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RESEARCH PAPER

Quantifying and analyzing food losses and wastes in Morocco's wheat processing industry: A novel methodological approach towards sustainable production

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Abstract

The global imperative to combat food losses and wastes (FLW) is an essential component of achieving sustainable food systems, as emphasized by the Sustainable Development Goals (SDG 12). This study presents a novel methodological approach for quantifying and analyzing FLW within Morocco's wheat processing industry, addressing a critical gap in both national and international research. By developing an integrative definitional framework, we identify and analyze seven primary drivers of FLW using the innovative 7M Model. Our findings reveal that management inefficiencies are the predominant cause of FLW, accounting for an 81% correlation with waste generation. Specifically, Pastry and Bakery Industries (PBI) experience a substantial FLW rate of 23.37% due to management and methodological factors, in stark contrast to the 10.64% observed in Milling Industries (MI), where material and measurement factors are more influential. This research not only challenges previous conceptions that food waste is predominantly a post-processing issue but also emphasizes the significant role of managerial practices in waste reduction. The outcomes of this study underscore the necessity of tailored, industry-specific interventions to reduce FLW and contribute to the broader objectives of sustainable production and consumption.

Keywords

Food losses and wastes, Food processing, Responsible production and consumption, Sustainable food systems

Introduction

The challenge of ensuring global food security in the face of a burgeoning population is increasingly intertwined with the imperative of sustainable food resource management. Recent estimates suggest that approximately one-third of all food produced globally, amounting to an astonishing 1.3 billion tons per year, is either lost or wasted before it can be consumed (Lott et al. 2020; FAO 2021). This staggering amount of food losses and wastes (FLW) not only signifies a gross inefficiency in the global food system but also exacerbates environmental degradation, contributes to economic loss, and perpetuates social inequity.

Producing food that will not be consumed leads to unnecessary consumption of 250 cubic kilometers of the global agricultural water (FAO 2013; Marston et al. 2021), which is estimated about one-quarter of all water used by agriculture each year (Kummu et al. 2012). Additionally, produced but uneaten food occupies nearly 1.4 billion hectares of land, which accounts for approximately 30 percent of the world's agricultural land area (FAO 2013), and produces about 8% to 10% of global greenhouse gas (GHG) emissions, equivalent to 3.3 billion tons of CO_2 annually (UNEP 2021). While, if FLW were considered a country, it would rank as the third-largest greenhouse gas emitter in the world, following China and the United States (WRI 2019; WRAP 2023).

Economically, the annual global costs associated with FLW amount to about USD 2.6 trillion per year, comprising USD 1 trillion from economic losses due to wasted and lost production, USD 900 billion from individual well-being losses, and USD 700 billion from environmental costs with GHG emissions and water as the most important items (FAO 2014; Britz et al. 2019). Deeply, quantitative economic studies explicitly acknowledge the direct impacts within the food supply chain (FSC) as well as the ripple effects on the broader macro-economy (Campoy-Muñoz et al. 2021). Reducing FLW could potentially increase national income by reallocating the resources saved along the FSC (Chrisendo et al. 2023). However, the distributional effects of FLW reduction may vary across different economic agents and regions (Jafari et al. 2020; Campoy-Muñoz et al. 2021).

The United Nations has recognized the severity of this issue, embedding the reduction of FLW within the Sustainable Development Goals (SDGs), specifically SDG 12, which calls for "Responsible Production and Consumption." This goal ambitiously targets halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains by 2030 (United Nations 2020; Carlsen and Bruggemann 2022). The achievement of SDG 12 is crucial for promoting sustainable consumption patterns, minimizing the environmental footprint of the food production system, and ensuring that economic growth and food security advancements are achieved without compromising the health of our planet or the well-being of future generations (Schanes et al. 2022; Xue et al. 2022). Despite the critical nature of this challenge, progress toward the SDG 12 targets has been uneven, with significant gaps remaining in both the understanding and implementation of effective FLW reduction strategies across different regions and sectors of the global food system (Parfitt et al. 2010; Hebrok and Boks 2021).

The delineation of FLW into two distinct categories—food losses, occurring from the initial stages of production to the point of retail, and food wastage, manifesting at the retail and consumption levels—serves as a foundational concept for understanding and addressing the multifaceted challenge of FLW. This distinction was adopted by the FAO (FAO 2021) and the World Bank (World Bank Group 2020), and it is instrumental in identifying targeted interventions as the causes, impacts, and solutions for food losses differ significantly from those of food wastage. Food losses often result from inefficiencies in agricultural practices, storage, processing, and transportation, while food wastage predominantly arises due to consumer behavior and retail practices (McCracken and Brandt 1987; Béné 2020). On the other hand, the FUSIONS program (Food Use for Social Innovation by Optimizing waste prevention Strategies) developed a methodological framework titled "FUSIONS Definitional Framework for Food Waste" with the aim of providing a coherent and common basis for defining food losses and waste. This framework combined the terms "Food Losses" and "Food Waste" into a single term "Food Waste". FUSIONS define the concept of "Food Waste" as any food or inedible parts of food removed from the food supply chain for treatment or disposal, including: composting, plowing in/non-harvesting, anaerobic digestion, bioenergy production, cogeneration, incineration, disposal into sewers, landfilling, or disposal at sea (Östergren et al. 2014). To broaden the scope of Food Waste definitions, FUSIONS has included liquid or beverage waste, fish discarded at sea, and waste from any materials ready to be harvested but not collected (Tostivint et al. 2016). FUSIONS also consider non-edible parts of food (such as skin, bones.) as food waste to support the development of efficient and sustainable food systems (Östergren et al. 2014). Similarly, The WRAP (Waste & Resources Action Program) is also aware of the difficulty in distinguishing between these two terms. Consequently, WRAP has also removed the term "Food Losses" and retained only "Food Waste" to describe food waste throughout the food chain, which refers to any food waste or inedible parts redirected to one of the following destinations: composting, land application, anaerobic digestion (biogas production), incineration, landfill, or wastewater (WRAP 2018). According to this British framework, food or inedible parts redistributed for human or animal consumption, or which have undergone biochemical treatment to produce bio-based materials, are considered "surplus food" (WRAP 2018). In contrast to the FUSIONS framework, which groups these food components under the term "Valorization and conversion."

The complexity of FLW is further compounded by its varying impacts on environmental sustainability, economic viability, and social equity across different geographies and food systems (Beretta 2021; Gascón et al. 2022; Willersinn et al. 2022). Despite an increasing political and academic focus on FLW, detailed and representative studies that quantify and analyze FLW, particularly within the context of developing countries, are scarce (Garnett et al. 2022). These countries face unique challenges exacerbated by infrastructural deficiencies and limited access to technologies that can mitigate FLW. The need for comprehensive studies in such contexts is crucial for devising effective strategies to reduce FLW, thereby contributing towards the achievement of SDG 12.3 and enhancing food security, environmental sustainability, and economic efficiency (FAO 2022).

Our comprehensive literature review aimed to consolidate various definitions of "Food Loss" and "Food Waste" encountered across scientific literature, revealing a notable absence of standardization (Östergren et al. 2014; Buzby et al. 2015). This investigation highlighted the challenge of developing universally applicable assessment and quantification methods, critical for crafting effective strategies against FLW. The review encompassed both academic journals and reports from leading global food and agricultural organizations, ensuring a broad and inclusive understanding of FLW conceptualizations.

Wheat sector has a great socio-economic importance in developing countries (Pataco et al. 2015). Expanding upon the unique challenges and significance of Morocco's wheat processing industry within the context of food losses and wastes (FLW) requires an in-depth examination of both the socio-economic implications and the potential avenues for sustainable management practices. Morocco's reliance on wheat as a staple food, coupled with its increasing per capita consumption, underscores the critical role that efficient wheat processing plays in the nation's food security and economic stability. This reliance is further highlighted by the fact that wheat consumption in Morocco is among the highest globally (with an annual average consumption per capita increasing from 138 kg in the 1960s to an average of 255 kg during the period from 2001 to 2016), significantly exceeding the global average (67 kg per capita) and reflecting the cultural and dietary importance of wheat within the country (Bishaw et al. 2019; Mottaleb et al. 2021). Furthermore, since Moroccan domestic wheat production fails to significantly satisfy national consumption, the country depends largely on imports (Bartali et al. 2022). According to FAO statistical databases for the year 2022, Morocco ranks among the top 20 countries in terms of wheat cultivation area, occupying the 17th position with approximately 2,436,350 hectares. However, national wheat production ranks 35th with 2,707,652 tonnes due to low yield, ranked 109th, reaching only 11.114 quintals per hectare (FAO 2024). The wheat processing industry, therefore, not only has a direct impact on food availability and affordability but also on the sustainability of Morocco's food system.

Recent studies have begun to shed light on the multifaceted nature of FLW within the cereal sector, illustrating that inefficiencies and losses are not merely a matter of resource mismanagement but also a reflection of underlying structural issues within the food supply chain (Affognon et al. 2021; Kumar and Kalita 2022). For Morocco, the wheat processing industry faces specific challenges related to infrastructure, technology adoption, and supply chain logistics, which can exacerbate the levels of FLW and hinder efforts towards achieving SDG 12 (Jribi et al. 2020; Lozano et al. 2021). Moreover, the environmental implications of FLW in the wheat processing sector, from excessive water use to unnecessary carbon emissions, highlight the urgent need for integrated strategies that address both food security and environmental sustainability (Reynolds et al. 2014; Kummu et al. 2022).

Studies on Food Loss and Waste (FLW) in the Moroccan wheat sector are limited, with only one notable study conducted by Bartali et al. in (2022). This study provides insights using the life cycle framework, and estimates the annual amount of wheat-based food lost or wasted from farm to fork in Morocco to be 4 million tons, representing 36% of the total supply and valued at US$1.0 billion (Bartali et al. 2022).

Addressing FLW within Morocco's wheat processing industry thus requires a holistic approach that considers not only the technological and infrastructural upgrades necessary for reducing losses but also the socio-economic factors that influence production and consumption patterns. Initiatives aimed at enhancing the efficiency of the wheat processing chain, from harvest to market, can lead to significant reductions in FLW, contributing to food security, economic savings, and environmental benefits. Such initiatives may include the adoption of innovative storage solutions, improved logistics and transportation methods, and the implementation of best practices in processing that minimize waste (Smith et al. 2010; Heck et al. 2022). By focusing on these areas, Morocco can make substantial progress towards sustainable wheat production and consumption, setting a precedent for similar efforts in other countries facing comparable challenges.

Morocco's reliance on wheat as a staple food item, with a consumption rate that has significantly increased over the years, exemplifies the cereal's central role in the national diet and underscores the socio-economic significance of its processing industry. The nation ranks among the highest per capita consumers of wheat globally, a trend that reflects broader socio-economic patterns and nutritional preferences (Bishaw et al. 2019; Mottaleb et al. 2021). This dietary preference for wheat places a spotlight on the wheat processing industry, which plays a pivotal role in ensuring food security and economic stability in Morocco. Yet, this sector grapples with substantial challenges in minimizing FLW, a concern that is magnified by the implications for food security, environmental sustainability, and economic efficiency in a country marked by its agricultural bounty. The wheat processing industry's struggles with FLW are emblematic of larger systemic inefficiencies that include gaps in infrastructure, technology, and management practices (El Bilali and Callenius 2021; FAO 2022). Addressing these challenges is critical not only for enhancing the industry's sustainability but also for contributing to the national goals of reducing FLW in alignment with SDG 12 (United Nations 2020; Srivastava et al. 2021). Efforts to mitigate FLW within this context can yield substantial benefits, ranging from improved food availability to enhanced resource use efficiency and reduced environmental impact, underpinning the urgent need for focused research and targeted interventions in the Moroccan wheat processing sector (UNECE and ESCWA 2022).

Our research aims to bridge the critical gap in the literature by providing a comprehensive analysis of FLW in the

Moroccan wheat processing industry, employing a novel and methodologically robust approach for quantification and analysis. By developing a new definitional framework for FLW that integrates both food losses and food waste into a unified concept, our study addresses the entire food supply chain's complexities. This nuanced understanding allows for the identification of FLW at stages previously underexplored, particularly within the processing sector, where data have been notably lacking (Smith et al. 2010). Utilizing the Ishikawa diagram to categorize the drivers of FLW, we delve into the systemic inefficiencies and management practices contributing to waste, offering insights that are crucial for devising targeted interventions (Yan et al. 2021). Our findings not only highlight the significant correlation between management practices and FLW generation but also set the stage for implementing strategies that can significantly reduce FLW at a national level, contributing to the broader goals of SDG 12 and enhancing food security (United Nations 2020; FAO 2022). This study's methodological innovation and findings are instrumental for policymakers, industry stakeholders, and the international community, providing a replicable model for assessing and addressing FLW in similar contexts globally.

Our research not only fills a critical gap in the literature by offering a novel approach to quantifying FLW in Morocco's wheat processing industry but also lays the groundwork for transformative strategies to mitigate these losses. Through the development of a new definitional framework and the identification of key FLW drivers using the Ishikawa diagram, our study illuminates the path toward more sustainable production practices. The strong correlation identified between management practices and FLW generation underscores the urgent need for comprehensive strategies that address these systemic inefficiencies. As such, our findings are poised to inform policy decisions, guide industry practices, and inspire further research, contributing significantly to the global pursuit of SDG 12. This study represents a pivotal step in the collective effort to enhance food security, promote environmental sustainability, and foster economic efficiency, providing a model that can be replicated in similar contexts worldwide to combat FLW effectively.

Material and methods

In response to the disparities found in the literature, this study developed a new definitional framework for FLW quantification. Thus, we synthesized the concepts of "Food Losses" and "Food Wastes" into a cohesive framework. This innovative approach allows for a holistic assessment of FLW across the entire food supply chain, acknowledging that food losses are not confined to the early stages of the supply chain, nor are food wastes solely the result of consumer behavior.

Our study employed a stratified random sampling method to select a representative sample of 97 managers from wheat industrial entities (34 from wheat milling and 63 from pastry-bakery industries) in the Beni Mellal-Khenifra region. Criteria for selection included industry size, geographic location, and annual production volume to ensure a diverse and comprehensive dataset. Data were collected through structured interviews, designed for depth and sensitivity to contextual variations, providing insights into the industry practices, challenges, and FLW rates.

We adopted the Ishikawa diagram for a detailed classification of FLW causes within the wheat processing industry, identifying seven major categories: Manpower, Material, Method, Milieu (Environment), Raw Material, Management and Measurement (Fig. 1). This model facilitated a systematic analysis of the factors contributing to FLW, guiding the identification of targeted interventions.

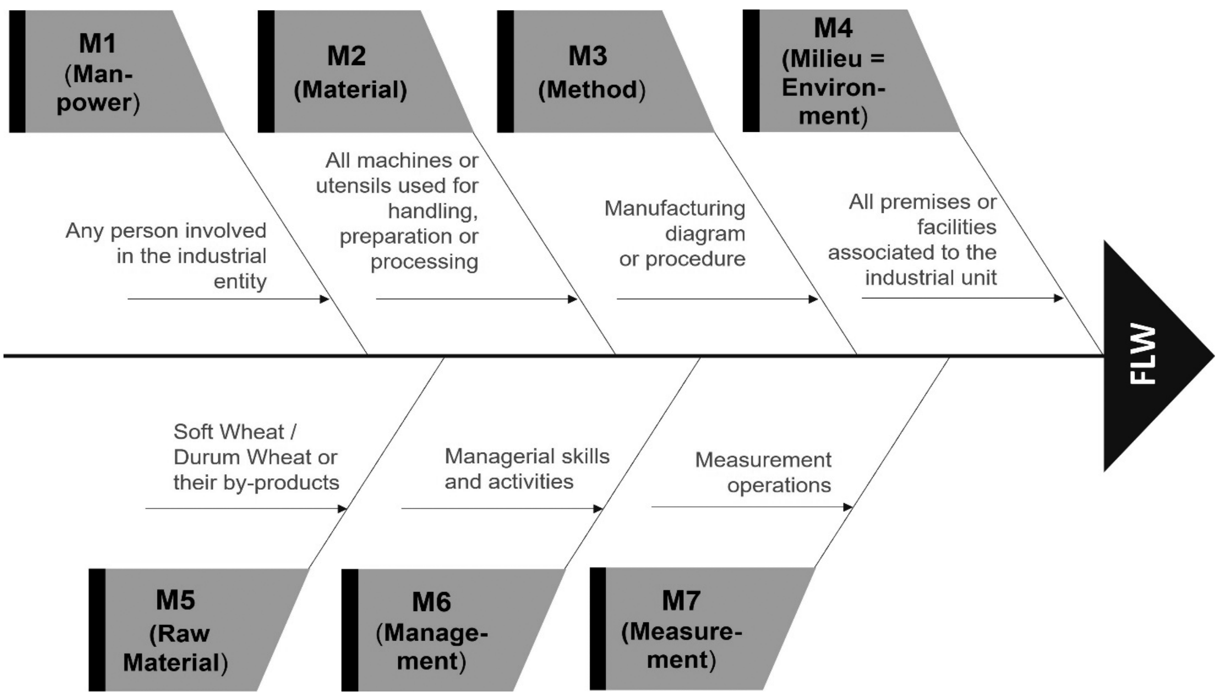

Figure 1. Graphical presentation of the Ishikawa diagram designed by the authors.

After collecting data using the questionnaire based on developed 7M model (Table 1). Calculations of the annual purchased quantity and the annual quantity lost or wasted are performed using the conversion coefficient associated with each frequency scale (Table 2).

Table 1. Data collection approch using 7M: Extract from survey questionnaire used.

Product	Purchased quantity	Purchasing frequency	Causes of FLW	Quantity lost or wasted	Loss or wastage frequency
Soft Wheat (SW) / SW by-products	…	…	M1	…	…
			M2	…	…
			M3	…	…
			M4	…	…
			M5	…	…
			M6	…	…
			M7	…	…
Durum Wheat (DW) / DW by-products	…	…	M1	…	…
			M2	…	…
			M3	…	…
			M4	…	…
			M5	…	…
			M6	…	…
			M7	…	…

Table 2. Conversion coefficient, for annual calculation, according to frequency scale.

Frequency scale	Frequency	Months per year	Weeks per year	Dayspcr year	Conversion coefficient for annual calculation
1	Twice a day	12	52,1429	365	730
2	Every day				365
3	Four times a week				208,5716
4	Twice a week				104,2858
5	Once a week				52,1429
6	Twice a month				24
7	Once a month				12
8	Four times a year				4
9	Twice a year				2
10	Only once a year				1
11	Never				0

- For each type of product/by-product, the annual purchased quantity is calculated using the formula 1.

$$\text{Annual purchased quantity} = \text{Purchased quantity} \times \text{Conversion coefficient for annual calculation} \quad (1)$$

- For each type of FLW causes, the annual quantity lost or wasted is calculated using the formula 2.

$$\text{Annual lost or wasted quantity} = \text{Quantity lost or wasted} \times \text{Conversion coefficient for annual calculation} \quad (2)$$

- FLW rate is calculated using the formula 3.

$$\text{FLW rate} = (\text{Annual lost or wasted quantity} / \text{Annual purchased quantity}) \times 100 \quad (3)$$

This approach provided a quantitative measure of FLW, essential for assessing the efficacy of existing management practices and identifying areas for improvement.

Statistical analyses were performed using both ANOVA and Newman-Keuls tests in Statistica (V6.0) software to obtain an extended analysis of FLW rates across industry types. Alongside principal component analysis (PCA) conducted in open-source R software, with the "Factoextra" and "Factominer" packages, to achieve a comprehensive examination of key determinants of FLW rates. This dual approach allowed for a nuanced exploration of the relationships between industry characteristics, FLW rates, and the categorized causes of FLW, offering a comprehensive understanding of the drivers behind FLW in the Moroccan wheat processing industry.

Results

Extended analysis of FLW rates across industry types

As illustrated in Table 3 and Fig. 2, the FLW rates vary significantly between Milling Industries (MI) and Pastry and Bakery Industries (PBI), highlighting the need for industry-specific waste reduction strategies. The comprehensive application of three-way ANOVA provided a nuanced understanding of how industry type significantly impacts FLW rates, with PBI and MI presenting contrasting profiles of waste generation. The pronounced difference in FLW rates, with PBI at 23.37% and MI at 10.64%, not only underscores the variability in waste across the wheat processing sector but also reflects the underlying operational and procedural dynamics unique to each industry type. The significantly higher waste in PBI could be attributed to the complex nature of pastry and bakery production processes, which often involve multiple stages of handling and processing that inherently increase the risk of waste.

Table 3. Statistical Analysis of Industry and Cause-Specific Food Loss and Waste Rates in Moroccan Wheat Processing Industries.

Factor	Dof	F	p-value
Industry	1	95.8679	**0.000000*** **
Product	1	0.2722	0.601921
Cause (7M)	6	21.3043	**0.000000*** **
Industry*Product	1	0.0263	0.871305
Industry*Cause (7M)	6	32.3648	**0.000000*** **
Product*Cause (7M)	6	0.4280	0.860600
Industry*Product* Cause (7M)	6	0.2949	0.939516

Additionally, the diversity of products and the sensitivity of bakery goods to quality and freshness standards may further exacerbate FLW rates. In contrast, MI's lower FLW rates suggest a streamlined process with potentially greater control over production variables and efficiencies gained from economies of scale. This stark variance ($p < 0.0001$) invites a deeper exploration of specific practices and areas within each industry that are amenable to interventions

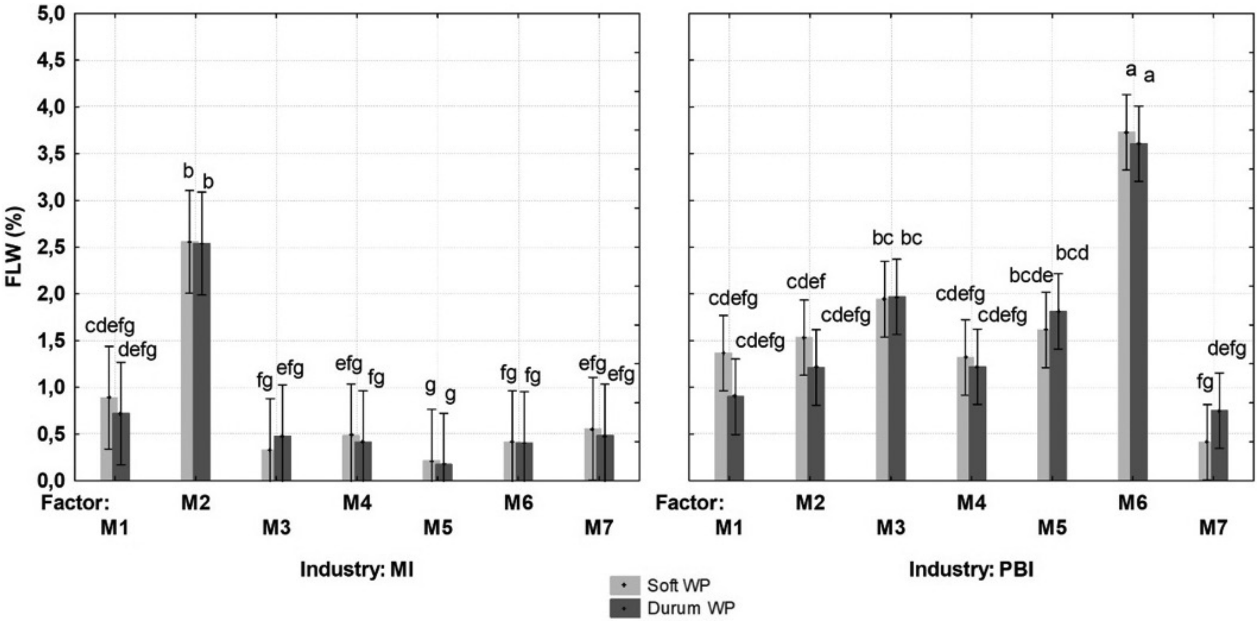

Figure 2. Comparative FLW Rates by Cause in Wheat Processing: A Cross-Industry Evaluation (MI: "Milling Industry" vs PBI: "Pastry and Bakery Industries"). Comparisons were performed using Newman-Keuls tests, ($P < 0.05$). Causes categories sharing the same letter are not significantly different. Causes categories are namely: **M1**: Manpower, **M2**: Material, **M3**: Method, **M4**: Milieu (Environment), **M5**: Raw Material, **M6**: Management and **M7**: Measurement.

aimed at reducing FLW, highlighting the need for tailored strategies that account for the unique challenges and opportunities within PBI and MI.

Detailed examination of FLW cause categories on waste generation

Investigating the impact of FLW cause categories, as delineated by the Ishikawa diagram (7M), our study unearthed that Management (M6) and Material (M2) emerge as predominant forces driving waste (Fig. 2). The finding that Management-related issues contribute to an average FLW rate of 25.24% signals a substantial area for improvement. It suggests that inefficiencies in organizational processes, decision-making, and human resource management play a critical role in exacerbating waste. Specifically, in PBI, the complexity of production schedules, inventory management, and quality control can significantly influence waste levels. The notable influence of Material-related deficiencies (17.83%) further points to challenges in the procurement, handling, and utilization of raw materials and resources. These deficiencies might include the use of suboptimal materials, issues in storage and transportation that compromise material quality, and inefficiencies in the production process that lead to excess material use or spoilage. The statistical significance of these findings ($p < 0.0001$) emphasizes the urgency of addressing these areas, particularly in PBI, where the scope for reducing FLW appears substantial. Implementing targeted interventions to streamline management processes and optimize material usage could lead to significant reductions in FLW, enhancing sustainability and operational efficiency in the wheat processing industry.

Detailed insights into the effect of product type on FLW rate

The analysis indicating that the type of wheat product (Soft Wheat vs. Durum Wheat) has no significant impact on FLW rates (p-value of 0.601921) is particularly revealing. This finding challenges the assumption that the physical or chemical properties of different wheat varieties inherently lead to varying levels of waste. Instead, it underscores the overriding influence of production methods and industry practices on FLW rates. Such an outcome prompts a deeper inquiry into the operational aspects of the wheat processing sector, suggesting that improvements in processing techniques, equipment efficiency, and workforce training could be universally beneficial, regardless of the wheat variety in question. This insight paves the way for industry-wide strategies aimed at enhancing efficiency and sustainability, highlighting the potential for cross-industry learning and the adoption of best practices that can effectively reduce FLW without necessitating varietal-specific interventions.

Comprehensive examination of key determinants of FLW rates through PCA

The application of Principal Component Analysis (PCA) provided a sophisticated understanding of the multifaceted nature of FLW, identifying Management (M6) and Method (M3) as significant contributors to waste across the industry (Fig. 3). This analysis not only confirms the critical role of operational efficiencies but also points to specific areas within management and production methodologies that are ripe

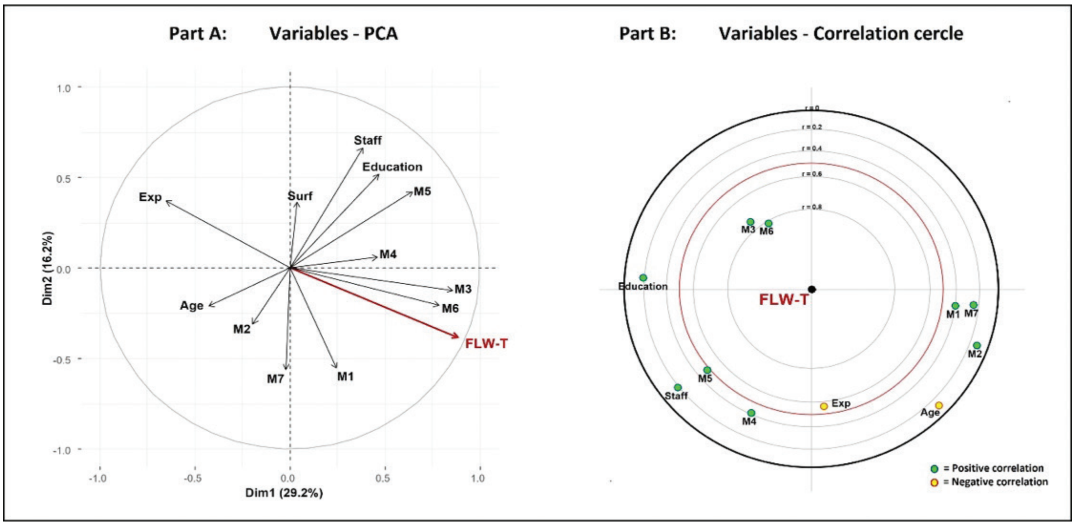

Figure 3. Principal Component Analysis: Interplay Between Wheat Industry Characteristics and FLW Rates Across All Cause Categories (7M). Variables are namely: Industry Characteristics (**Staff**: Staff size, **Surf**: Surface area); Manager characteristics (**Education**: Educational level, **Exp**: Experience level and **Age**); FLW rate associated to each cause category (**M1**: Manpower, **M2**: Material, **M3**: Method, **M4**: Milieu (Environment), **M5**: Raw Material, **M6**: Management and **M7**: Measurement) and **FLW-T**: Total FLW rate regardless industry type.

for innovation and improvement. The strong correlation between management experience (Exp) and lower FLW rates further illustrates the impact of skilled, knowledgeable leadership on minimizing waste. This relationship underscores the importance of investing in managerial training and development as a direct strategy for waste reduction. It suggests that enhancing the decision-making capabilities, strategic planning, and operational oversight of management personnel could lead to more effective resource utilization and process optimization, ultimately reducing FLW. Furthermore, this insight into the value of experience highlights the potential benefits of mentorship programs, continuous professional development, and knowledge exchange initiatives within the wheat processing industry.

Elaborated distinctive patterns among wheat milling and pastry and bakery industries

The Principal Component Analysis (PCA) offers a granular view into the operational nuances that differentiate MI and PBI, with specific FLW drivers emerging in each sector. In MI (Fig. 4), the significant role of Material (M2) and Measurement (M7) in contributing to FLW underscores the technical and procedural dimensions where improvements can be impactful. The emphasis on Material suggests issues with raw material quality, storage, and handling, whereas Measurement challenges point to the accuracy of ingredient portioning and process control. Enhancements in these areas, potentially through technological upgrades and stricter procedural standards, could markedly reduce FLW.

Conversely, PBI's FLW challenges (Fig. 5) are rooted in Management (M6) and Method (M3), areas that reflect the complexity of bakery operations which often involve intricate recipes, variable production volumes, and tight quality criteria. The findings suggest a pivotal need for strategic management interventions focused on process optimization and waste minimization techniques, as well as methodological innovations that streamline production processes and enhance efficiency. Addressing these areas could lead to significant waste reduction in PBI, with broader implications for operational sustainability and cost management.

Comparative analysis of FLW causes

The comparative analysis further delineates the complex interplay of factors contributing to FLW across industry types, offering a nuanced perspective on the systemic and operational dynamics at play. This analysis illuminates how different facets of the 7M causes—ranging from manpower to management and materials—interact to influence FLW rates. The interdependencies among these causes highlight the interconnected nature of operational challenges, where improvements in one area can have cascading effects on others. For instance, enhancing material quality and storage (M2) can lead to better outcomes in production (M3) and, consequently, lower FLW.

Moreover, the comparison between MI and PBI reveals the sector-specific strategies required to tackle FLW effectively. It points to the necessity of adopting a holistic approach that considers the unique characteristics and challenges of each industry type. For MI, focusing on technological advancements and precision in operations can yield significant reductions in FLW. For PBI, leveraging managerial expertise and innovative production methods emerges as a key pathway to waste reduction. This detailed analysis underscores the importance of

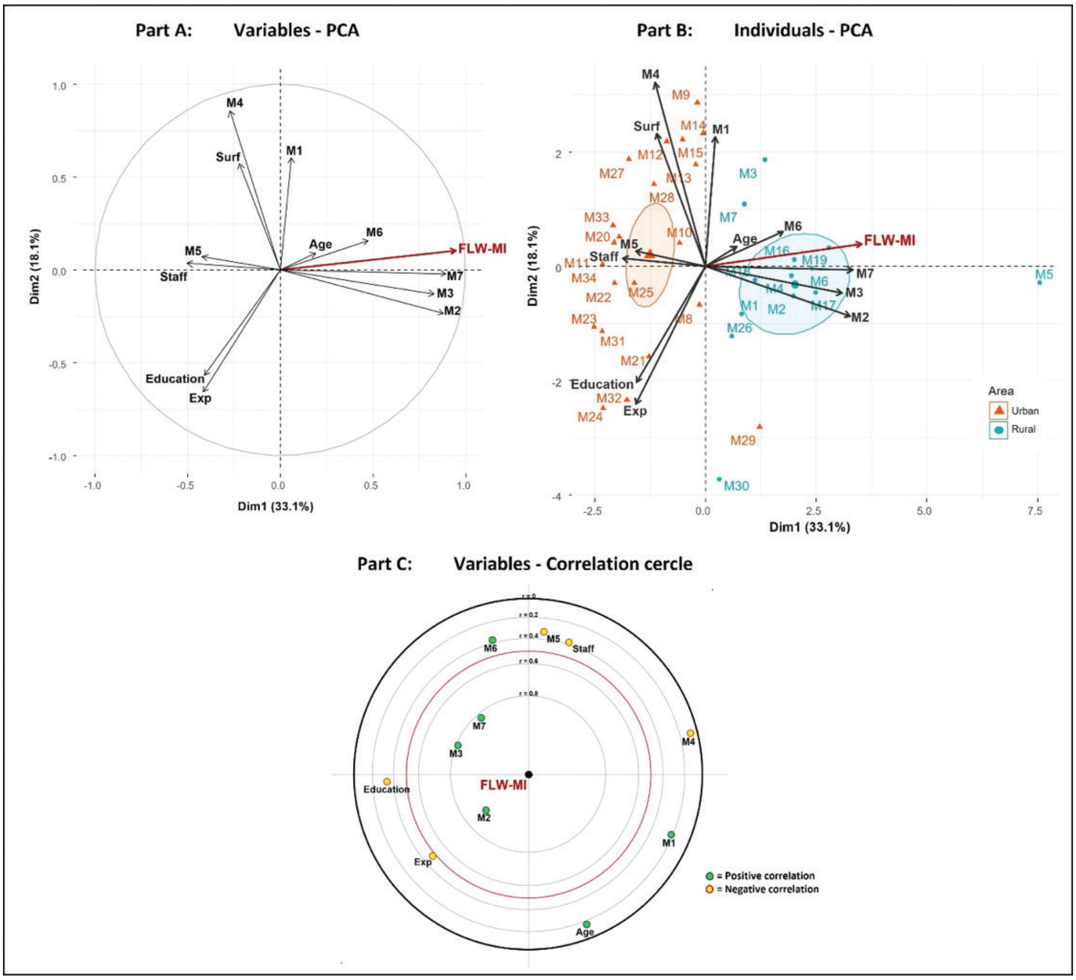

Figure 4. PCA-Driven Insights: Correlation of FLW Rates with Wheat Milling Industry Features and FLW Causes. Variables are namely: Industry Characteristics (**Staff**: Staff size, **Surf**: Surface area); Manager characteristics (**Education**: Educational level, **Exp**: Experience level and **Age**); FLW rate associated to each cause category (**M1**: Manpower, **M2**: Material, **M3**: Method, **M4**: Milieu (Environment), **M5**: Raw Material, **M6**: Management and **M7**: Measurement) and **FLW-MI**: Total FLW rate associated to Milling Industries.

tailored, industry-specific interventions that address the root causes of FLW, facilitating more targeted and effective strategies for waste minimization.

Discussion

The academic discourse has traditionally segmented food losses and wastes (FLW) into two distinct methodologies: one based on the stage of the food supply chain (FSC) where losses occur (Parfitt et al. 2010; Gustavsson et al. 2011; Kummu et al. 2012; FAO 2013, 2019; Arivazhagan et al. 2016; Vilariño et al. 2017) and another based on the causality—whether these losses are intentional or result from negligence (Lipinski et al. 2013; Buzby et al. 2014; Priefer et al. 2016; FAO 2020). However, these classifications present limitations in comprehensively addressing the multifaceted nature of FLW.

In the stage-based classification, it is acknowledged that even at stages typically associated with wastage, such as distribution or consumption, there can still be unintentional losses stemming from biological, physical, or chemical contamination. Similarly, during the processing phase, wastages can arise from managerial oversights, excessive supply, or neglect. The causality-based approach, meanwhile, lacks a nuanced, standardized categorization of FLW causes, an area where this study's 7M Model proposes significant advancements (Papargyropoulou et al. 2014; Thyberg and Tonjes 2016).

Most existing research on FLW quantification predominantly relies on extrapolation and generic data collection methods that may not fully capture the specificities of individual study areas or the nuanced factors contributing to FLW. This often results in a failure to distinguish between primary products and by-products in their analyses, a critical oversight that this research aims to rectify. Recent studies, such as those by Affognon et al. (2015) and Corrado and Sala (2018), highlight the necessity of adopting more granular and context-specific approaches to accurately measure FLW, underlining the importance of differentiating between various types of losses and wastes within the food supply chain.

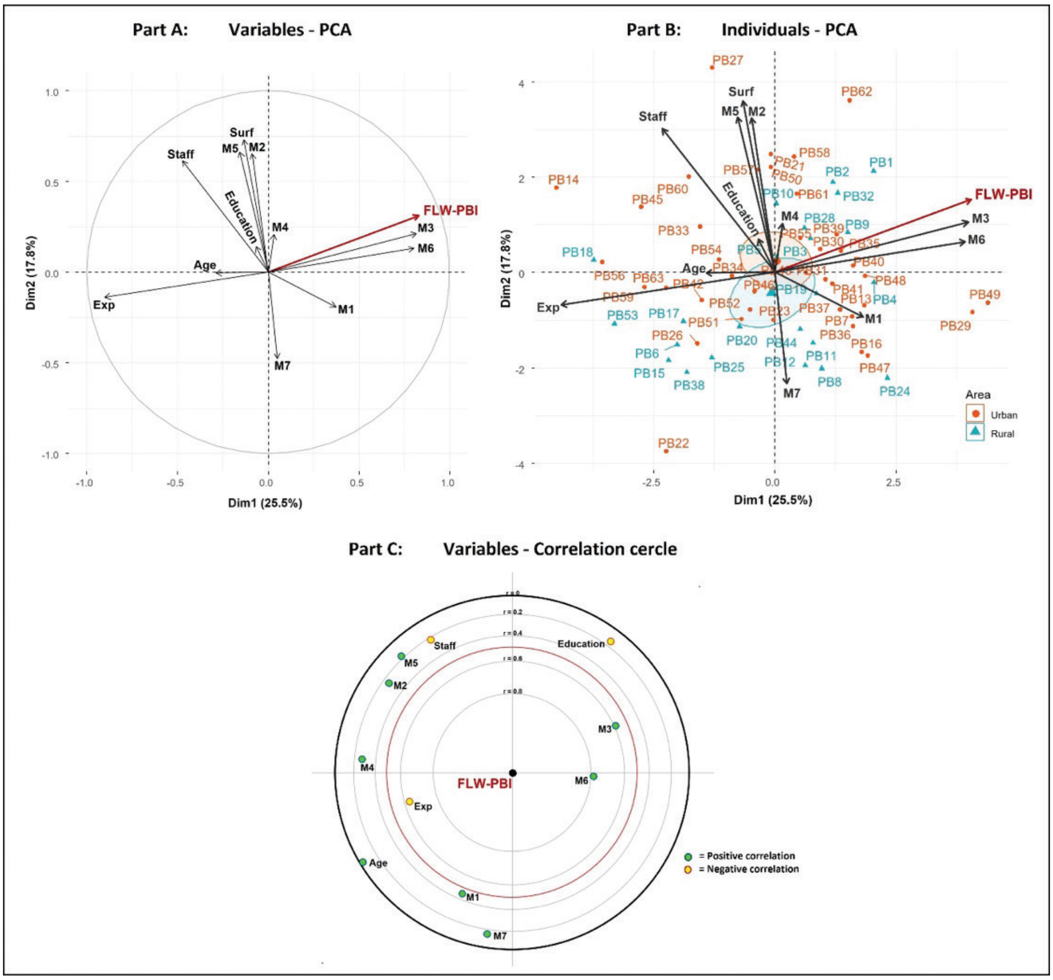

Figure 5. PCA Correlation Patterns: Evaluating FLW Rates and Causal Factors in Pastry and Bakery Industries. Variables are namely: Industry Characteristics (**Staff**: Staff size, **Surf**: Surface area); Manager characteristics (**Education**: Educational level, **Exp**: Experience level and **Age**); FLW rate associated to each cause category (**M1**: Manpower, **M2**: Material, **M3**: Method, **M4**: Milieu (Environment), **M5**: Raw Material, **M6**: Management and **M7**: Measurement) and **FLW-PBI**: Total FLW rate associated to Pastry and Bakery Industries.

This study marks a pivotal departure from previous literature by demonstrating, for the first time, the occurrence of food wastes during the food processing stage—a finding that challenges traditional perceptions of waste generation. Furthermore, it elucidates that management-related causes of waste significantly surpass other categories in the wheat processing stage. This revelation underscores the critical impact of management (M6) inefficiencies, contributing to an 81% correlation with FLW across all industry types. The work by Papargyropoulou et al. (2014) and Beretta et al. (2013) supports the assertion that management practices play a crucial role in FLW generation, with their studies revealing how organizational inefficiencies can lead to significant losses and wastes, particularly in the processing sector.

The introduction of food wastes in the food processing stage represents a significant shift in understanding FLW dynamics. Traditionally, FLW analyses have focused predominantly on post-harvest and retail stages, overlooking the critical processing phase where significant losses can occur. This oversight is addressed in our study, aligning with findings from Ghosh and Eriksson (2019), who emphasized the complexity of food processing operations and their susceptibility to generating waste. Additionally, Buzby and Hyman (2012) have detailed the extent of food loss within the United States, underscoring the need for a comprehensive approach that includes processing stages to accurately assess FLW.

Our findings on the dominance of management-related causes in FLW, particularly in wheat processing, highlight the need for improved managerial practices. The correlation of management inefficiencies with FLW, exceeding 81%, corroborates with studies by Göbel et al. (2015) and Canali et al. (2017), which identify organizational inefficiencies as a significant driver of FLW. These studies emphasize that enhancing managerial skills and operational practices can lead to substantial reductions in FLW, supporting the critical role of effective management in achieving FLW reduction targets as part of Sustainable Development Goal 12.3.

Conclusion

This study has provided a comprehensive examination of food losses and wastes (FLW) within the Moroccan wheat processing industry, unveiling significant insights that contribute to both the academic literature and practical approaches to sustainability in food production. Through meticulous statistical analysis and the innovative use of Principal Component Analysis (PCA), we have identified distinct patterns of FLW across different segments of the industry—namely, Milling Industries (MI) and Pastry and Bakery Industries (PBI). Our findings reveal that while the type of wheat product does not significantly influence FLW rates, industry-specific practices and challenges play a pivotal role in waste generation. Specifically, MI could benefit from advancements in material handling and measurement accuracy, whereas PBI's FLW rates could be markedly reduced by improving managerial practices and refining production methodologies.

Moreover, our study underscores the multifaceted nature of FLW, driven by a complex interplay of factors including management inefficiencies, material quality, and operational methodologies. The identification of these key determinants offers actionable insights for stakeholders across the wheat processing sector, highlighting targeted areas for intervention that could significantly reduce waste and enhance sustainability.

Several studies underscore the importance of understanding key factors influencing food waste rates. This comprehension is crucial for taking appropriate action and developing strategies and programs adapted to each context, thereby alleviating environmental impacts caused by human activities (Hermanussen et al. 2022; Rodrigues and Bortoleto 2022; Leal Filho et al. 2024; Martianto et al. 2024; Zoubi et al. 2024).

Importantly, this research contributes to the global effort to achieve Sustainable Development Goal 12 (SDG 12) by providing a quantifiable assessment of FLW and a methodological blueprint that can be adapted and applied in other contexts. By addressing the critical issue of FLW through a focused study on the Moroccan wheat processing industry, we not only illuminate the challenges specific to this context but also offer a model for similar analyses in other industries and regions.

Future directions and practical implications

Looking forward, it is imperative that further research continues to explore the intricacies of FLW in different segments of the food supply chain, both within Morocco and globally. Future studies should aim to replicate and extend our methodology to other food sectors and geographical areas, enhancing the generalizability and applicability of our findings. Additionally, the development of industry-specific, evidence-based strategies for FLW reduction remains a critical need. Stakeholders across the food production spectrum—ranging from policymakers to industry leaders and practitioners—can leverage the insights gained from this study to implement practical interventions aimed at reducing waste, improving efficiency, and fostering sustainability in food systems.

In conclusion, our research not only sheds light on the pressing issue of FLW within the Moroccan wheat processing industry but also contributes to the broader discourse on sustainable food production practices. By highlighting key areas for improvement and offering a comprehensive methodological approach to quantifying and analyzing FLW, this study paves the way for impactful changes that align with global sustainability goals and enhance food security for future generations.

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