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ORIGINAL ARTICLE

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From Storage to Disposal: An Investigation of Household Bread Management and Waste in Algeria and Tunisia

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ABSTRACT

Background: The management of unconsumed bread plays a crucial role in addressing food waste, as bread is one of the most commonly wasted foods worldwide.

Aims: This study aims to contribute to the bread wastage reduction by investigating the interrelationship between storage practices, management of unconsumed bread, bread waste, and sociodemographic factors in Algeria and in Tunisia.

Methods: The study was conducted by an online survey from September to December 2023, with 636 respondents: 316 Algerians (62,8% female, 64,9% aged 25 - 60 years old, 76% university educated) and on 320 Tunisians (76,3% female, 76,2% aged 25 - 60 years old, 90% university educated). The questionnaire included questions about household bread storage practices, waste management, future intentions to reduce waste, motivations, and policy recommendations in Algeria and Tunisia.

Results: In Algeria, freezing (83.8%) and room temperature storage (76.5%) were common, with plastic bags prevalent at room temperature (47.5%). Storage duration (mean of 2 days for 46.1%) was linked to respondents' age and marital status. A significant 55.8% discarded stored bread, associated with gender, age, and marital status. In Tunisia, room temperature storage (72.4%) was most frequent, with plastic (32.1%) and cotton bags (26.9%). Storage duration (mean of 2 days for 44.9%) was influenced by age, purchase quantity, and purchase place. Discarding stored bread (43.6%) was linked to storage duration. Notably, a high percentage in both countries perceived bread weight contributing to waste (Algeria: 73.9%, Tunisia: 50%). Bread management practices revealed high rates of reheating and reuse in meals, particularly in Algeria. Animal feeding and donation to waste collectors/the poor were also common, while composting was minimal. Sociodemographic factors significantly influenced these practices. Regarding future intentions, 38.3% of Algerians and 38.4% of Tunisians were willing to reduce or stop waste, driven primarily by ethical and religious values. However, a significant portion, especially in Algeria (33.8%), showed resistance to change. Lastly, respondents' policy recommendations emphasized awareness campaigns, improved bread quality for preservation, and subsidy adjustments.

Conclusions: These findings underscore the need for targeted educational interventions considering sociodemographic variations and leveraging ethical and religious motivations to promote sustainable bread consumption and reduce household waste in the North African context.

Keywords: Bread Waste; Sociodemographic Factors; Storage Practices; SDG12.3; Food Waste Management.

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1 INTRODUCTION

Food waste is a growing global concern with significant repercussions for food security, environmental sustainability, and economic stability. The Food and Agriculture Organization (FAO, 2025) estimates that one-third of all food produced for human consumption is either lost or wasted annually. This translates to a staggering economic loss and accounts for 8–10% of global greenhouse gas (GHG) emissions (UNEP, 2024). These emissions not only exacerbate climate change but also highlight the inefficiencies in food production and consumption systems. As the global population continues to grow, reducing food waste has become a critical component of achieving food security and sustainable development.

Among the most wasted food items, bread holds a unique position due to its nutritional importance and cultural

significance. Bread is a staple food for billions of people worldwide and serves as a symbol of sustenance across diverse cultures and religions. It is featured prominently in rituals and ceremonies within Islam, Christianity, and Judaism, underlining its cultural resonance. In 2022, global bread production reached approximately 265 million metric tons, and projections indicate an annual growth rate of 6.25% from 2025 to 2030 (Statista, 2025). Despite its prominence, bread waste is widespread, primarily due to its susceptibility to staling and microbial spoilage, driven by its nutritional composition and storage practices (Ben Rejeb *et al.*, 2022). Quantitative studies underscore the magnitude of bread waste globally. Allipour Birgani *et al.* (2023) reported that 18% of wheat bread is wasted worldwide, with substantial variations across regions. In the United Kingdom, the Waste and Resources Action Programme (WRAP, 2011) identified a household bread waste rate of 29%, while in Australia, bread accounts for 12% of total edible food waste (Ananda *et al.*, 2024). Similar patterns have been observed in other regions. In Sweden, annual bread waste was estimated at 80,410 tons, or 8.1 kilograms per person, with the primary sources being households and the supplier-retailer interface (Brancoli *et al.*, 2019). In North Africa, bread waste represents a significant proportion of overall food waste. Studies in Morocco, Algeria, and Tunisia highlight bread as a major contributor, exacerbated by governmental subsidy systems that reduce bread prices (Bahia, 2018; Capone *et al.*, 2016). However, while subsidies are often identified as a driver, other factors, such as sensory deficiencies (e.g., staling and poor texture) and behavioral patterns, play critical roles. For instance, Bouledroua *et al.* (2025) revealed high post-meal bread wastage rates in Algeria (7.8% of respondents) and Tunisia (17.9% of respondents), with sensory factors being key reasons for disposal. Additionally, incorrect estimation of required quantities and low costs further contribute to the issue.

Bread waste reduction strategies must address both systemic and household-level factors. On a systemic level, the European Union's Waste Framework Directive (2008/98/EC) establishes a hierarchy for waste management, prioritizing prevention, followed by reuse and recycling. This framework has informed the food waste management hierarchy, which advocates for measures such as prevention, redistribution, repurposing, and composting before resorting to disposal (Hardy and Desmet, 2021). At the household level, consumer management skills and specifically food management strategies can significantly reduce bread waste. Conscious shopping habits, such as purchasing smaller quantities more frequently, can help households align bread consumption with its shelf life (Mattar *et al.*, 2018; Østergaard *et al.*, 2018; Ananda *et al.*, 2024). Proper storage techniques, including freezing, also play a critical role in prolonging freshness and preventing spoilage (Sarica *et al.*, 2021). When surplus bread is generated, repurposing it into new culinary items, such as breadcrumbs, croutons, or recipes for stale bread, offers a sustainable solution (Demirtaş *et al.*, 2018; Bilska *et al.*, 2024). Surplus bread can also be redirected to animal feed (considered a recycling method), donated to food banks, or composted to enrich soil (Gul *et al.*, 2003; Brancoli *et al.*, 2020; Ananda *et al.*, 2024). These measures align with sustainable development principles and contribute to the circular economy by conserving resources and reducing the environmental impact of bread production.

The role of sociodemographic factors in shaping bread waste behaviors has garnered increasing attention. Studies have shown that variables such as age, gender, household size, income, and education influence how bread is managed within households. For instance, older adults are more likely to repurpose stale bread due to their culinary knowledge and habits, while younger individuals often discard it (Bilska *et al.*, 2024). Gender differences are also apparent; women tend to reuse stale bread in recipes, while men are more likely to feed it to animals or dispose of it (Bilska *et al.*, 2024). Household size plays a role as well; larger households are more likely to engage in practices such as preparing breadcrumbs or donating surplus bread, likely driven by economic considerations and the need to feed more individuals (Bilska *et al.*, 2024).

Despite these insights, research on bread waste management in North Africa remains limited, particularly concerning the role of sociodemographic and behavioral factors. This knowledge gap is especially significant given the unique context of the region, characterized by government-subsidized bread prices and high reliance on imported wheat for bread production. In Tunisia, for example, only 20% of bread wheat is sourced domestically, underscoring the strategic importance of minimizing bread waste (Thabet *et al.*, 2024). Few studies have provided some preliminary insights into North African bread waste behaviors (Capone *et al.*, 2016). Bouledroua *et al.* (2025) identified demographic variables such as gender, age, marital status, and household size as significant predictors of shopping and waste behaviors in Algeria and Tunisia. For example, larger households were more likely to repurpose stale bread, while younger individuals and those in smaller households were more likely to discard it. Incorrect quantity estimation and sensory deficiencies were common reasons for waste, while leftover bread was often stored but later discarded.

Understanding the complex interplay of sociodemographic and behavioral factors in bread waste management can inform targeted interventions to reduce waste and promote sustainable consumption. By identifying key drivers and barriers to sustainable practices, policymakers and stakeholders can design educational campaigns and incentives tailored to specific demographic groups. These

initiatives could focus on promoting mindful shopping, improving storage techniques, and encouraging the repurposing or donation of surplus bread.

The objective of the present study was to systematically assess household bread management practices—from storage to disposal—and evaluate their impact on bread waste in Algeria and Tunisia. This work aimed to quantify the prevalence of different practices and identify which specific behaviors are most strongly associated with reduced waste levels. The findings hold potential to inform targeted interventions, fostering more sustainable consumption patterns and contributing to the achievement of Sustainable Development Goal SDG 12.3, which aims to halve global food waste by 2030.

2 Participants and Methods

This investigation employed an exploratory survey methodology in Algeria and Tunisia, based on prior research within the Middle East and North Africa (MENA) region (Capone *et al.*, 2016; Demirtaş *et al.*, 2018; Jribi *et al.*, 2020, 2021). A structured questionnaire, adapted for the North African socio-cultural context, served as the primary data collection instrument.

Data regarding bread waste management behaviors were collected via a self-administered online questionnaire, developed using Google Forms and administered in French, the prevalent academic language in both study locations. The instrument comprised 32 items organized into three distinct sections. The initial section explored patterns of bread purchase and consumption. The second section focused on the household bread storage practices, waste management, and future intentions to reduce waste, as well as policy recommendations. The final section gathered demographic information, including participant gender, age, education, and household size. Either 3-point or 5-point Likert scales were used to measure respondents' attitudes, opinions, or level of impact or agreement with a statement.

The survey was conducted between September and December 2023 using a convenience sample. The questionnaire was disseminated through diverse institutional communication channels, encompassing official websites, email distributions, and social media platforms, notably Facebook/META. The high internet penetration rates (72.9% in Algeria and 79.6% in Tunisia in 2024) supported the use of online distribution for this study (Data Reportal, 2025a, 2025b).

A total of 636 completed questionnaires were received (Algeria: n = 316; Tunisia: n = 320), as detailed in Table 1. Participation was voluntary, and respondent anonymity was maintained throughout the data collection process. Valid questionnaires were selected if they were fully completed and submitted by participants, as reflected a response rate of respectively 4.5 % for the Tunisian panel and 4.9% for the Algerian panel.

Quantitative data analysis was performed using SPSS version 25 and Microsoft Excel. Descriptive statistics, specifically percentages, and confidence intervals at 95% (CI 95%) were calculated to summarize the data. Inferential statistical analysis involved Chi-square tests to ascertain the strength of associations between the variables of interest and the collected demographic characteristics. The threshold for statistical significance was set at $p < 0.05$.

3 Results

3.1 Characteristics of the Study Participants

Table 1. displays general socio-demographic characteristics of Algerian and Tunisian survey respondents.

Both panels are predominantly composed of women, with a slightly higher percentage in the Tunisian panel (62.8% of Algerian and 76.3% of Tunisian respondents). Most respondents are aged between 25 and 60 years (64.9% of Algerian and 76.2% of Tunisian), which represents a broad working-age demographic. Both panels consist largely of highly educated individuals, with a higher proportion of university-educated respondents in the Tunisian panel (76% of Algerian and 90.4% of Tunisian), and 52% are single.

However, differences in household size and employment status between the two panels were observed. Algerian respondents (63%) typically belong to larger households (5 or more members), while Tunisian respondents are more likely to belong to smaller households (fewer than 5 members) (77.5%). There was a difference in professional activity between the two panels, with more Tunisian respondents (66.7%) being employed than Algerian respondents (32.5%). Consequently, these differences in panel composition could influence survey responses related to economic or consumption patterns.

This was related to the fact that this study used a convenience sampling method. We selected participants solely on a voluntary basis. This selection limits the generalizability of our findings. Therefore, the sample is not fully representative of the entire adult population in Algeria and Tunisia. This happens because of its non-probabilistic nature. Nevertheless, the sample accurately represents the specific demographic groups we studied (Jribi *et al.*, 2020). The profiles also largely match similar studies done in the region. This holds true for gender, education, and professional activity (Arous *et al.*, 2017; Jribi *et al.*, 2020; Sassi *et al.*, 2016). To reduce the limitations of the non-random sampling, we applied survey weights in all our Chi-square

Table 1. Socio-demographic characteristics of Algerian and Tunisian survey respondents.

% Respondents	Algeria (n=316)	Tunisia (n=320)
Category		
Sex		
Women	62.8	76.3
Men	37.2	23.7
Age (years old)		
18 – 24	22.1	14.7
24 – 40	44.9	53.8
41 – 60	25.4	22.4
≥ 61	7.6	9.1
Marital Status		
Single	52	52
Married	48	48
Education		
Primary/High schools	4.3	1.9
Professional training	12.9	7.7
University	82.8	90.4
Number of persons in the household		
1	7.3	12.8
2	11.6	17.9
3	16.5	23.1
4	21.8	23.7
5	22.4	15.4
≥ 6	20.4	7.1

analyses (Jribi *et al.*, 2020). This action helps us improve the data's representativeness.

3.2 Household Bread Storage and Wastage Patterns: Influence of Sociodemographic Characteristics

To assess current levels of bread waste in relation to household storage practices, participants were initially asked about their methods and duration of storing unconsumed bread at room temperature. The results are presented in Table 2. Multiple responses were permitted.

In Algeria, the majority of respondents declared storing bread in the freezer (83.8%) and at room temperature (76.5%), with a smaller proportion indicating storage in the refrigerator (23.4%). When asked about storage conditions at room temperature, 47.5% reported using plastic bags, 20.1% used cotton bags, and 2% did not follow any specific storage method. No statistically significant associations were found between these practices and sociodemographic characteristics. Regarding the duration of room temperature storage, 46.1% of Algerian respondents affirmed storing bread for two days, 27.9% for three to four days, and 23.4% for one day. Storage duration was significantly associated with age and marital status ($p < 0.05$).

In Tunisia, bread was most commonly stored at room temperature (72.4%), followed by the freezer (60.3%) and, to a lesser extent, the refrigerator (27.6%). Among those storing bread at room temperature, 32.1% used plastic bags and 26.9% used cotton bags, while 3.8% did not apply any specific storage method. No significant associations were observed with sociodemographic factors but were significant with place of purchase (χ^2; $p = 0.003$) (data not shown). In terms of storage duration, 44.9% of Tunisian respondents reported keeping bread for two days, 28.2% for one day, and 26.3% for five days or more. Reported storage duration was significantly associated with age ($p < 0.05$), as well as with bread purchase quantity (χ^2; $p = 0.024$) and place of purchase (χ^2; $p = 0.001$) (data not shown).

Finally, survey data analysis indicated that storage methods did not exhibit significant associations with the perception of bread price and quality in either the Tunisia or Algeria panels (data not shown). However, the perception of price significantly influenced storage duration in the Tunisia panel (χ^2; $p = 0.001$). Similarly, storage duration was significantly associated with the perception of quality in both Algeria (χ^2; $p = 0.001$) and Tunisia (χ^2; $p = 0.042$) panels (data not shown).

Respondents were also requested about the fate of bread after storage (Table 2). In Algeria, 40.8% reported discarding bread after storage, and this behavior was significantly associated with gender, age, and marital status ($p < 0.05$). In Tunisia, 43.6% reported discarding stored bread, with no significant associations identified with sociodemographic variables. Additionally, discarding store bread was not significantly associated with the storage methods for both panels, but with storage duration in the Tunisian panel (χ^2; $p = 0.004$) (data not shown).

Furthermore, 73.9% of Algerian respondents and 50% of Tunisian respondents indicated that bread weight contributes to wastage (Table 2). While no sociodemographic associations were found in Tunisian panel, gender and household size were significantly related to perceptions of the influence of bread weight on waste in Algerian panel ($p < 0.05$).

Furthermore, 73.9% of Algerian respondents and 50% of Tunisian respondents indicated that bread weight contributes to wastage (Table 2). While no sociodemographic associations were found in Tunisian panel, gender and household size were significantly related to perceptions of the influence of bread weight on waste in Algerian panel ($p < 0.05$).

Table 2. Algerian and Tunisian Respondents' Self-Reported Storage Practices of Unconsumed Bread, by Demographics*

	Algeria Panel			Tunisia Panel		
	% Respondents	CI (95%)	Significant demographics (Chi² p-value < 0.05)	% Respondents	CI (95%)	Significant demographics (Chi² p-value < 0.05)
Storage method						
Room temperature	76.5	[73.9 – 7 9.0]	None**	72.4	[69.8 – 75.0]	None**
Plastic Bag	46.6	[44.0 – 49.1]		2.1	[29.5 – 34.7]	
Cotton Bag	21.5	[18.9 – 24.0]		26.9	[24.3 – 29.4]	
Bread Box	7.3	[4.7 – 9.8]		9.6	[7.0 – 12.1]	
None	1.6	[0.9 – 4.1]		3.8	[1.2 – 6.3]	
Refrigerator	23	[20.4 – 25.5]		27.6	[25.0 – 30.1]	
Freezer	78.9	[78.1 – 79.6]		60.3	[59.5 – 61.0]	
Room temperature Storage time (days)						
1	31.6	[30.0 – 33.1]	Age p = 0.020 Marital status p = 0.027	28.2	[29.9 – 33.2]	Age p = 0.047
2	46.1	[44.5 – 47.6]		44.9	[44.4 – 47.7]	
3-4	18.4	[16.8 – 19.9]		0.6	[16.7 – 20.0]	
5 and more	3.9	[2.3 – 5.4]		26.3	[2.2 – 5.5]	
Discarding bread after storage						
Yes	40.8	[39.8 – 41.7]	Gender p = 0.010 Age p = 0.020 Marital Status p = 0.047	43.6	[42.8 – 44.5]	None**
Bread Weight						
Fosters wastage	67.1	[60.5 – 73.7]	Gender p = 0.010 Household size p < 0.001	50.0	[49.0 – 50.9]	None**
Reduces wastage	32.9	[26.3 – 39.5]		50.0	[49.0 – 50.9]	

*Data are more detailed in Supplementary data; Tables S1 and S2.
**None: no significant difference was observed in neither demographic category p > 0.05.

3.3 Bread Management Practices and their Association with Sociodemographic Factors

To better understand how bread leftovers are managed at the household level, respondents were asked to report their reuse and disposal practices. The results, allowing for multiple responses, are presented in Table 3.

Algerian respondents reported slightly higher rates of reheating (82.5%) and humidifying prior reheating (55.2%) stored bread (Table 3). These practices were significantly associated with gender and marital status for reheating (p < 0.05), and with education level for humidifying prior to reheating (p < 0.05). In contrast, among Tunisian respondents (Table 3), the most common practice was reheating bread directly in the oven or toaster (78.8%), followed by humidifying the bread prior to reheating (41.0%). No significant associations were found between these practices and sociodemographic variables.

The reuse of stored bread in meals emerged as the most prevalent practice among Algerian households (87.0%), with significant associations observed for gender, age, and household size (p < 0.05) (Table 3). This reuse practice was less common in Tunisia (Table 3), where 63.5% of respondents reported incorporating leftover bread into meals, and its use was significantly associated only with household size (p < 0.05).

Feeding leftover bread to animals was another widely adopted management strategy, particularly in Algeria, where 83.1% of respondents reported this practice. The behavior was significantly influenced by household size (p < 0.05). In Tunisia, 46.2% of respondents indicated using bread in animal feed, with significant associations observed for both age and household size (p < 0.05).

3.4 Future Intentions and Motivations to Reduce Bread Waste

Figure 1 presents the respondents' self-reported intentions regarding future efforts to minimize bread waste in Algeria and Tunisia.

Approximately 37.7% of Algerian respondents and 16.0% of Tunisian respondents expressed a clear intention to

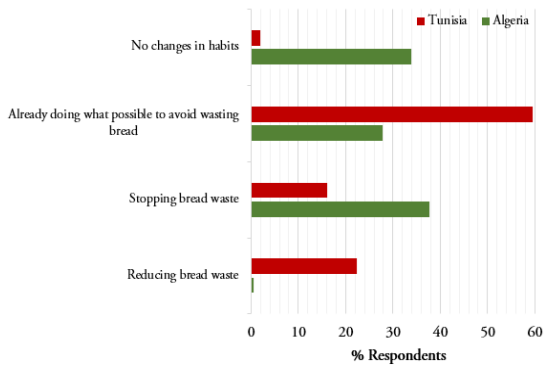

Figure 1. Survey Results on the Respondents' Future Intentional Behavior Toward Bread Waste Prevention

completely stop wasting bread. An additional 0.6% of Algerians and 22.4%

of Tunisians reported being willing to reduce their bread waste. Meanwhile, 27.9% of Algerian and 59.6% of Tunisian respondents stated that they were already doing everything within their means to avoid wasting bread. Notably, 33.8% of Algerian respondents and only 1.9% of Tunisian respondents indicated no willingness to modify their behavior toward bread waste prevention. These behavioral intentions were significantly influenced only by marital status (χ^2; p = 0.001) and behavior towards bread waste (χ^2; p = 0.006) for the Algeria panel (data not shown).

Participants were also requested to indicate their primary motivations for minimizing bread waste in the future (Table 4). Moral and ethical concerns emerged as the most frequently cited reason, reported by 47.9% of Algerians and 51.9% of Tunisians. Religious considerations were the second most common motivator, particularly in the Algeria panel (36.6%), followed by the Tunisia panel (27.6%). In contrast, environmental concerns (7.0% in Algeria and 12.8% in Tunisia panels) and economic factors (8.5% in Algeria and 7.7% in Tunisia panels) were the least cited motivations. Among Algerian respondents, gender and household size were the demographic variable found to be significantly associated with motivations to reduce bread waste. For the Tunisia panel, motivations were significantly influenced only by age (χ^2 p = 0.001), and for the Algeria panel, by age and behavior towards bread waste (χ^2; p = 0.001) (data not shown).

3.5 Policy Recommendations for Reducing Bread Wastage

To inform strategies for bread waste reduction, respondents were asked to provide their policy recommendations in Algeria and in Tunisia (Figure 2).

Implementing awareness and education campaigns to combat bread wastage was the most frequently suggested measure for both Algeria (38.8%) and Tunisia (39.2%) panels. Improving bread quality for enhanced preservation was the second most cited recommendation (Algeria: 31.1%; Tunisia: 23.1%), followed by the removal of subsidies on baguettes to reflect the true price (Algeria: 21.4%; Tunisia: 26.9%). A minority of respondents recommended providing anti-waste recipe booklets for bread reuse (cakes, desserts, dishes, etc.) (Algeria: 8.7%; Tunisia: 10.0%), while only a

Table 3. Self-Reported Strategies for Handling Bread Leftovers Among Algerian Respondents, Categorized by Demographics*

	Algeria Panel			Tunisia Panel		
	% Respondents	CI (95%)	Significant demographics (Chi² p-value < 0.05)	% Respondents	CI (95%)	Significant demographics (Chi² p-value < 0.05)
Reuse in meals	87.0	[86.1 – 87.8]	Gender p = 0.012 Age p = 0.022 Household size p < 0.001	63.5	[62.6 – 64.3]	Household size p = 0.036
Heating	82.5	[76.0 – 89.0]	Gender p = 0.018 Education p = 0.028	78.8	[78.0 – 79.5]	None**
Humification and heat	55.2	[47.0 – 56.1]	Education p = 0.009	41	[40.0 – 42.0]	None**
Animal feed	83.1	[77.0 – 89.0]	None**	46.2	[45.2 – 47.1]	Age p = 0.034 Household size p = 0.028
Donation to vulnerable	70.1	[63.0 – 77.0]	Gender p = 0.001 Household size p < 0.001	46.8	[69.1 – 71.0]	None**
Donation to collectors	59.1	[51.0 – 67.0]	None**	37.8	[36.8 – 38.7]	Household size p = 0.006
Compost	11.7	[7.0 – 17.0]	None**	9.6	[8.9 – 10.2]	None**

*Data are more detailed in Supplementary data; Tables S3 and S4; **None: no significant difference was observed in neither demographic category p > 0.05

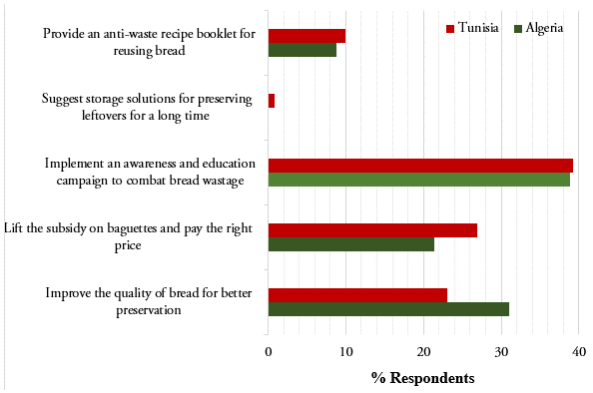

Figure 2. Survey Results on the Respondents' Policy

small fraction suggested solutions for long-term storage of unconsumed bread (Tunisia: 0.8%). These recommendations were significantly influenced by household size in Tunisia (χ^2; p = 0.001) and by existing behavior towards bread waste for both Algeria (χ^2; p = 0.043) and Tunisia (χ^2; p = 0.024) panels (data not shown).

proportion of Tunisian households opting for ambient storage exposes a critical vulnerability. This preference, particularly in the region's warm climate, directly contributes to accelerated quality degradation and subsequent disposal. The inconsistencies with earlier studies (Ghaziani *et al.*, 2022) further underscore the lack of consistent adoption of evidence-based preservation methods across different populations and contexts, signifying a failure in disseminating and internalizing crucial knowledge. The widespread use of plastic bags in both countries (47.5% and 32.1%, respectively) presents another point of contention. While intended to retain moisture, their propensity to foster mold growth in humid conditions (Alpers *et al.*, 2021) actively undermines waste reduction efforts. Similarly, the continued practice of refrigeration (23.4% in Algeria, 27.6% in Tunisia), despite its documented acceleration of starch retrogradation and subsequent staling (Alpers *et al.*, 2021), reveals a persistent misunderstanding of optimal storage conditions. The assertion that consumers often store bread inappropriately (Svanes *et al.*, 2018; Fami *et al.*, 2019; Belska

Table 4. Self-Reported Reasons for Avoiding Bread Wastage Among Algerian and Tunisian Respondents, Categorized by Demographics.

	Algeria Panel		Tunisia Panel	
	% Respondents	CI (95%)	% respondents	CI (95%)
Environmental	7	[5.6-8.4]	12.8	[11-14.5]
Economical	8.5	[7.1-9.9]	7.7	[5.9-9.4]
Religious	36.6	[35.2-38]	27.6	[25.8-29.3]
Significant demographics (Chi² p <0.05)	Gender p = 0.049		Age p = 0.001	

*Data are more detailed in Supplementary data Tables S5 and S6

4 Discussion

The present investigation, conducted *online* in Tunisia and Algeria, provides valuable insights into household bread storage practices, waste management behaviors, future intentions, motivations, and policy recommendations concerning bread wastage. The findings revealed a complex interplay of storage habits, waste management behaviors, sociodemographic factors, and attitudinal drivers influencing the significant levels of bread waste observed in both contexts.

Gap Between Reported Practices and Optimal Bread Preservation

Firstly, the reported differences in bread storage practices between Algeria and Tunisia, while seemingly descriptive, actually highlight a fundamental failure in the adoption of optimal preservation techniques. The Algerian preference for freezing (83.8%) stands in stark contrast to the Tunisian reliance on room temperature storage (72.4%). While freezing is undeniably the superior method for extending shelf life and minimizing waste by inhibiting microbial spoilage and staling (Dong & Karboune, 2021), the significant

et al., 2024) is not merely an observation but an indictment of the prevailing lack of awareness and effective guidance.

Furthermore, this study revealed that a significant share of respondent's store bread at room temperature for two days or longer, with some Tunisians extending this to five days or more, demonstrating a disregard for the limited shelf life of bread and the associated risks of spoilage and quality deterioration (Fadda *et al.*, 2014; Dong & Karboune, 2021; Alpers *et al.*, 2021). The fact that sensory judgment is the primary reason for discarding food (WRAP, 2011; Jribi *et al.*, 2021) directly links these prolonged, suboptimal storage practices to increased waste. While the study found no significant associations between storage methods and the perception of price and quality, the positive correlation between perceived price and storage duration in Tunisia, and between storage duration and perceived quality in both countries, offers a weak argument for intrinsic motivation. It suggests that value perception influences storage duration, not necessarily the adoption of effective storage methods. This nuanced finding does not negate the overarching problem of

inadequate storage techniques leading to premature spoilage and avoidable waste.

High Levels of Post-Storage Bread Wastage as Evidence of Ineffective Practices

Substantial reported levels of post-storage bread wastage – 55.8% in Algeria and 43.6% in Tunisia – serve as irrefutable evidence of the failure to translate even basic storage into effective waste prevention. The significant associations between sociodemographic factors (gender, age, marital status in Algeria) and discarding bread highlight the heterogeneous nature of this problem and the inadequacy of blanket solutions. The lack of such associations in Tunisia does not diminish the overall high rate of disposal. The suggestion that this behavior stems from limited control over storage practices and inadequate shopping/planning (Ananda *et al.*, 2024; Jribi *et al.*, 2021; Mattar *et al.*, 2018; Østergaard *et al.*, 2018;) merely identifies contributing factors, not solutions. The argument that improper storage is a "critical driver" of waste (Shahnoushi *et al.*, 2013; Østergaard *et al.*, 2018) is self-evident and underscores the urgent need for targeted interventions to improve these practices. The finding that storage duration is more strongly associated with post-storage waste than method in this study, contrasting with Ghaziani *et al.* (2022), does not lessen the importance of both factors. Prolonged storage, regardless of the method, inevitably leads to waste if the initial storage conditions are not conducive to maintaining quality. The potential for technological innovations like natural preservatives and optimized fermentation (Dong & Karboune, 2021), and modern storage solutions like vacuum-sealing (Alpers *et al.*, 2021), while promising, remain largely unimplemented at the household level in these contexts. Therefore, the call for public awareness campaigns on appropriate storage and portion planning is not a novel solution but a reiteration of a persistently unmet need.

Intuitive Adoption of the 3R Approach: A Reflect of Sustainable Behavior

Interestingly, the findings of the present study suggest that both Algerian and Tunisian consumers have, to some extent, intuitively adopted a 3R approach—Reduce, Reuse, and Recycle—in managing leftover bread, rather than discarding it outright. This behavior reflects not only economic considerations but also the deep cultural and symbolic value attributed to bread in North African societies, where it is regarded as a staple food imbued with significant social and religious meaning (Allipour Birgani *et al.*, 2023; Ben Ismail *et al.*, 2022). Such cultural reverence may act as a deterrent to wasteful practices and reinforce the importance of utilizing leftover bread. Reheating—either directly or following humidification—emerged as the most commonly reported method of repurposing stored bread among respondents in both Algeria and Tunisia. In addition, the incorporation of stale bread into traditional recipes remains a widespread practice, particularly in Algeria. Examples include its use in dishes such as *lablebi*, *mchalwich*, *ftet*, *blankit* salad, stuffed vegetables (*mehchi*), tagines, breaded meats (*mkaffan*), and soups where toasted bread (*bochmat*) is added for texture and flavor. Reuse of leftover bread in meal preparation was particularly prevalent among Algerian households (87.0%), contrasting with Tunisians (63.5%). Likewise, previous studies indicated varying adoption rates of these practices, with Śmiechowska and Chrzanowska (2015) reporting that 38% of consumers process bread leftovers into breadcrumbs, 18% into toasts, and 14% into croutons. Similarly, Bilska *et al.* (2024) found that over one-third of their respondents prepare breadcrumbs, while less than 14% utilize stale bread for other dishes. In Turkey, primary repurposing methods for stale bread were mainly reuse in meals (64%; Demirtaş *et al.*, 2018), including frying (40.82%) and reuse in other meals (39.56%) (Gul *et al.*, 2003). This disparity in adoption rates may reflect differences in cultural habits, time constraints, or culinary knowledge. In Tunisia, creative reuse of bread may not be embedded in everyday routines or may be perceived as too time-consuming, especially in busy households. Furthermore, intergenerational transfer of knowledge about traditional reuse methods may be weakening, leading to a decline in sustainable practices among younger demographics (Allipour Birgani *et al.*, 2023). In this context, targeted educational initiatives aimed at promoting the reuse of bread—especially among younger generations and time-constrained households—could prove effective in reducing food waste. Digital platforms and social media campaigns offer promising avenues for disseminating information about sustainable practices, as demonstrated by Jribi *et al.* (2023), who emphasized the importance of tailoring food waste interventions to the values and habits of *Generation Z*. Moreover, mobile applications designed to monitor household food consumption could further support behavioral change by tracking bread purchases, suggesting appropriate storage methods, and offering timely reminders to consume bread before spoilage. Such tools could also recommend recipes based on available leftovers, thereby facilitating bread reuse while accommodating user preferences.

The current study also highlights the widespread practice of repurposing leftover bread for animal feed, especially in Algeria (83.1% vs. 46.2% in Tunisia), this is a pragmatic solution aligning with the food waste management hierarchy (Hardy & Desmet, 2021) and offering environmental benefits (Brancoli *et al.*, 2020). This form of reuse aligns with previous findings reported by Gul *et al.* (2003), Śmiechowska and Chrzanowska (2015), Capone *et al.* (2016), Demirtaş *et al.* (2018), Ananda *et al.* (2024), and Bilska *et al.* (2024). However, its lower adoption due to the urban Tunisian panel

highlights the limitations of this method based on access to livestock. Similarly, the donation of leftover bread to waste collectors (including *barbechas* in Tunisia), while a valuable recycling mechanism, relies on an informal system with inherent limitations in scale and efficiency. The act of donating to the vulnerable (70.1% in Algeria, 46.8% in Tunisia), while commendable from a social perspective, does not fundamentally address the root cause of bread waste. Composting, the most environmentally sound option for unsalvageable bread, remains sadly underutilized (9.6% in Algeria, 11.7% in Tunisia), indicating a significant gap in awareness and implementation of sustainable disposal methods (Ananda *et al.*, 2024; Capone *et al.*, 2016; Lundie & Peters, 2005).

The Interplay of Bread Storage, Waste, and Sociodemographic Factors

The present research has established the interrelationship between storage practices, consumer management skills, bread waste, and sociodemographic factors in Algeria and in Tunisia. On one hand, it has clearly demonstrated significant associations between sociodemographic and behavioral factors (age, marital status in Algeria; age, purchase quantity, place of purchase in Tunisia) and storage duration, as well as the discarding of stored bread (Algeria). On the other hand, it has shown that older adults are more likely to find alternative uses for stale bread, such as using it for dishes, compared to younger individuals. This could be due to a higher level of culinary knowledge and skills. Older adults also report feeding leftover bread to animals. Furthermore, gender was found to have an impact on how individuals manage stale bread. Men reported more frequently discarding stale bread, but surprisingly in Algeria men reuse stale bread in other dishes, contrasting with findings of Bilska *et al.* (2024). This trend was not observed in Tunisia ($p>0.05$). Women are more inclined than men to heat stale bread and to donate, whereas men reported feeding leftover bread to animals. Bilska *et al.* (2024) pointed out that gender, age, and education level did not significantly affect the practice of giving stale bread to individuals with animals or efforts to prevent staling. The present investigation exhibited that marital status and household size can also play a role in how individuals manage stale bread. Larger households may be more likely to find creative uses for stale bread in order to feed a greater number of people. They also report to feed stale bread to animals and to donate. Similar findings were noted by Bilska *et al.* (2024). Large households might be more aware of the economic implications of food waste, leading them to be more proactive in finding ways to repurpose stale bread. Smaller households may be more inclined to compost, more aware of environmental implications of food waste. Overall, sociodemographic factors were shown to significantly impact how individuals store and manage stale bread, suggesting that targeted educational campaigns or interventions could be more effective if tailored to specific demographic groups.

Willingness to Reduce Waste versus Resistance to Change: A Behavioral Challenge

Interestingly the expressed willingness of a significant proportion of respondents to reduce waste (around 38% in both countries) presents an opportunity, but the substantial segments who believe they "already do what they can" (especially 59.6% in Tunisia) or are unwilling to change (33.8% in Algeria) pose significant challenges. Addressing the former requires education on more effective practices, while the latter necessitates strategies to foster problem awareness and personal responsibility (Hebrok & Boks, 2017). Leveraging moral, ethical and religious values in communication campaigns (Demirtaş *et al.*, 2018) can be a promising avenue. Chammas & Yehya (2020) and Aleshaiwi & Harries (2021) have reported that in Arab countries such Lebanon and Saudi Arabia, the religious prohibition ('haram') against wasting edible food ('bayt'), despite its lower preference compared to fresh food, compels consumers to adopt management strategies to avoid this transgression. This creates a tension between the desire for the enhanced enjoyment of freshly prepared meals and the religious obligation to utilize edible leftovers, highlighting the significant influence of religious values on food consumption behaviors and waste avoidance. By thoughtfully weaving together religious teachings, moral considerations, practical solutions, and culturally relevant communication channels, it would possible to develop a powerful and effective awareness campaign that leverages the inherent desire to avoid the "sin of waste" and promotes more sustainable food practices, but it requires careful and culturally sensitive implementation.

Despite the cultural and practical motivations for reducing waste, economic factors may act as barriers to reuse in North African context. In this region where bread is subsidized (Capone *et al.*, 2016), consumers may perceive limited financial incentive to extend its use. Our analysis indicated that in Tunisia, perceived bread value influenced storage duration, suggesting that consumers might be more inclined to retain bread when it is seen as economically significant. However, this perception did not necessarily translate into higher rates of bread reuse.

Altogether, the findings of this study point out the need for multidimensional strategies—incorporating cultural, educational, and technological components—to foster sustainable consumption and reduce bread wastage in North African households.

Policy Implications for Algeria and Tunisia: Towards a Multifaceted Strategy

In terms of policy implications for Algeria and Tunisia, this study reinforces existing recommendations for household-level food waste mitigation. Consumer education emerges as a crucial element, evidenced by its top ranking as a suggested measure in both Algeria (38.8%) and Tunisia (39.2%). This aligns with findings from Abouabdillah *et al.* (2015), Capone *et al.* (2016), Arous *et al.* (2017) and Jribi *et al.* (2023), regarding the need for enhanced information and guidance to prevent food wastage. Information dissemination can increase awareness, subsequently fostering pro-environmental behavior change (van Geffen *et al.*, 2020). Effective information tools should address specific knowledge gaps driving wasteful practices, such as providing practical resources like anti-waste recipe booklets or mobile applications for bread reuse (Algeria: 8.7%; Tunisia: 10.0%), as suggested by our respondents, alongside education on the environmental consequences of food waste. However, the policy implications are clear: consumer education, while consistently recommended, is insufficient on its own (Hebrok & Boks, 2017; Stöckli *et al.*, 2018). It must be integrated with non-informational interventions like modeling, prompts, and economic incentives or disincentives. The significant relationships between sociodemographic factors and bread management practices unequivocally support the need for targeted interventions. The recommendation for enhanced bread preservation qualities necessitates government intervention through minimum quality standards and potentially incentivizing bakeries to adopt longer-lasting production methods. The Tunisian Ministry of Agriculture mandated for a more nutritious, bran-inclusive subsidized bread, while aimed at nutritional improvement and curbing flour misuse, may indirectly contribute to longer shelf life due to the nature of wholemeal bread (AfricanManager, 2023). However, its effectiveness in reducing overall bread waste requires further monitoring. Readdressing subsidies and pricing as recommended by survey panelists is a politically sensitive but potentially crucial step towards promoting a more realistic valuation of bread and reducing wasteful consumption patterns (Obeidat *et al.*, 2015; Khader *et al.*, 2019). In Egypt, Yigezu *et al.* (2021) have observed a decline in household bread waste, linked to the 2014 implementation of targeted food vouchers for the most vulnerable populations, replacing widespread flour subsidies. The former subsidy model, by maintaining artificially low bread prices, may have inadvertently contributed to higher consumption and subsequent waste. In contrast, the voucher system appears to have fostered more judicious bread consumption among recipient households, potentially enhancing their overall nutritional intake (Yigezu *et al.*, 2021).

In conclusion, the persistent problem of household bread waste in Algeria and Tunisia demands a comprehensive and assertive strategy. Relying solely on consumer awareness campaigns or traditional reuse practices is demonstrably inadequate. A multifaceted approach encompassing targeted education, economic incentives, technological innovation in bread production and storage, and a critical re-evaluation of existing subsidy policies is essential to achieve meaningful reductions in bread waste and progress towards SDG 12.3. Further research, as acknowledged by the study's limitations regarding online surveys, is crucial to gain a more nuanced understanding of actual household practices and the effectiveness of various interventions. Only through a concerted and evidence-based argumentative approach can these nations hope to truly address the persistent problem of the wasted loaf.

It is worth noting that our study has several limitations, due to web-based panels for consumer survey and convenience sampling. Due to significant differences in the demographic composition of the Algerian and Tunisian panels, this study does not perform direct statistical comparisons between countries. Instead, the analysis focuses on identifying and comparing the patterns of significant associations within each national context, treating them as separate case studies. Online food waste surveys can suffer from sampling bias (exclusion of less connected populations) and potentially inaccurate reporting (under- or over-estimation by respondents) (Ben Hassen *et al.*, 2022), which limits the generalizability of findings. Survey participants may have under-reported their actual levels of food waste while over-reporting their efforts to reduce it (Van Gefen *et al.*, 2020; Jribi *et al.*, 2020). Furthermore, they do not allow direct observation of actual food waste management practices.

5 Conclusion

This study highlights significant gaps in bread storage and management practices across Algerian and Tunisian households, underscoring the need for targeted interventions to mitigate bread wastage. Findings revealed that improper storage practices, coupled with extended storage durations, contribute substantially to bread waste. While a considerable proportion of respondents express a willingness to reduce their bread waste, current storage practices, particularly regarding room temperature storage in plastic bags and the subsequent discarding of stored bread, present key areas for intervention. Sociodemographic factors such as age, marital status, and household size influenced both storage duration and bread reuse practices, pointing to the need for tailored solutions addressing specific demographics.

Bread management practices varied, with reheating and incorporating leftover bread into meals being prominent in Algeria, while direct reheating was the preferred method in Tunisia. Notably, practices like composting remained underutilized in both countries. Motivations to reduce bread waste were primarily driven by ethical and religious

considerations, with environmental and economic concerns playing a secondary role. This indicates a cultural and moral impetus for change but highlights the need to strengthen awareness around the environmental and financial implications of bread waste.

Respondents' policy recommendations emphasized information and education campaigns, improving bread quality for extended shelf life, and potential subsidy adjustments to reflect the true cost of bread. Such measures align with the behavioral drivers identified in the study and suggest a multi-pronged approach to reducing bread waste in North Africa. Indeed, these policy measures, when implemented collaboratively by governments, NGOs, and community organizations, can significantly mitigate bread waste, reducing environmental impacts, fostering more sustainable consumption habits and aligning with the goals of SDG 12.3. in Algeria and Tunisia.

To further advance our understanding and inform more effective interventions, future research should focus on the analysis of the North African bread supply chain, by investigate potential points of waste along the bread supply chain, from production to retail, to identify systemic issues that contribute to the overall problem.

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