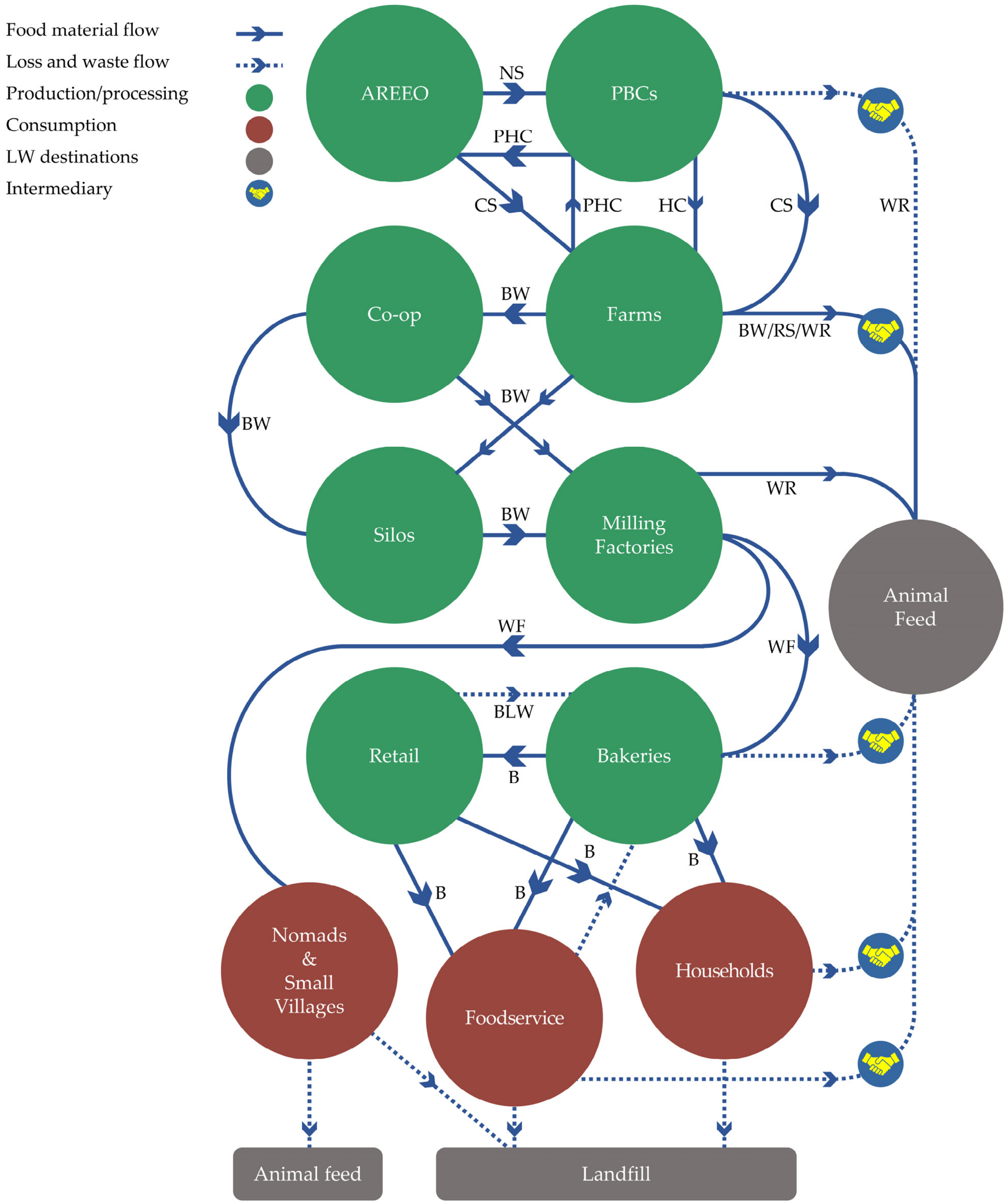

Figure 2. Schematic presentation of wheat and bread lifecycle in Fars province. NS = nucleus seed (the best quality seed with high genetic purity used as the foundation for producing subsequent generations of seeds); HC = hybrid cultivar (produced by crossing two or more genetically distinct nucleus parents to create offspring with desirable traits); PHC = propagated hybrid cultivar (seeds that are produced abundantly by propagating hybrid cultivars); CS = certified seed (propagated hybrid cultivar seeds after being winnowed and threshed, and then treated with pesticides and fungicides, and officially certified); WR = winnowing residues (the byproducts left after winnowing wheat); BW = bread wheat (wheat intended for bread production); WF = wheat flour; B = bread.

"We produce two types of wheat: one for seed using the hybrid cultivars supplied by breeding companies and another for consumption produced from certified seeds. . . . The price of the seeds is normally 20–25% more than bread wheat" (Farmer 1)

AREEO selects farmers who meet the criteria after inspecting their farms and provides instructions to produce seeds. This process ensures that the seeds produced meet the required quality standards [66].

"The cultivation for seed production is executed more carefully compared to bread wheat. For example, AREEO requires farmers to test the soil for efficient fertilization." (Co-op CEO)

The farmers return the seeds to private companies or AREEO. The companies or AREEO grade a seed batch based on the besatz content and pay the farmers accordingly. According to the International Association for Cereal Science and Technology (ICC) [67], the besatz of wheat refers to any material in a wheat sample other than the intact, perfect grains. The Iranian authorities use the same grain grading system [68,69]. The two classifications of besatz of wheat are grain dockage and black dockage, also known as useful and non-useful Besatz [67]. Grain dockage includes the undesirable forms of wheat grains, e.g., broken, shriveled, sprouted, damaged, or grains of other varieties or crops [67]. Any other extraneous material and impurities, such as weed, ergot, soil, chaff, and straws, are known as black dockage [67]. The seeds that do not meet the minimum quality criteria regarding besatz will be rejected and sold as animal feed.

"If the seeds produced by farmers contain high soil and weed dockage or too many broken grains, the companies or AREEO reject them, and farmers sell them as normal wheat." (GCCS inspector)

Traditionally, farmers used to produce their own seeds, but currently, they prefer to purchase high-performance certified seeds.

"I purchase the certified seeds distributed by the rural cooperative. My father used to reuse the good wheat grains as seeds for the next year's cultivation. Or if a neighboring farmer had good seeds worth more than bread wheat, my father used to make a deal with them to replace their good batch with bread wheat and get their good seeds for cultivation. The other farmer was selling the bread wheat batch at a normal price, and my father would pay them the difference. The good grains were sprayed with a certain pesticide and stored to be used as seeds in the following year. I do not do that." (Baker 3)

Moreover, because seed production requires extra attendance, not all farmers are willing to participate in the seed production program.

"I could also produce seeds, but they [breeding companies or AREEO] do not buy them because they [the seeds] include too much soil and weed impurities." (Farmer 3)

AREEO certifies the seeds after they are threshed and sprayed with pesticides. This seed treatment helps to prevent pests and diseases from infecting the seeds and the young plants that emerge from them, preventing yield and quality loss [70]. The residues derived from the threshing, e.g., broken seeds, straws, leaves, and weeds, are sold as animal feed through intermediaries. Intermediaries are private buyers who purchase agricultural products or byproducts at a negotiated price and sell them to other parties, usually to feed factories or livestock farms. By linking smallholder farmers with traders and feed markets, intermediaries can help improve farmers' commercialization opportunities while utilizing byproducts that are unsuitable for human consumption, leading to reduced biomass loss [71]. These intermediaries purchase not only threshing residues or uncultivatable seeds but also bread wheat. However, the primary buyer of the bread wheat is the government through agricultural cooperatives. Oligopolistic state trade of wheat is also common in other countries, such as Ethiopia [72], China [73], Kazakhstan, and Russia [74].

Farmers cultivate wheat in the Fars region through rainfed or irrigation. Their chosen method depends on the available water resources, such as a well, qanat, spring, or dam.

"Farmers usually do not irrigate the field if it rains about 30–40 mm after sowing." (Co-op CEO)

The farmers sow wheat at the end of summer (around September and October) and irrigate the land until two to three weeks after germination at the beginning of winter and before the dormancy starts. Dormancy is a survival mechanism that refers to a period of reduced metabolic activity and growth, which enables the plant to conserve resources until environmental conditions allow for resuming growth and development [75]. The crops enter their vegetative phase as the weather warms up at the end of February. At this stage, pesticide implementation and fertilization occur at intervals of a few days. Nitrogen fertilizer should be applied after dormancy in order to achieve optimal yield and protein levels [76]. Farmers again irrigate the land if the precipitation is inadequate before they harvest the crops at the beginning of summer, around mid-June and July.

"We harvest [wheat] in June or July." (Farmer 3)

Once harvested, the wheat is transported to agricultural cooperative purchasing centers. From there, it is shipped to government-run storage facilities, i.e., silos.

"We sell our [wheat] products to the cooperative, and they send them to silos." (Farmer 2)

Depending on the logistics, some farmers may ship their products directly to silos.

"We sell the product directly to silos. Sometimes we sell to the cooperative." (Farmer 3)

"We deliver the yield to the cooperative." (Farmer 4)

The cooperatives and silos test the purity of wheat grains to determine the price based on the purity table. The purity table indicates wheat prices according to the besatz content and sunn pest-damaged grains using random sampling by grain spears [68,69]. Sunn pests include a number of insects belonging to the sub-order *Heteroptera*, which have been identified as a severe threat to wheat and other cereals in the Near and Middle East and a large portion of the former Soviet Union [77]. The presence of sunn pest-damaged grains in a wheat bulk, even as low as 2%, causes a decline in the physical, chemical, and technological quality of wheat [78]. After quality evaluation, cooperative purchasing centers or silos weigh the delivered wheat cargo and issue a payment remittance.

"The wheat is delivered to the cooperative's purchasing center. It is weighted here, and the amount is recorded in the online system under the farmer's name. The online system is connected to the Keshavarzi Bank (Bank of Agriculture), GCCS, and the Ministry of Industry, Mine, and Trade." (Co-op CEO)

"The cooperative records the yield. They also assess the besatz content to determine the price based on their tables. They give us a receipt with all the details and record everything on a computer." (Farmer 4)

The cooperatives are public joint stock companies with a stewardship contract with GCCS. Each cooperative is run by its members, who are usually the farmers in a distinct region.

"Our cooperative has 2000 members (shareholders) from 14 surrounding villages." (Co-op CEO)

These cooperatives are responsible for testing and delivering wheat, storing and safekeeping it, and shipping it to silos or milling factories, depending on the orders from GCCS.

"From the moment producers deliver wheat to us, we are responsible for storing and safekeeping the wheat and later loading trucks and sending it to its designated destiny, which GCCS of Fars [province] determines. The destinations can be a milling factory or a silo . . . . GCCS uses an online system to tell us where to distribute wheat." (Co-op CEO)

The government pays the total value of the wheat cargo to the farmer. The Council of Pricing and Implementation of Supportive Policies for Basic Agricultural Products of the Ministry of Agriculture annually determines the procurement price for wheat—which literally translates to "guaranteed price"—before each cultivation season [79]. Wheat procurement price refers to the price at which the government or authorized agencies commit to purchase wheat from farmers [80]. Such a trading strategy has also been implemented in other countries such as Egypt [81], Pakistan [82], and India [83]. Implementing procurement prices can improve the economic situation of farmers and promote agricultural productivity [84]. However, the impacts of procurement price may vary depending on a range of factors, such as the design and implementation of the policy, the specific crop and region, and the economic context [85]. Therefore, policymakers must carefully evaluate the potential trade-offs before determining prices and contractual terms.

After farmers deliver the wheat they harvested to the purchasing centers, it may take up to three months for them to receive payment.

> *"The payment takes around two months. I sold my last batch at the end of June 2018. The payment took two to three months."* (Farmer 3)

Cargos with besatz and sunn pest-damaged grains more than the maximum legally tolerated level determined in the purity table and water content higher than 12%—with the exception of distinct humid regions, in which the limit is 14%—are rejected [68,69]. Wheat grains with high moisture content are prone to fungal infection [86]. Wheat storage for up to nine months requires a maximum moisture content of 14%, while for longer-term storage exceeding nine months, the moisture content should not exceed 12% [87]. Assuring the quality of wheat that enters the human consumption chain is crucial for maintaining high technological performance while protecting consumer health, sustaining international trade relationships, improving market competitiveness, and promoting agricultural productivity [88]. Farmers sell the wheat rejected due to quality reasons as animal feed through intermediaries.

As mentioned before, farmers may also sell bread wheat as animal feed to intermediaries besides the cultivation byproducts, e.g., chaff and straw, and seeds or wheat gains rejected due to lack of quality.

> *"Not all the wheat the farmers produce is purchased by the cooperative. Some private buyers pay a negotiated price to the farmers . . . . These buyers either sell to the milling factories or the silos."* (Co-op CEO)

> *"Some intermediaries buy [bread] wheat to sell to the livestock feed-producing factories or directly to livestock farms. They normally have storage and weighing facilities."* (Farmer 2)

Using wheat as animal feed can negatively affect food security by decreasing food availability and increasing food prices [89]. On the other hand, using wheat byproducts for animal feed, such as middling, can have some positive outcomes, including reduced CO_2 emissions due to the shift of application [90]. The incentive for selling bread wheat to intermediaries is mainly economic. Transacting with intermediaries is less time-consuming than with the government.

> *"They [intermediaries] normally pay less than the government, but they pay right away."* (Co-op CEO)

> *"[With intermediaries,] there is no waiting time to weigh farmers' products, and the payment is instant, although at a bit lower price."* (Farmer 2)

Although negotiated price usually is less than the government's procurement price, depending on the market climate in the feed industry, intermediaries may sometimes pay more than what the government pays for bread wheat.

> *"[Currently,] intermediaries pay more than cooperatives or silos . . . . They sell the wheat for livestock feed at a slightly higher price."* (Farmer 3)

Although procurement price is fixed and controlled by the government, because animal feed is traded in a free market, animal feed prices fluctuate depending on supply and demand, weather conditions, government policies, transportation costs, and global market trends. That is why farmers would sometimes benefit more if they sell their products as animal feed.

Despite the procurement price being fixed and regulated by the government, animal feed prices remain subject to free market fluctuations. In a free market, food and feed prices are constantly changing due to factors such as supply and demand, weather conditions, government policies, transportation costs, and global market trends [91]. As a result, farmers may benefit more by selling their products as animal feed. Therefore, some farmers may retain part of their harvested wheat to later sell at a higher price to intermediaries.

> *"Normally, farmers sell wheat to silos or the cooperative right after harvest. They also store part of their harvest, which they later sell to intermediaries for livestock feed. Some farmers build a storage room, usually made of cement and isolated with tiles from the inside."* (Farmer 3)

Nonetheless, farmers sell most of their wheat to the government. One reason is that not all can afford a storage room, and the on-farm storage rooms have relatively limited space. A suitable storage room for wheat must have regulated temperature and humidity, along with appropriate ventilation and isolation, to prevent insects and animals from damaging the wheat [92]. Due to the demanding and complex nature of wheat storage, most farmers tend to sell their wheat to the government once it is harvested to reap some economic gain, despite the delayed payments.

> *"Almost 90% of the farmers are not able to store their yield. Therefore, they need to sell their product as soon as possible to gain some revenue to compensate for their costs for at least nine months."* (Co-op CEO)

Moreover, farmers can benefit from governmental support for the upcoming cultivation season based on their last season's performance.

> *"The advantage of selling to silos or cooperatives is receiving subsidized seeds, fertilizers, and pesticides. Moreover, our personal storage room is limited."* (Farmer 3)

> *"It is sometimes better to sell to the cooperative [or to silos] because we can buy fertilizer and pesticides with a discount for the next year in proportion to our current harvest amount."* (Farmer 2)

Additionally, although regulations change according to circumstances, farmers may be legally obliged to sell their wheat only to the government during certain times.

> *"[Currently,] supplying wheat outside the governmental supply chain is against the law, even to individuals."* (GCCS inspector)

Wheat is stored at the cooperative's purchasing centers for a relatively short time and shipped mainly to silos and, as explained before, sometimes to milling factories.

> *"We receive wheat starting from June 10 until around July 1. We store the wheat (about 6000–8000 tonnes) here, usually around 20–30 days. In rare cases, we store wheat here for up to three months."* (Co-op CEO)

Afterward, wheat is stored in silos and supplied to milling factories, depending on the demand.

> *"Wheat remains in silos and will be distributed based on demands throughout the year. The silos are organized by the government."* (Co-op CEO)

Silos are proven to be the best means of wheat storage [93]. GCCS is the custodian of silos and is responsible for supplying wheat to milling factories through an online platform.

> *"The GCCS of Fars uses the online system to tell us how to distribute wheat. For example, the GCCS of Fars would give us transportation permission for shipping 2000 tonnes of wheat to [company's name] milling factory."* (Co-op CEO)

Milling factories store wheat and gradually process it over the course of a year. The wheat in silos includes besatz and needs to be threshed at milling factories. The threshing residues are sold to intermediaries for animal feed.

> *"The grains in silos are not threshed and include soil and weed residues or broken grains."* (Farmer 1)

Milling factories grade the wheat grains based on their quality and pack them for shipment. Wheat grading is determined by factors including test weight, moisture content, protein content, foreign material, damaged kernels, and other relevant characteristics [94]. GCCS, together with the Bakers Union, are responsible for setting wheat flour quotas for bakeries based on their needs and production outcome. Milling factories ship the bakeries' flour quota over time. All such transactions are executed through the GCCS website.

> *"Milling factories separate the bran from the grains and grade them based on the existing standards. These factories distribute wheat flour to local or industrial bakeries based on quotas designated by GCCS Fars province and the union of bakers."* (Farmer 2)

> *"The government controls the distribution through an online platform, and bakers receive wheat flour based on their quota. . . . Our baking factory produces up to one thousand bread pieces per day. This amount is produced from our wheat flour quota."* (Baker 4)

> *"We order online based on our quota. The milling companies ship flour to each bakery based on online orders. We also pay transportation costs and store flour here."* (Baker 3)

> *"We order wheat flour via a website. Each bakery has a quota for each month. We store the flour here and prepare the dough, and then bake the bread."* (Baker 1)

The use of digital platforms within the WBL in Fars has the potential to not only increase overall efficiency but also enhance food traceability, contributing to food safety and improved economic transparency [95]. Additionally, the digitalization of food supply chains allows for identifying the hotspots of FLW and reducing it [96].

Milling factories may sell their surplus production through the free market.

> *"The milling factories supply wheat flour either to the free market via whole sellers or directly to bakers."* (Baker 4)

Parts of the flour are shipped from the milling factories to nomads and small villages in the neighboring region for their consumption.

> *"The nomadic families and households in small villages also have flour quotas to bake their own bread."* (Farmer 2)

Bakeries produce bread and supply it to end consumers via foodservice or supermarkets or directly to households.

> *"Our buyers are supermarkets, household consumers, and fast food stores . . . . We sell bread to supermarkets in dated plastic packs . . . . Household consumers and fast foods buy fresh bread daily."* (Baker 4)

In the event that the dough is ruined, the bakers repurpose it into dry bread, which they then sell to intermediaries as livestock feed.

Foodservice enterprises purchase from different types of bread producers based on their needs.

> *"We have a contract with an industrial bakery. The bread comes daily in box packs of 40 pieces."* (Foodservice 1)

> *"We buy our bread from a local bakery . . . . We use the fresh bread for the day and store the surplus in a freezer."* (Foodservice 2)

3.3. Loss and Waste Hotspots and Data Gaps

This subsection outlines details on the hotspots of loss and waste, along with the availability of relevant data. The participants reported that loss and waste are likely to occur at each stage of WBL. However, the losses incurred at the stages between the farm and the retail stage are limited. On the other hand, significant losses and waste of wheat and bread occur at the primary production and consumption stages.

Wheat loss at purchasing centers, silos, and milling factories is kept to a minimum.

> *"The loss in the cooperative's purchasing center is minimal. I am personally liable for any loss that may happen here . . . . Silos have a minimal amount of loss. For example, the nearby Silo in Sivand has a capacity of 70,000 tonnes. When the silo is fully loaded, it can preserve between 69,500 and 69,700 tonnes [about 0.07% loss]. The rest could rot or absorb too much moisture, which is insignificant."* (Co-op CEO)

> *"Once wheat enters milling factories, there is no loss. All parts of the wheat will be sold. For example, the wheat bran separated to produce white flour for confectioneries will be sold for animal feed."* (Farmer 1)

The main reasons for food loss at purchasing centers and silos may include inadequate management, inappropriate handling and storage practices, and restrictive regulations [97]. In the case of cereal grains, high moisture content and inadequate management practices can lead to substantial food loss in silos caused by mold infestation and in milling factories due to spoiled raw material [98]. However, high moisture content does not seem to be a significant issue in arid areas such as Fars province.

> *"The highest loss in storage can happen due to high water content, and because wheat has low water content in Iran, this loss is limited."* (Agri. Mins. Officer)

Under normal circumstances, the amount of wheat or bread lost during transportation between different lifecycle segments is negligible.

> *"Transport loss is limited unless the trucks are not sealed well, which does not happen often."* (Farmer 4)

A study by Melese et al. [99] in Ethiopia revealed that there was a relatively small wheat loss (0.17%) during transportation from the farm to the threshing field. Additionally, according to the FAO [100], losses during the transportation of wheat do not exceed 1% due to well-sealed transportation containers and careful handling of the crops during transportation. According to a study by Łaba et al. [101] in Poland, 1.7% of the total cereal supply intended for human consumption was lost during transportation from the field to the purchase centers or processing units.

The interviewees employed at bakeries claimed that very little loss and waste occur at their workplace. The bakeries tend to repurpose expired or stall bread to avoid waste.

> *"We do not experience any flour loss, and we are able to sell all the bread we produce. However, if the dough is ruined, we have to convert it into dried bread and sell it to intermediaries who eventually sell it to livestock farms."* (Baker 1)

> *"We usually sell 100% of our white bread production, although other bread types may experience some loss. During certain conditions, such as heavy rain or cold weather when we have fewer customers, we may not sell 100% of our production. Consequently, we end up with some unsold bread which we typically dry and sell as breadcrumbs."* (Baker 4)

Likewise, the amount of bread waste at food stores and supermarkets is minimal, and bread products that pass their expiration date are sold as animal feed through intermediaries. Bread waste is often considered a potential livestock feed source due to its high carbohydrate content and availability in large quantities [102]. However, using bread waste as animal feed is not without its hazards. One of the main concerns is the potential presence of aflatoxins [103], which are toxic substances produced by certain types of fungi [104]. Aflatoxin contamination occurs in bread as a result of fungus growth [105]. The use of bread waste as animal feed in Iran has led to indirect contamination of food and animal products [106,107]. For example, Mokhtari et al. [108] detected levels of aflatoxin in milk distributed in northwest Iran that can pose a risk of liver cancer to consumers.

Aflatoxins are highly toxic and carcinogenic, and the ingestion of contaminated feed by animals can result in various health complications, and the potential transfer of aflatoxins to humans through contaminated animal-derived food products poses a significant health risk [109]. The toxic effects of aflatoxins can impair protein synthesis, coagulation, weight gain, and immunity, leading to further health complications [110]. Prolonged exposure to elevated levels of aflatoxin can lead to a progressive decline in health in humans and animals, resulting from liver damage and immune suppression [111]. In light of the foregoing, while utilizing bread waste as animal feed may promote the circularity of WBL, it also entails substantial health hazards and raises concerns about food safety. Therefore, careful monitoring and management are required to ensure that bread waste used as animal feed is free of contaminants and safe for consumption by livestock.

> *"The main reasons for bread loss in supermarkets are expiration date and stale bread. Supermarkets typically sell their bread waste to bread waste recyclers, who in turn sell it as livestock feed."* (Baker 4)

Despite the limited loss and waste at the WBL stages mentioned above, participants identified farms, foodservice, and households as the major hotspots for wheat and bread loss and waste.

On-farm wheat loss is considerable, as stated by the participants, primarily due to the excessive use of seeds during planting, pest and weed infestation, and inefficient harvesting practices.

> *"The on-farm loss is due to seed overuse, pests and harvesting."* (Seed producer)

Farms are a primary contributor to food loss due to inefficient cultivation, harvesting, and handling practices [112,113].

The results also showed that considerable food waste happens in the foodservice and hospitality sectors.

> *"Bread waste happens in restaurants due to consumers having leftovers or passing expiration dates and staling."* (Baker 4)

Restaurants and other foodservice establishments generate a significant amount of waste, mainly due to their inefficient operating practices and policies, as well as social norms that lead to excessive purchasing and consumption of food [114].

The participants identify households as the primary point of bread waste along WBL.

> *"The highest bread waste amount is in households because the consumers do not manage their grocery shopping appropriately."* (Baker 4)

It is well-established that households are among the biggest contributors to food waste [24]. However, due to its multifaceted complexity, household food waste cannot be attributed to a single factor [115]. These factors may include, among other things, packaging [116], food pricing and consumers' purchasing behavior [117], consumers' level of education and their awareness about sustainability attributes of food [118], households' dietary behavior [53,119,120], household's socioeconomic status [53], and consumption recipes [121].

Although the results presented here offer insight into the extent of loss and waste across various stages of WBL, they reflect subjective opinions from the participants. Hence, more precise quantification of these losses is necessary to efficiently monitor and implement loss and waste reduction plans. The following subsection examines the feasibility of measuring waste and wheat loss at different stages of WBL based on the availability of material flow data.

3.4. Material Flow Inventory along the Wheat and Bread Lifecycle

Using color codes, Figure 3 provides an overview of the level of data availability related to the inputs and outputs of wheat and bread across various stages of WBL. However, it must be noted that the data availability level only confirms the existence of the data in their raw form and does not necessarily imply their accessibility. All material flow data, regardless of availability levels, have primarily been recorded for bookkeeping and administrative purposes and, to our knowledge, have not been analyzed to calculate or report loss and waste. Moreover, quantitative material flow data could not be accessed for the present study due to restrictive data ownership policies. Therefore, this article solely relies on qualitative information from interviewees regarding documented data that are available for potentially reporting loss and waste. As a result, quantitative information about the amount of loss or waste cannot be provided with acceptable certainty.

Figure 3. Data availability throughout the wheat and bread lifecycle in Fars province, Iran; [1] no valid data could be found regarding on-farm losses; [2] any movement of wheat and bread between lifecycle segments falls under the purview of transportation.

In Figure 3, green marks indicate that data on the mass amount of wheat is available for individual farms, factories, agencies, or commercial units. This means that the amount of wheat produced or traded by these entities is known and recorded. Yellow marks on the figure signify that data on money transactions due to wheat trades are available for mass units of wheat, which can be converted to the amount. This means that while the exact mass amount of wheat produced or traded may not be known, the monetary value of the traded amount is recorded. The orange markings represent that data on monetary transactions resulting from wheat or bread trades is available, but the transactions do not seem to correspond clearly to the mass amount of wheat or bread. This suggests that although some information regarding monetary transactions of wheat production or trade is obtainable, determining the wheat mass amount may be unclear or complicated. The red markings indicate that data on wheat or bread's input or output quantity, or the monetary transactions resulting from their trades, are not obtainable. This suggests that there is a lack of information about the wheat material flow in these areas.

The study revealed that the material flow at seed supply, farms, purchasing centers, silos, milling factories, and transportation is well-documented and potentially available for calculating wheat loss. The records of material input at bakeries are also accurately recorded in the digital platform of GCCS. However, material output data is only available at bakeries based on the monetary value of bread units sold. The same applies to the material input and output at retail units and the input of foodservice. In the meantime, quantifying the amount of bread sold in the foodservice sector is challenging because bread is sold alongside other food items rather than individual units. Commercial entities also record their trades with intermediaries who act as food waste recyclers for bookkeeping purposes.

> *"We sell expired or stalled bread to intermediaries who sell them to animal farms as feed. We also record the amount we sell to them."* (Baker 2)

> *"We record what we sell to bread recyclers for internal accounting."* (Baker 3)

> *"We sell bread leftover to bread recyclers. They measure the amount and pay us accordingly."* (Foodservice 1)

In the case of loss during production, although material flow is accurately documented, this information alone cannot be used to calculate the on-farm loss amount due to the multifaceted nature of crop production. The outcome of an arable farm depends on multiple factors besides the amount of seed input, including climatic conditions, geographical location, soil conditions, the availability of water, and the choice of plant variety [122]. On the contrary, the production output of a milling factory, for example, is directly proportional to wheat input, although the ratio may differ depending on the specific equipment and technology used in the factory [123]. Similarly, the amount of bread produced from a certain amount of flour is predictable at a bakery based on the baking recipe. Additionally, the acceptable loss level at storage or purchasing centers can be predicted unless an unexpected issue, such as fungal contamination, occurs.

> *The input and output of this purchasing center are accurately recorded. There is weight loss, which is due to losing moisture. We record moisture content both at purchasing time and later at loading time. [In the last measurement], the average moisture content of 12 random samples was 8.9%. The average at the time of loading was 8.1%, which means a 0.8% mass reduction was expected.* (Co-op CEO)

The data on the amount of on-farm loss of cereals is scarce. According to the FAO's 2011 report [113], primary production accounts for approximately 2% and 5–7% of cereals lost in developed and developing countries, respectively. However, Johnson et al. [124] shrewdly observed that almost all reports on on-farm loss rely on approximate estimation without field-level measurement and, at best, are based on questionnaire results from farmers. Farmers' estimation of on-farm loss is often biased and inaccurate [125]. Furthermore, the data at the farm level often lack consistency and accuracy, which makes it challenging to compare and aggregate loss and waste figures across farms and regions [1,124].

The primary data gap exists at the household level, as the amounts of bread households purchase are not documented. Nonetheless, the average amount of bread households consume could be obtained on a regional scale based on macro data on bread supply or households' expenditure information. Yu and Jaenicke [126] utilized food acquisition data to estimate household food waste in the United States, revealing that food waste at the household level in the country is 31.9%. However, this method is subject to high uncertainty due to its reliance on approximations [24]. Additionally, reporting waste figures for individual food items or even food groups may not be feasible.

The only recent primary data collection on household bread waste in Iran was conducted by Ghaziani et al. [127] in the capital of Fars, Shiraz. The study found that 1.8% of the bread households purchase in Shiraz is wasted [127]. Nevertheless, this result may be underestimated due to the method used, which relied on recall questionnaires to determine household waste. Ghaziani et al. [121] carried out an additional study to identify a methodological approach to account for underestimation errors by comparing questionnaire results with lab measurements after replicating consumption recipes. Their research revealed that the estimated waste was underestimated by factors ranging from 1.24 to 1.80, indicating that an estimated bread waste amount of around 3.5% might be more accurate [127].

Generally, self-assessment methods such as recall questionnaire surveys may underestimate the amount of household food waste due to their reliance on individuals' perceptions [23,128–130]. In comparison, approaches that entail physically measuring household food waste may generate more reliable results [131]. Nevertheless, these methods are less commonly employed in practice due to their high costs and labor-intensive nature [132]. The only studies to have measured household bread waste in Iran were conducted by Mirfakhrayi et al. [133] in 1991 and Irani et al. [134] in 2005. The former estimated that 30% of bread was wasted in households, while the latter found that the amount of bread waste varied between 12–16%. Ghaziani et al. [127] compared their own findings with these two reports and explored potential explanations for the relatively large deviation. The possible reasons include differences in waste definitions and methodologies, changes in domestic storage practices, and increased access to freezers in households [127]. Additionally, the study discussed the impact of the 2019 recession on consumer purchasing power, which could have led to more frugal lifestyles and a reduction in food waste. Given the age of the previous estimates [133,134] and their large deviation from Ghaziani et al.'s [127] findings, conducting new research using accurate methods in other locations of the country is necessary to provide a realistic estimation of household bread waste in Iran.

3.5. Limitations of the Study and Future Research Directions

This study employed a judgmental sampling strategy to select participants with specific expertise and knowledge of the WBL in Fars. However, while judgmental sampling can be useful in certain research contexts, it is essential to be aware of its potential biases and limitations. Judgmental sampling can introduce bias and subjectivity due to conditional information search strategies, potentially leading to limited external validity, poor reliability, and non-representative samples [135–138]. Nonetheless, judgmental sampling is a useful technique in multifaceted situations where classical measurement theory assumptions are invalid, particularly in quality improvement studies [138], and can be more representative and accurate than probability sampling strategies when used by an authority with specialty knowledge [50]. It can also be a time- and cost-effective approach for selecting participants with the necessary expertise and experience [136,138]. Additionally, judgmental sampling can be the most suitable and efficient approach when the objective is to learn about a specific process [138]. Considering that the objective of the present study was to understand the intricacies of WBL and identify areas that require further research and quantification of loss and waste amounts, judgmental sampling was employed as an appropriate technique. Nonetheless, in research contexts where classical measurement theory assumptions hold and the collection and analysis of quantitative data are necessary, it is advisable for researchers to avoid judgmental sampling and instead employ probability sampling techniques.

One potential limitation of our study on WBL was the absence of certain experts, including processors, packers, and transporters, who could have provided valuable insights. Unfortunately, their unwillingness to participate was mainly due to restrictive policies, particularly in private companies. However, this limitation was partially compensated for by the valuable information provided by other interviewees, particularly the CEO of the local agricultural cooperative, the technical inspector of Grain Company and Commercial Services (GCCS), and a high-ranking officer at the Ministry of Agriculture. These individuals possessed expertise and knowledge in areas where other experts did not participate in the survey. Therefore, the collected data can still provide relevant insights into loss and waste hotspots along WBL. However, it is important to note that the absence of some experts may still have resulted in overlooked information in certain segments. Future studies should aim to include a broader range of experts to gain a more comprehensive understanding of WBL and identify further loss and waste hotspots.

One drawback of this paper is that it did not provide any quantitative data. This was partly due to the sampling strategy used, which, as discussed above, does not permit the analysis and reporting of quantitative data in a representative and generalizable manner. Additionally, the lack of transparency in both private companies and public authorities was a significant hurdle. The study revealed that material flow records were well-documented and often submitted to the Ministry of Agriculture, GCCS, or the Union of Bakers, making them potentially obtainable. Nevertheless, despite our extensive efforts, our request to access quantitative material flow data to determine loss or waste was denied due to restrictive policies. To overcome such obstacles in future research, it is necessary to collaborate with stakeholders and policymakers to develop policies that promote transparency and access to data. This can be achieved through building partnerships between researchers, public authorities, and private companies to facilitate data sharing and establish transparent data reporting mechanisms. By doing so, researchers can gain access to relevant data to conduct comprehensive studies and inform evidence-based policies to address food waste and loss at different stages of the food supply chain.

Furthermore, it is essential to acknowledge that the data used in this study were collected in October 2018, and there have been significant global events, such as the COVID-19 pandemic and the Russia–Ukraine conflict, that may have impacted the wheat and bread supply chain since then. A study on the Italian artisan bread supply chain by Amicarelli et al. [139] revealed that the input costs for wheat farming increased by 62%, the milling process by 76%, and bread production by 265%, with an average input cost increase of 232% across all three stages during the Russia–Ukraine conflict. Similarly, prices and trades have been subject to fluctuations and inflation in Iran. Particularly, the wheat supply chain in Iran faced a major setback due to the Russia–Ukraine conflict, given that Iran imported nearly 20% of its wheat from Ukraine [140].

However, the structure of WBL, as presented in this study, is unlikely to be significantly affected, as the qualitative nature of this study makes it less prone to change over time. Therefore, the results can still be considered valid for gaining insights into WBL and identifying loss and waste hotspots in the target region. In some cases, qualitative data can be more resistant to change because it is often based on in-depth interviews, observations, and other forms of data collection that allow for a deeper exploration of a phenomenon [141]. This depth and richness of data can make it more durable and less susceptible to changes in the external environment [142].

Additionally, although the data were collected in 2018, the study's findings are still relevant today as they highlight critical data gaps that have yet to be addressed. To the best of our knowledge, no study or official report has been published since the data collection to change the status of these knowledge gaps, apart from the references cited in this paper. Therefore, while we acknowledge the limitations of using the data from 2018, we believe that this study's findings are still valuable and relevant to addressing the issue of wheat and bread loss and waste in Fars province, Iran, and beyond.

4. Conclusions

The present article provides a detailed cradle-to-grave overview of the WBL in Fars province. The study's findings revealed that farms, foodservice facilities, and households were the primary wheat loss and waste hotspots in the province. The interviewees also explained that records of the material flow exist throughout WBL at all stages except for households. Moreover, there is insufficient information regarding the on-farm loss of wheat.

Therefore, gathering primary data is crucial to fill the knowledge gaps on on-farm loss and household waste.

Data availability at other stages of WBL has not been leveraged to report loss and waste, emphasizing the need for studies that compile these data for estimating wheat and bread loss and waste. However, accessing data possessed by private companies or public authorities remains a challenge, highlighting the pressing need for enhanced transparency. Access to data from various stages of WBL is imperative for researchers to accurately evaluate the extent of loss and waste and develop effective strategies to reduce it. Public authorities have a crucial role in promoting data sharing and transparency in the industry. By incentivizing private companies to disclose the material flow data, public authorities can encourage increased participation from private actors in reducing wheat and bread loss and waste.

Despite its specific focus, this study has implications in broader contexts for research and business in cereal production and FLW reduction. The study's outcome will be valuable not only to researchers studying FLW but also to those conducting LCA and circular economy studies on wheat and other cereals or similar food items in different geographical and socioeconomic contexts. The use of VSM in the present study resulted in a detailed and inclusive portrayal of WBL which can be useful in defining a clear and accurate scope in LCA and circular economy studies, minimizing the risk of overlooking essential lifecycle segments. Furthermore, the comprehensive description of the WBL presented in this study can serve as an educational tool for researchers and practitioners seeking to expand their knowledge of cereal production and supply chains.

In conclusion, accurate and up-to-date data inventory is essential for monitoring FLW throughout the food lifecycle and developing effective reduction plans and strategies. By collecting and analyzing data on the material flow at food production, processing, distribution, consumption, and disposal, stakeholders in the food industry can identify areas for improvement, set goals, track progress, and develop innovative solutions. Nonetheless, the stages of the food lifecycle where loss and waste can be attributed to multiple factors, rather than mainly material flow, require closer examination. Future research should focus on studying on-farm food loss, which depends on a complex set of biological, technological, chemical, and climate elements, and household food waste, which is affected by habitual, behavioral, and psychological factors. In addition to accurate quantification of FLW, a more comprehensive understanding of causes and affecting factors is crucial to paving the way to achieve goals for establishing a sustainable and responsible food production and consumption system.

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