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Original Article

Global Magnitude of the Bread Wastes and its Reasons: A Systematic Review and Meta-analysis of Observational Studies

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ABSTRACT

Background and Objectives: Bread, as a staple food, is a significant part of food waste and a potential threat to food security. This study aims to systematically investigate and quantify the global extent of bread waste and its reasons.

Materials and Methods: We searched PubMed, EMBASE, Web of Science and Scopus databases from 1990 to February 2024. We selected observational studies that reported the proportion of bread waste. Random effects models were used to calculate the pooled effect sizes of bread waste.

Results: 28 observational studies were included in the systematic review and 22 in the meta-analysis, with a sample size of 8,408,344 participants. The pooled size (weighted proportion) of bread waste was 18% (95% confidence interval (CI): 14–24; I2 = 99.94%, $p < 0.002$). Proportion of bread waste as a consequence of consumers' practices and beliefs estimated with pooled effect size 24% (95% CI: 21–28; I2 = 95.2%, $p < 0.001$) compared with retailers and producers' activities pooled effect size 14% (95% CI: 10–18; I2 = 98.2%, $p < 0.001$).

Conclusions: Bread waste prevalence was high, which is due to the behaviors of consumers and retailers. Therefore, community food and nutrition education are prescribed.

Keywords: Bread waste, systematic review, consumer behavior; meta-analysis

Highlights

- Bread wastes have increased during recent years in middle income and high-income countries.
- The 18% of global bread waste threaten three goals of the sustainable development goals (SDGs), including zero hunger (Goal 2), responsible consumption and production (Goal 12) and climate change (Goal 13).
- Evidence-based policies from different countries may help policymakers to reduce bread waste by changing consumer's behavior and overcome food insecurity globally.
- The 24% of global bread waste was related to consumers' behavior, belief and knowledge.
- Bread waste proportion decreased during world economic bankruptcy and food inflation (2007–2011) years, hence showed positive correlations to economic situations of consumers.

Introduction

Food wastes has a significant effects on global food and nutrition security, food quality and safety, natural resource conservation and environmental preservation. It has an impact on economic growth and food system sustainability (1). Despite a dramatic increase in food production, approximately one in nine people in the world is food insecure (2). Because of its nutritional properties and because it is a staple food, it is not surprising that nutritionists define bread as an essential part of the food pyramid and the base of the diet (3). Bread is one of the world's most widely consumed cereal products. Therefore, bread wastes are serious global concerns (4). Bread wastes relates to the part of breads, which are removed from the food supply chain and frequently considered as avoidable wastes simply because of their lack of inedible components (5).

Several investigations have been performed to assess quantity of bread wastes across various nations. According

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to a study undertaken by the Waste and Resources Action Programme (WRAP), it was found that homes in the UK disposed of nearly 20 million complete slices of breads each day in 2012. This disposal was mostly attributed to the phenomenon of 'not used in time' (6, 7). Official reports in Iran frequently state that consumers' waste about one-third of the breads because breads are often not appropriately baked. Moreover, as a consequence, consumers may not perceive the whole of breads as edible, while the staling process of breads starts shortly (8). A study in Shiraz, in the south of Iran, showed that nearly 30% of wheat wastes occur in the supply chain in the form of breads, especially during consumption (9). Consumers and retailers often dispose significant quantities of breads due to their susceptibility to staling and spoilage, resulting in potential economic losses (10). Reducing bread wastes includes great potentials to decrease the environmental effects associated to breads (11).

Several countries try to determine the actual proportion of bread wastes amongst their populations and compare their worldwide standings. Nevertheless, the quantity of global bread wastes lacks definitive scientific data. These statistics provide potential values for food policymakers since they enable them to ascertain factors contributing to this predicament and identify policies that contribute to their occurrence. Therefore, the present study was carried out to quantify the extent of bread wastes in several stages of the bread supply chain, including consumers and producers and to clarify primary factors contributing to this issue.

Materials and Methods

This is a systematic review and meta-analysis that was designed based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) (12) and meta-analysis of observational studies in epidemiology (MOOSE) guideline statement (13). In this study, PICOTS was referred to population, people consuming breads in their diets, intervention, none; comparator, none, ; and outcome, changes in proportion of bread waste by the consumers, bakeries, retailers and producers (industrial bread companies).

Search strategy

We systematically searched of online databases, including SCOPUS, PubMed, EMBASE, Web of Science, Google Scholar, Magiran and Iranian Scientific Information databases for observational studies, which were published from 1990 to February 2024. No limits were included for geographic regions and languages. Furthermore, a manual search was carried out for additional relevant studies by screening reference lists of the retrieved studies and grey literature. In addition, reference lists of review articles were checked to identify further relevant studies. Duplicate citations were removed. The search strategy is provided in detail in Supplementary Table 1.

Study selection (inclusion criteria)

We selected relevant studies based on the following criteria: Observational studies designed with case-control, cohort or cross-sectional, all studies reported the prevalence of bread waste, studies assessed the bread waste in production process, retail stage or in consumption phase and those investigated reasons of wheat bread waste. No restrictions were imposed on geographical regions (e.g. urban, rural, Asia and Africa), time period or age groups. Two investigators (SL and RAB) independently checked the titles and abstracts initially. Reviewers excluded articles that did not meet the eligibility criteria by designing screen form and conducted hierarchical approaches based on the study design, exposure, population and outcome. During the second evaluation, full-texts of all eligible articles were retrieved and screened. Disagreements were discussed and resolved by consensuses.

Exclusion criteria

We excluded articles if they were reviews, animal studies, short communications, letters, books, grey literatures, including congress abstracts, dissertations, and patents, published in languages other than English and those were irrelevant to the subject of the review. In addition, articles that investigated other types of bread waste (e.g. corn, rice and sorghum) or did not report the proportion of bread wastes were excluded.

Data extraction

Two researchers (SL and RAB) independently extracted data from each eligible study according to a predefined format and resolved disagreements by discussion. The following data were extracted: first author, date of publication, country, continent, study design, time of data collection, reported effect sizes, including prevalence of bread waste and 95% CI of wheat bread waste in bakeries, retailers or households, bread waste assessment method, total sample size, number of total subjects and bakeries or retailers in each category of bread waste production, proportion in each category of wheat bread waste was the key outcome variable and area/place of bread waste production (consumers in households and bakeries or retailers).

Quality assessment and assessment of the risk of bias

Quality of the observational studies was assessed based on the set of criteria based on Joanna Briggs Institute (GBI) guidance on conducting prevalence and incidence reviews (14), common method known as GBI for the quality assessment of studies in systematic reviews and meta-analyses of observational studies. Studies were classified

into three quality groups and labeled high quality if they managed to obtain 7–9 points, medium quality when 4–6 points were collected and low quality when they scored less than 3 points (9 was considered as the highest quality, while the low-quality studies did not meet the criteria for meta-analysis). All discrepancies were resolved through discussion between the corresponding authors (SL and RAB). Supplementary Table 2 presents result of the risks of bias assessment.

Data analysis

Statistical analysis

Pooled prevalence estimates with 95% CIs for bread waste were calculated using random-effects model. If between-study heterogeneity was significant, DerSimonian-Laird random-effects model was used to take between-study variations into account. In some studies, proportions were under 5%, therefore CI Method (exact) or binominal method was used based on the metaprop commands (15). Heterogeneity in the studies was assessed using Cochran Q test and I^2 statistics (16). Heterogeneity was considered significant if Q statistic included $p < 0.1$ or $I^2 > 50\%$ (17). In the analysis, where $I^2 > 50\%$ was observed, possible sources of heterogeneity were investigated using sub-group analyses based on pre-defined criteria, including setting of bread waste production (bakeries and retailers) or consumption (households), geographical region (five continents), period of study or time of data collection (from 1990 to February 2024, categorized every 5 y). Results are presented in tables and forest plots, where prevalence ratio and 95% confidence intervals (CI) were figured out for every study inserted in the model and overall estimation. To examine heterogeneity between the subgroups, fixed-effects model was applied.

Sensitivity analysis was used to assess unusually large influence of an individual study or a group of studies on the results. If this was the case, data were reanalyzed by excluding that study. Trim and fill method was used to detect the effect of possible missing studies on the overall effect. In addition, publication bias was examined to visualize inspection of asymmetry in funnels plots. Egger's regression asymmetry test was used to assess potential publication bias. To avoid systematic bias, studies were entered into the model of each cumulative meta-analysis successively based on data collection time not the publication time. However, for those studies; in which, dates of data collection were not reported, dates of publication for the purpose of the cumulative analysis were used. All statistical analyses for the current meta-analysis were performed using STATA software v.14.0. A *p*-value of less than 0.05 was considered significant for all tests, including Cochran's Q test.

Results

We identified 849 articles in initial search. In electronic search, 1027 articles were retrieved while additional hand search was carried out in grey literature (n = 8) such as theses (n = 2), official unpublished reports (n = 4), government documents (n = 2) and Persian databases (n = 32) (SID, Magiran and identified extra sources). After removing duplicates (n = 111), other 852 papers were excluded through title and abstract screening. Out of 64 remaining articles, 36 articles were excluded due to the following reasons of 1) studies that assessed other type of breads (n = 10); 2) those that did not report the wheat bread waste on effect size of percentage (n = 7); and 3) studies that assessed other characteristics of breads (n = 12). Out of seven remaining studies, three were reviews, one was not observational study, one was a report and two were conference articles. Furthermore, three studies were conducted in two various areas and the percentage of bread waste (bakeries or retailers and households) was unclear. Finally, 28 cross-sectional studies were included in this systematic review; of them, 22 articles were entered in the meta-analysis. The reviewers reached consensus on the final articles eligible for inclusion in the study (18).

Finding of systematic review

A summary describing characteristics of the selected studies on the prevalence of bread waste worldwide is present in Table 1. Overall, the 28 studies selected in this systematic review comprised 8,408,346 subjects, 16 out of 28 of which were recruited from households (9, 19–33), seven studies selected from bakeries and retailers (34–40) while the remaining five studies were conducted in the two areas (5, 11, 41–43). Five studies (37–40, 43) with samples from retailers or bakeries did not report the number of participants but reported the percentage of bread wastes. Prevalence of bread wastes reported by all the studies ranged from 3% to 43%. From 12 studies whose study participants were both from retailers or bakeries and households (5, 11, 34–43), seven studies reported prevalence data for all participants as well as for households, retailers or bakeries separately (5, 11, 34, 40–43). Most studies (17 out of 28) were conducted in the European countries (5, 11, 19, 20, 25–27, 29–31, 34–40). Ten studies (9, 21, 22, 24, 28, 32, 33, 41–43) were from the most populated continent (Asia) and only one study (23) was from North America continent. Moreover, 19 studies carried out in high-income countries (5, 11, 19, 20, 23–27, 29–31, 34–40), nine studies were from middle-income countries (9, 21, 22, 28, 32, 33, 41–43), while no studies were from low-income countries.

Table 1. Descriptive summary of 28 studies on the global magnitude of bread waste, included for systematic review and meta-analyses, 1990 to February 2024

Author	Country	year	Origin of Bread Waste production	Measurement approach	Bread waste (%)	Sample size	Household size	Country Income Classification	Time (data collection)	Continent	Reasons of bread wasting
Fami	Iran	2019	Consumer	Questionnaire or Interview	20.05	3950	3.3	Middle	2018	Asia	-Being not familiar with the advanced methods of keeping bread at home, -Members of traditional bakeries should be educated
Brancolia (a)	Sweden	2019	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	13	1430	2.2	High	2015	Europe	-Households over purchasing, -Take-back agreements of retailers, -Price reductions, -Bakeries produce more to meet demand of fresh bread -The bread stock is usually purchased in a last-in, first-out, -Stores routinely remove products from their shelves up to three days before the best-before date
Katajajuuri	Finland	2014	Consumer	Both approach	13	1054	2.8	High	2010	Europe	- Bread was either mouldy or otherwise undesirable, -Presumably due to drying out and becoming less appetizing
López-Avilés	UK	2019	Consumer	Questionnaire or Interview	27	158000	2.6	High	2004	Europe	-Consumer habits (e.g. weekly shopping in supermarkets and large retailers or preferring to buy fresh bread more frequently and locally when walking to and from work)
Gül.	Turkey	2003	Consumer	Questionnaire or Interview	9.6	1656	4.14	Middle	2002-2003	Asia	-Consumer habits (don't like stale bread)
Mahdavi D.	Iran	2008	Consumer	Questionnaire or Interview	42.6	8200000	3.41	Middle	2004-2005	Asia	-Inappropriate production methods, -Inappropriate storage and consumption by households, - Low bakeries' facilities
Carroll	Canada	2020	Consumer	Both approach	25	339	3.98	High	2017-2018	3	-Eat out or purchase takeout food on a regular basis
Herzberg	Germany	2020	Consumer	Questionnaire or Interview	13.8	11917	2.1	High	2016-2017	Europe	-Limited durability, - Quantity-related problems: large packaging or portion sizes
Bilska	Poland	2019	Consumer	Questionnaire or Interview	23.8	1115	2.6	High	2019	Europe	-Purchasing bread in bulk, -Frequency of buying
Djekic	Serbia	2019	Consumer	Questionnaire or Interview	31	1746	2.9	High	2018	Asia	- Insufficient knowledge of the meaning of 'best before' and 'use by' stated on food labels may be one of the triggers for this reason

Author	Country	year	Origin of Bread Waste production	Measurement approach	Bread waste (%)	Sample size	Household size	Country Income Classification	Time (data collection)	Continent	Reasons of bread wasting
Hanssen	Norway	2016	Consumer	Questionnaire or Interview	27	592	2.69	High	2011	Europe	-Norwegian consumers eat more bread-based meals and have also different preferences for fresh bread, -Focus on "crunchy" products which will be naturally soften quickly and hence be vulnerable to wastage
Khader	Jordan	2019	Both (Consumer &Bakeries-Retailers)	Both approach	12.93	480	4.8	Middle	2011-2015	Asia	-Using bread as animal feed, -Large package sizes, -Flour subsidies,
Dooren	Netherland	2019	Consumer	Observe waste	26.25	1049	2.2	High	2016-2020	Europe	-People with an above-average income have twice waste, -Not using a shopping list, -Less aware of their food wasting behavior
Mohammadi (a)	Iran	2007	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	22	8000	3.3	Middle	2003-2004	Asia	-No vocational education in baking, -Low level of labors' expertise job satisfaction, -Cooling down and remaining in that state for several hours so rapid staling, -Low level of baking quality was the prime cause of bread waste, -Family income was negatively related to bread waste, -Bread price have inverse effect
Milicevic	Italy	2019	Consumer	Questionnaire or Interview	35	50	2.4	High	2018	Europe	-Inferior quality or prepared and cooked badly, -No knowledge of the methods of food preservation, -Difficulty of storing, -Food surpluses are produced and cooked badly
Svanes E. (b)	Norway	2018	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	14.7	39	2.2	High	2010-2015	Europe	-Have mentioned before
Svanes E. (a)	Norway	2018	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	8.2	6000	2.2	High	2010-2015	Europe	-Poor product quality, -Bad packaging, -Poor storage at home or during transport to home, -Consumers confuse date labelling and poor quality, -Preferring fresh bread
Obeidat Z.	Jordan	2015	Consumer	Questionnaire or Interview	28.45	1644	4.8	Middle	2014-2015	Asia	-Behavior patterns especially in the consumption of bread, -The loss suffered by the subsidy of bread, -Low price in bakeries
Partearroyo	Spain	2018	Consumer	Questionnaire or Interview	25	2009	2.53	High	2013	Europe	-Bread is highly perishable and can dry quickly and becoming unappealing to consumers
Ratinger T.	Czech	2016	Bakeries-Retailers	Questionnaire or Interview	5	271	2.3	High	2015	Europe	-Lack of freshness and low quality of bakery products,

Author	Country	year	Origin of Bread Waste production	Measurement approach	Bread waste (%)	Sample size	Household size	Country Income Classification	Time (data collection)	Continent	Reasons of bread wasting
											-The enormous price changes might suggest shift from quantity toward quality for bakery products, -Large retail chains – their shops, -Notion of freshness of bakery products has changed, -Nowadays, molds develop faster than earlier in bread
Eriksson M.	Sweden	2015	Bakeries Retailers	Questionnaire or Interview	10	NR	2.2	High	2012	Europe	-Bread is one of the cheapest types of food that can be bought in Sweden
Brancolia P. (b)	Sweden	2019	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	13.7	380	2.2	High	2015	Europe	-Have mentioned before
Mena C.	UK-SPAIN	2011	Bakeries Retailers	Questionnaire or Interview	7	2	2.3	High	2010	Europe	-Products are generally fragile and have short shelf-life, -Primary packaging often plastic
Lebersorger S.	Austria	2014	Bakeries Retailers	Questionnaire or Interview	2.8	612	2.3	High	2011-2012	Europe	-Expiration of product dates, -Exceeding best before or sell-by date
Beretta C.	Switzerland	2013	Bakeries Retailers	Questionnaire or Interview	5.1	NR	2.18	High	2011	Europe	-Unsold food products
Mohammadi (b)	Iran	2007	Bakeries Retailers	Questionnaire or Interview	22	800	3.3	Middle	2003-2004	Asia	-No vocational education in baking, -Low level of labors' expertise job satisfaction, -Cooling down and remaining in that state for several hours so rapid staling, -Low level of baking quality was the prime cause of bread waste, -Family income was negatively related to bread waste, -Bread price have inverse effect
Asadi, A	Iran	2010	(Consumer & Bakeries-Retailers)	Questionnaire or Interview	16.3	NR	4.53	Middle	1995-2001	Asia	-Using of additives in baking breads, -Lack of facilities to preserve bread and flour, -Inappropriateness conditions of baking breads, -Lack of familiarity of bread consumption in restaurants and public organizations, -Uneducated personals in baking breads, - Low prices of breads, -Lack of bread distribution monitoring
Brancoli	Poland	2016	Bakeries Retailers	Observe waste	30	NR	2.6	High	2014-2015	Europe	- Supermarkets often produce 7% more than the expected sales in order to meet the consumer demands.

Author	Country	year	Origin of Bread Waste production	Measurement approach	Bread waste (%)	Sample size	Household size	Country Income Classification	Time (data collection)	Continent	Reasons of bread wasting
Banasik,A.	Netherland	2016	Bakeries Retailers	Questionnaire or Interview	11	NR	2.2	High	NR	Europe	- Most of the bread products must be sold on the production day due to quality characteristics and consumer acceptance, -The decision on production quantities is commonly made before the actual (exact) demand is known, - Supermarkets usually order more bread than the actual demand in order to avoid stock outs.
Shahnoushi N et al.	Iran	2013	Consumer	Questionnaire or Interview	13	4805	3.41	Middle	2008	Asia	-The habit of consuming bread fresh in Turkey raises consumer waste in stale bread. - poor quality and poor storage of bread constitute the majority bad taste - Poor quality, poor appearance, mold -kept in the room conditions or in the bread box for the daily consumption - the easy crumbling due to the hardening and the deterioration of the appearance are considered as staling, - excessive buying of bread. More than needed.
Demirtaş B. et al.	Turkey	2018	Consumer	Questionnaire or Interview	7	406	4.64	Middle		Asia	-Highly subsidized price for bread. -Mainly low price. -the existence of a market for sale -bread to be used as feed for livestock. -quality issues, the attachment of consumers to very fresh bread - particular having to walk to the bakery. - increased waiting time at the bakery- simply carrying it by hand) will also decrease the bread's shelf life. the number of visits to the bakery per week, method of carrying bread , monthly household income household education, -household average age, method of preserving bread

All studies except one reported time or duration of the bread waste proportion in their respected country (39). 11 studies (5, 11, 25, 28, 30, 34, 36–38, 40, 41) investigated bread waste production, during 2011–2015, followed by eight studies (9, 23, 24, 26, 27, 29, 31, 33) in 2016–2020. Only three studies (19, 32, 35) were carried out during 2006–2010, while five studies (20–22, 42, 43) were carried out before 2006.

Generally, 24 out of 28 studies measured bread waste through questionnaires or interviews as a measurement approach (5, 9, 11, 20–22, 24–29, 42, 43). Only one study used observational method to assess practices (40), while the remaining three studies used both approaches (19, 23, 41). Household size of the included participants was less than 2.5 in 11 studies (5, 11, 26, 29, 31, 34–39), Furthermore, 2.6– to 3 household size in seven studies (19, 20, 24, 25, 27, 30, 40) and above 3.1 in ten remaining studies (9, 21–23, 28, 32, 33, 41–43). All studies reported the main reasons of wheat bread waste. In eight studies, consumers' behavior, practice, belief and knowledge were reported to cause bread wastes production (20, 23–25, 27, 29, 31, 33). Only one study reported the retailer and producer (bakeries or bread companies) (35), while nine studies (9, 19, 21, 26, 30, 34, 38, 40, 43) reported both of consumers and retailers or producers (bakeries) as waste producers. Ten out of 28 studies stated that the governments, retailers, producers and consumers might cause bread wastes (5, 11, 22, 28, 32, 36, 37, 39, 41, 42). Fourteen included studies met the medium quality score, eight studies had high scores and the remaining six studies scored low quality. Maximum quality scores were achieved only in one study (Supplement Table 2).

Pooled estimates of the bread waste proportion and its causes

Analysis of 22 cross-sectional studies ranked as medium to high quality (5, 9, 11, 19–34, 36, 41, 42), estimated that the pooled proportion of wheat bread waste was 18% (95% CI: 14–24; I^2 = 99.94%). The total sample size of the studies included in the meta-analysis was 8,408,344 participants. Of them, 8,406,240 participants recreated from households and 2104 participants were selected from bakeries and retailers. Due to the heterogeneity of included studies, further sub-group analyses were carried out using the following study characteristics: Continent of the country, measurement approach (questionnaire, interview or observational waste behavior), reasons or causes of the bread waste (consumers, governments and retailers and producers), household size (≤ 2.5, 2.6–3 and ≥ 3.1), origin of bread waste production (household, consumer, bakeries-retailers or both of consumers and bakeries–retailers), study duration time (2001–2005, 2006–2010, 2011–2015 and 2016–2020), country income-level (high, middle and low incomes).

The prevalence of the bread waste was observed higher because of consumers' behavior, practice, belief and knowledge, compared to retailers and producers (bakeries or bread companies) in all three groups. Weighted pooled prevalence of bread waste was 24% (95% CI: 21–28%) with regard to consumers' behavior, practice, belief and knowledge, 14% (95% CI: 10–18%) for retailers and producers (bakeries or bread companies) and consumers and 16% (95% CI: 6–30%) for combined government, retailer, producer and consumer group (Figure 1). Generally, bread waste increased in larger households. Weighted pooled prevalence of bread waste was the lowest value as nearly 15% (95% CI: 11–20%) in households less than 2.5-person group, while the highest value as 24% (95% CI: 20–28%) was in 2.6–3-person group. In the largest family size of ≥ 3.1-person group, it was 19% (95% CI: 9–32%), a little lower than the second group (Figure 2).

The prevalence of bread waste could vary substantially in the household and retailer-producer (bakeries) areas as the origins of the bread waste production. Weighted pooled prevalence of bread waste was higher in the studies, whose participants were recruited from households as a bread waste origin [22% (95% CI: 17–28%)], compared to study from both origins of retailer-bakeries and households [10% (95% CI: 5–17%)], which insist on retailers or bakeries. In this group, the authors reported a cumulated proportion of both participants (Figure 3) (5, 11, 34, 36, 41, 42). Group of study participants, who were recruited from retailer-bakeries, did not meet the inclusion criteria in meta-analysis, as they did not mention the sample size and scored low quality (35, 37–40, 43). The prevalence of bread waste varied based on the time duration of data collection and the study publication date. The lowest weighted pooled prevalence of bread waste was during 2011–2015 [14% (95% CI: 8–21%)], compared to the highest values during 2001–2005 [24% (95% CI: 15–35%)] and [22% (95% CI: 16–28%)] during 2016-–2020. Only two study (19, 32) were included in duration time category of 2006–2010 with proportion of [13% (95% CI: 12–14%)] (Figure 4). The higher proportion of bread waste reported in Asia with weighted pooled prevalence of [20% (95% CI: 11–30%)] while, the proportion in Europe was almost close to this prevalence and showed [17% (95% CI: 12–23%)] (Figure 5).The global map of bread wastes according to pooled estimates is presented in (Figure 6).

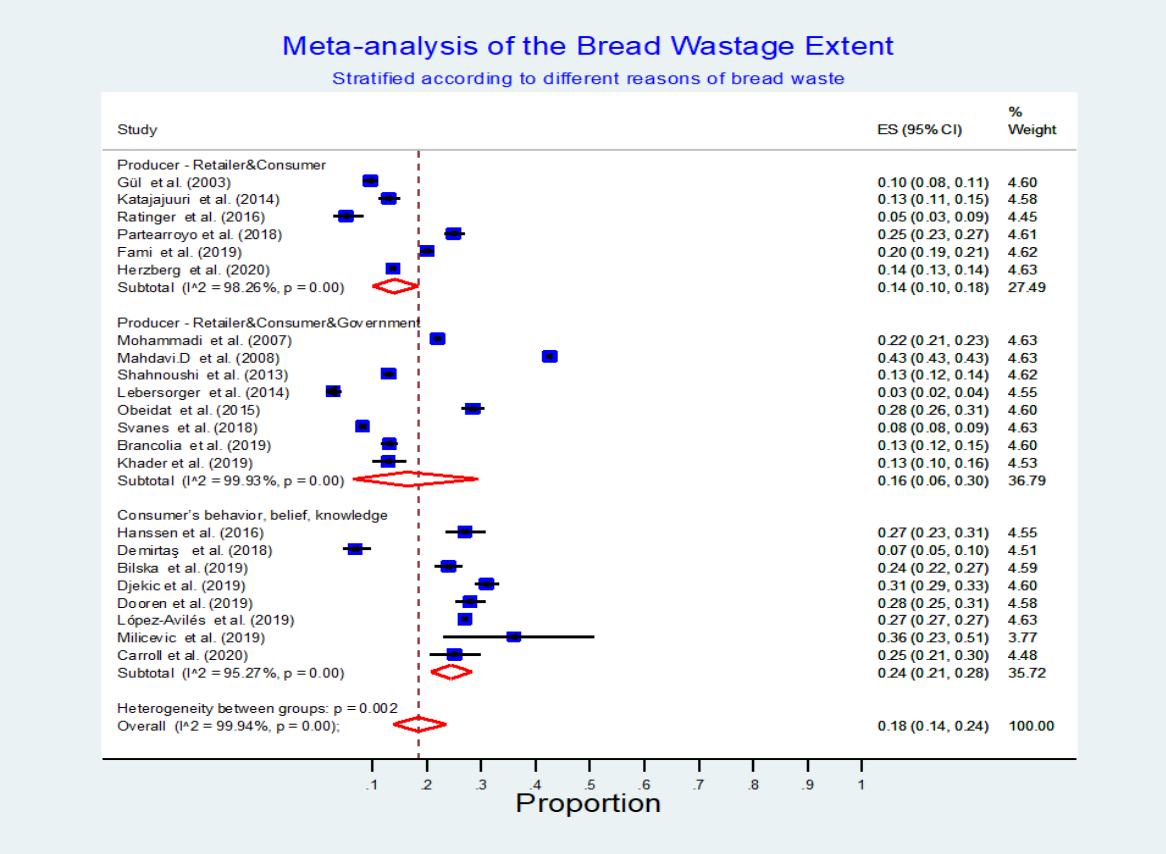

Figure 1. Forest plot of prevalence [95% confidence intervals (CIs)] of the bread waste extent worldwide, stratified based on the reasons of bread waste production. Diamonds represent pooled estimates from random effects analysis

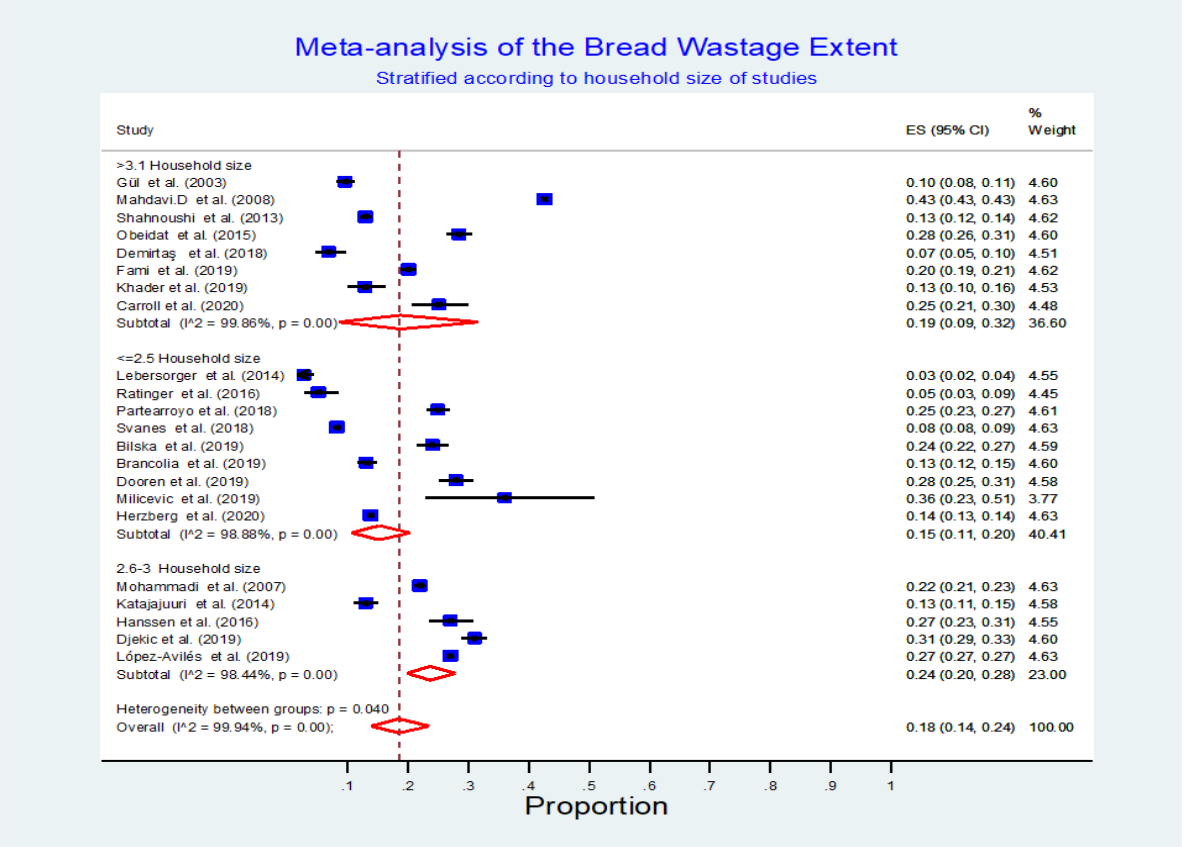

Figure 2. Forest plot of the prevalence [95% confidence intervals (CIs)] of bread waste extent worldwide, stratified based on the household size. Diamonds represent pooled estimates from random effects analysis

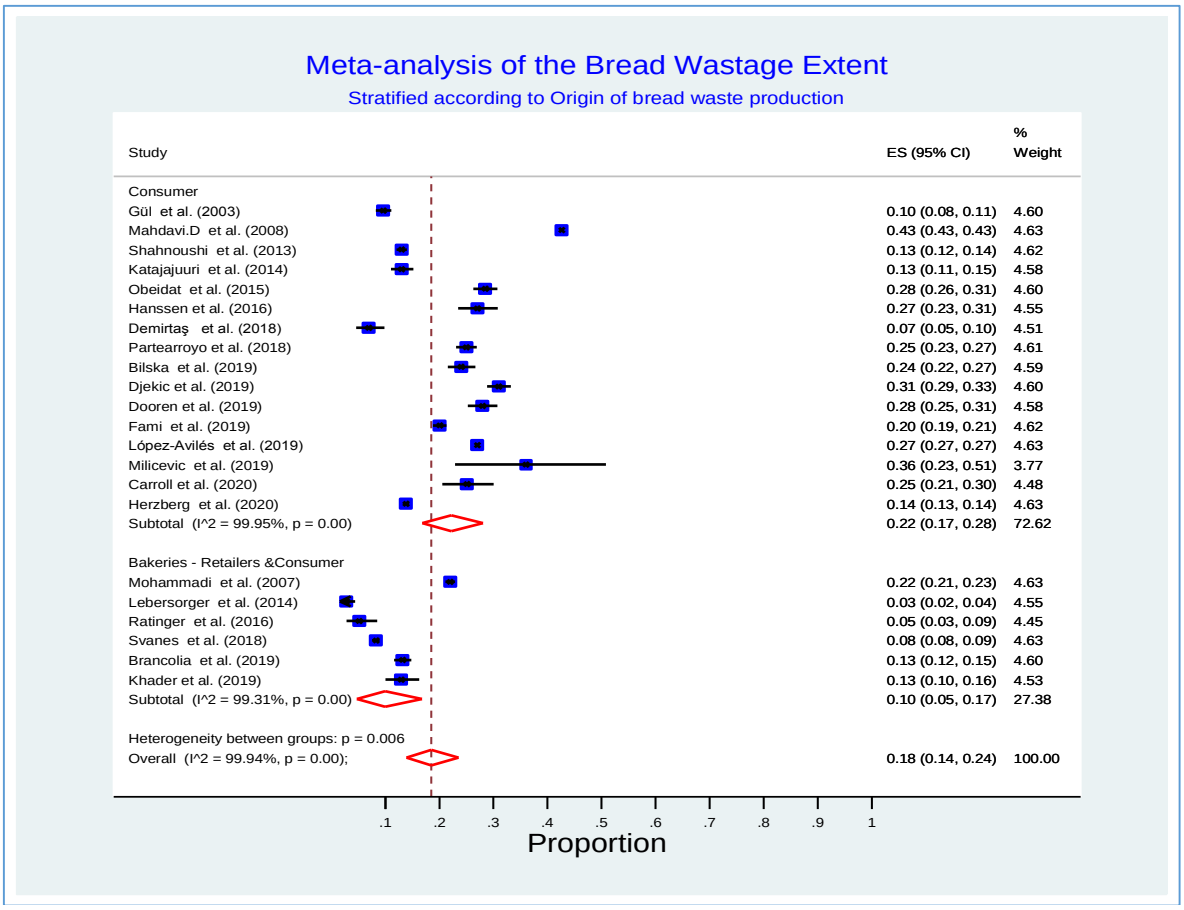

Figure 3. Forest plot of the prevalence [95% confidence intervals (CIs)] of bread waste extent worldwide, stratified based on the origin of bread waste production. Diamonds represent pooled estimates from random effects analysis

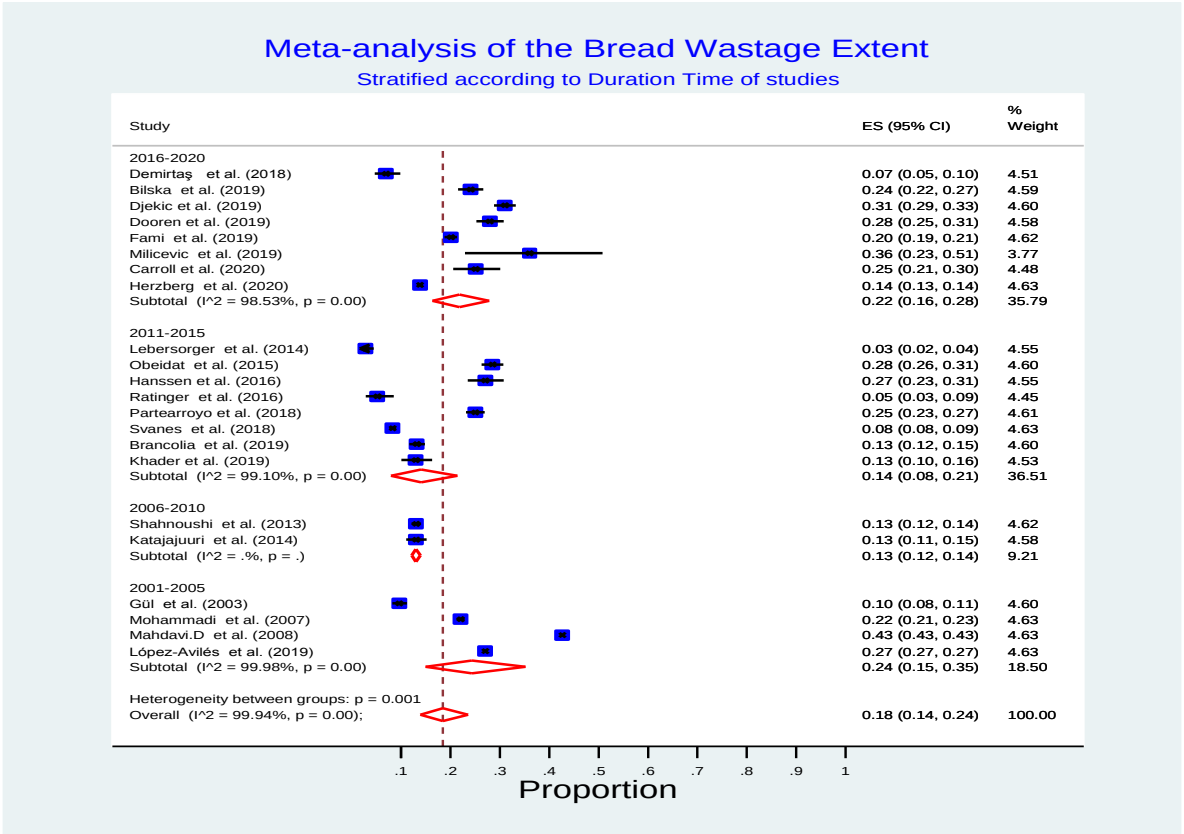

Figure 4. Forest plot of the prevalence [95% confidence intervals (CIs)] of bread waste extent worldwide, stratified based on the duration time of studies. Diamonds represent pooled estimates from random effects analysis

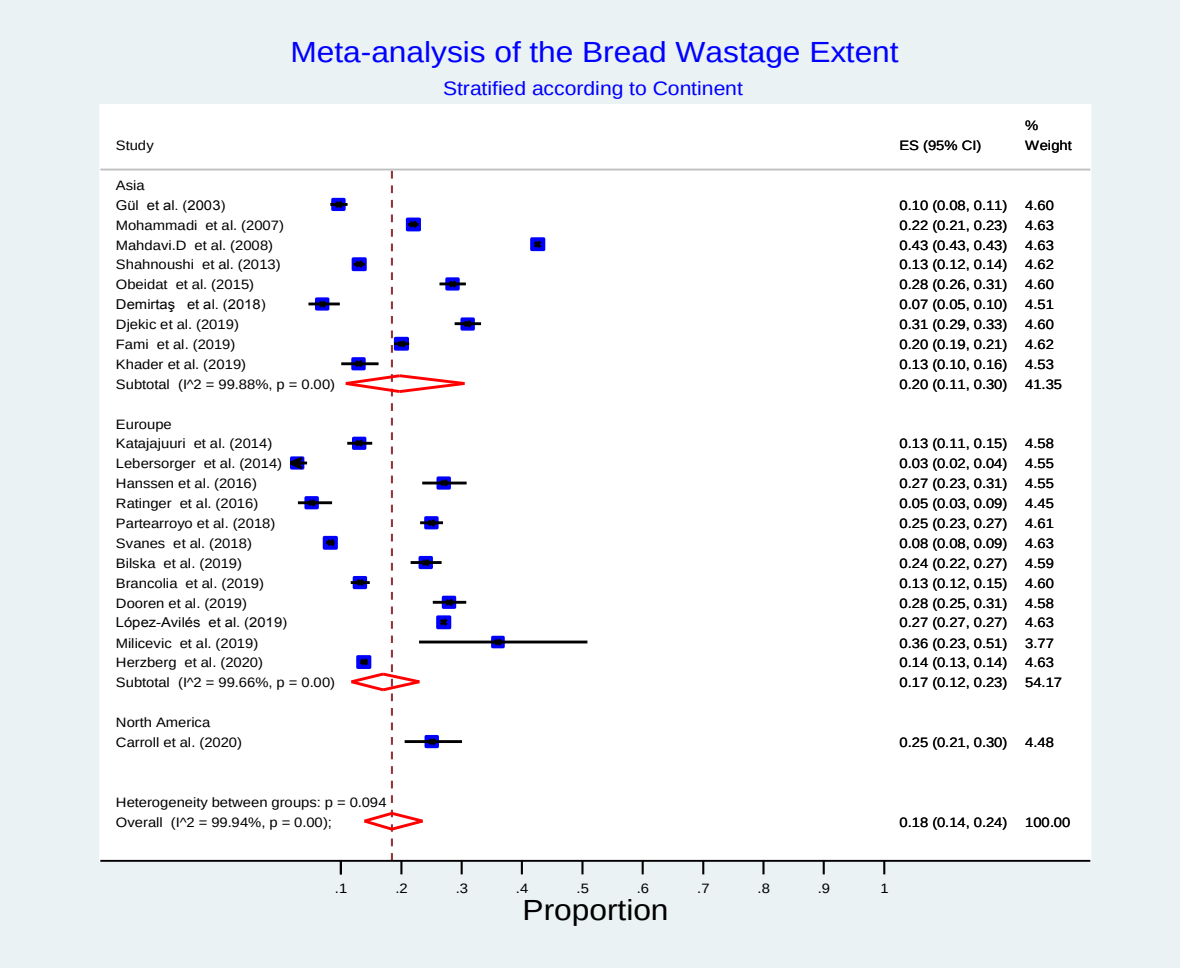

Figure 5. Forest plot of the prevalence [95% confidence intervals (CIs)] of bread waste extent worldwide, stratified based on the continent of studies. Diamonds represent pooled estimates from random effects analysis.

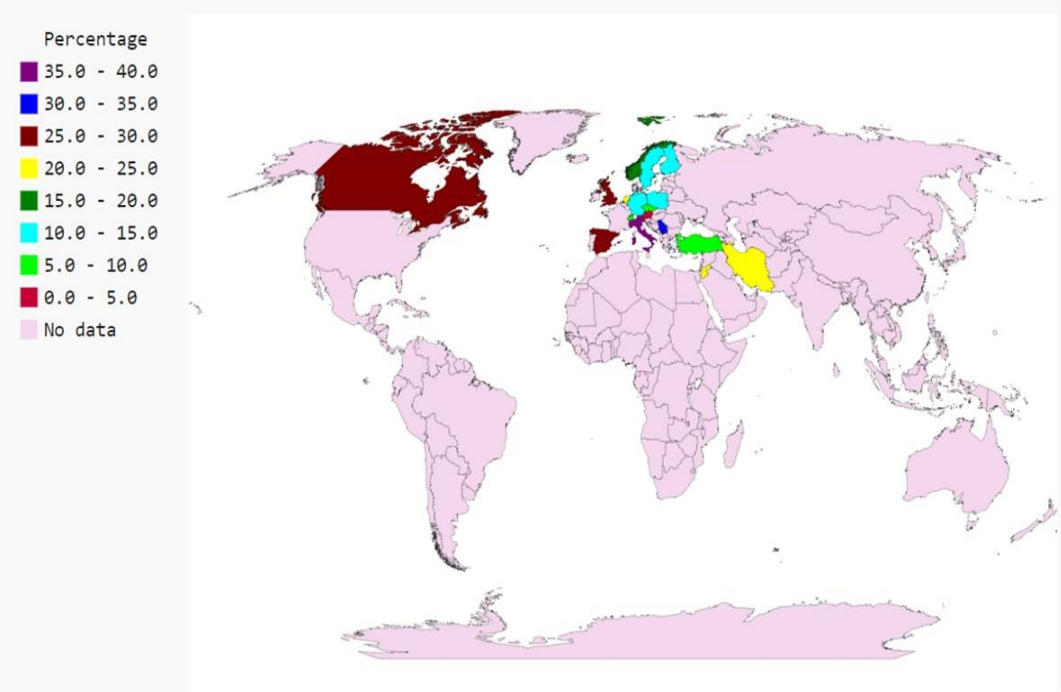

Figure 6. The global map of bread wastes

Publication bias and sensitivity analysis

Funnel plot indicated the existence of asymmetry and publication bias (Supplement Figure 2) and Egger's test ($p < 0.002$) (Supplement Figure 3) suggested the presence of small-study effects (44). Besides, trim and fill were carried out and reported publication bias. Funnel plot asymmetry could be due to many reasons other than publication bias. We are not also certain that the publication bias was the true cause of funnel plot asymmetry. However, it was included only English language studies and English language bias might also result in the publication bias. As such, we remain cautious in interpreting the results.

Sensitivity analysis

Leave-one-out sensitivity analysis was performed to confirm whether there were studies potentially biased the direction of the pooled estimate. Based on the leave-one-out sensitivity analysis, we found no outlier study that significantly shifted the primary pooled estimate (Supplemented Figure 4). Based on the GBI scale, a set of nine criteria were used to assess quality of the included studies. The sample was representative of the target population in 21 (75%) studies. Study participants were recruited appropriately in 14 (50%) studies. The sample size was adequate only in 14 (50%) studies. Study subjects and setting were described in detail in 19 (68%) studies. Data analysis was carried out with sufficient coverage of the identified samples in 13 (46%) studies. Objective standard criterion was used for reliably measure the conditions in most studies [22 (79%)]. All studies were accounted important for the subgroups. Results are summarized in Supplement Table 2. Our estimates did not show evidence of statistical heterogeneity between the groups of studies at the country level by income, quality assessment score of studies, sample size categories and measurement approach. Results are summarized in Supplement Table 3.

Discussion

The current systematic review and meta-analysis of observational studies revealed that the global pooled bread waste was 18%, with significant heterogeneity in the included studies. Subgroup analysis showed that households (consumers) were responsible for a higher proportion (22%) of bread waste as compared to producer-retailers (10%). Moreover, duration (study time) revealed the lowest bread waste rate (13%) during 2006–2010-time span category. The continent with the highest percentage of bread waste (20%) was Asia. Moreover, analysis showed that the most common reason for the bread waste was the consumers' knowledge, belief and practice with a proportion of 24%, compared to other reasons. The household size subgroup demonstrated the lowest proportion of bread waste among the category of smaller families with ≤ 2.5 persons (15%). Findings of the economic pooled analysis showed no differences between high and middle-income countries in production of bread wastes. There is scientific evidence that might explain this situation and the current study is an attempt in this regard.

Another review study reported a higher rate of wasting wheat bread (20%) (45, 46), which could be attributed to the fact that a majority of the primary studies included in the previous reviews were from MENA (Middle East and North Africa) (45, 47), a region with its population mostly consuming wheat breads as staple foods. Moreover, these studies were carried out on those countries with subsidy system for wheat flour and breads (45). A WRAP study relevant to the UK households reported that the household waste of bread was 29%. Indeed, bread waste represents a significant share of food wastes (48). It is estimated that bakery wastes correspond to 10% of all food wastes in the UK and 32% of all purchased breads are wasted in households.

Results of the subgroup analysis showed that consumers' behavior was responsible for 22% of the bread waste. In other words, the origin of this waste ratio was due to the consumers' unfavorable eating habits. The UK WRAP results also support our estimation (48). In line with the current results, studies in other European countries such as Norway shows that bread waste comprises 27% of the edible food waste masses (25, 49). Meta-analysis of studies on retail food-waste quantification also showed that 30.6% of the total waste mass in Italy were attributed to the practices of the retailers as well as the purchasing, storage and eating habits of the consumers (50). A significant high proportion (PP) of the bread wastes was observed during 2001–2005 (PP = 24%) and 2016–2020 (PP = 22%), compared to 2011–2015 (PP = 14%) and 2006–2010 (PP = 13%). Generally, in subgroup analysis of time duration within two categories of 2001–2006 and 2016–2020, food accessibility was credible for a majority of the people worldwide, especially to buy and consume wheat breads. Therefore, production of waste increased.

On the contrary, the years 2006 to 2010 group showed the least proportion, which led to food price inflation shocks during the global food price crisis in 2006–2008 (51), as well as in January 2011 (52). As a staple food, breads imposed more pressure on crop-importing countries in the Middle East. The present meta-analysis revealed that studies that investigated bread wastes were mostly conducted in countries where wheat was consumed as a staple food. During 2006–2008, food price surge happened due to the governmental policies in crop-producing countries, including the Russian Federation, Canada, USA, Argentina, the EU countries, Brazil, India, Pakistan, Thailand and Vietnam (53). Consequently, food accessibility has been lower, leading to decline of bread

purchase affordability and consumption in low and middle-income countries, which might have reduced quantity of the bread wastes (54).

We found that the rate of the bread waste was higher among consumers living in Asia (PP = 20%) as compared to consumers living in the European countries (PP = 17%). As Food and Agriculture Organization (FAO) and other meta-analyses have reported, most countries in west Asia and the Middle East consume wheat breads as staple foods, which might lead to increasing bread wastes in these countries (45, 55). However, a greater number of studies included in this systematic review and meta-analysis were from Europe. Larger households consumed higher quantities of breads. In a number of articles, more bread consumptions were directly related to bread waste production, and in line with to the current meta-analysis that showed the high prevalence of bread waste in larger household size between (19–24%) and the lowest bread waste was stated in lower household size of < 2.5 with a proportion of 15%. Study of WRAP showed the high prevalence of bread waste in the UK. In addition, studies from Iran and the UK that analyzed consumers' behavior were categorized in this subgroup with a prevalence of (24%) as the main reason for the bread waste production. Other studies (49, 56) showed similar findings to the present findings. In support of this several studies (28, 48, 49, 57, 58) stated that the knowledge and behavior of consumers were important factors for the bread waste production (45, 56), which in combination with producer-retailer and government activities constituted 16% of the reasons for waste production (45, 47, 50, 56). Governmental subsidies and rules were important as well (45). However, in producer-retailer part, the prevalence was 14%. Similar to the present findings, evidence from reviews (45, 56, 58) and primary studies (49) showed that a higher rate of bread waste by consumers was associated to the following factors: lack of knowledge on the distinction between best before and use by label dates, lack of knowledge on how to use the leftovers o in other recipes instead of discarding them, religious and cultural taboos in the region, methods of food preservation, less awareness of their food wasting behaviors and practices, purchasing in bulk and frequency of purchasing because of preferring fresh breads, weekly shopping in supermarkets and large retailers, using breads as animal feeds and not using shopping lists.

Several primary studies found a positive correlation between the household income and the quantity of bread waste. In some high-income countries such as Norway and the UK, proportion of the bread waste was unexpectedly high. However, pooled proportion of the bread waste in the subgroup analysis of this meta-analysis did not demonstrate significant heterogeneity between high and middle-income countries. The factors contributing to the increasing prevalence of bread waste in middle-income countries included food subsidies, government policies and consumer beliefs and traditions, especially in countries of the Eastern Mediterranean region i.e., Iran. Evidence showed that flour and bread subsidies in the Middle East region might promote wasteful consumption behaviors (32, 42, 45, 50, 59, 60). Therefore, it is necessary to make consumers and retailers aware about the environmental and health implications of their consuming behaviors (e.g. purchasing, overeating and wasting foods). It is essential to prioritize behavioral changes in bread consumption in all settings (61). Furthermore, modifiable factors involved in bread wastes, particularly those related to wheat bread producers or bakeries, need to be identified and addressed. In sum, increased public awareness and knowledge on the high prevalence of bread wastes, its consequences and burdens, educational programs on responsible eating practices and healthier lifestyles could be effective measures in preventing harmful impact of bread wastes on both the environment (decreases in carbon emissions) and natural resources (e.g. soil and water) (62, 63).

Strengths and limitations of the study

To the best of our knowledge, this is the first meta-analysis summarizing the prevalence of bread wastes in all countries of the world. The present findings may help policymakers improve bread production and consumption polices at various stages, including bread production, selling chain (e.g. supermarket, retailers, etc.) and at the household level. The major strength of this study is the large-pooled sample size, which might help estimate relationships between the major source of bread wastes areas and the related reasons that could not be estimated precisely in individual studies. In addition, this study included a broad diversity by including various countries from almost all continents.

Nevertheless, our study had three limitations. First, some included studies acquired data on bread waste through use of other effect sizes, which hampered the estimation of the proportion. Second, only the prevalence of wheat bread waste was explored, which led to identification of a limited number of studies, while most Latin American countries that consumed corn breads as well as the South East Asian countries, which mostly used rice breads were excluded. Third, all studies were cross sectional without diversities in types of observational studies, and only published in English, which might limit inclusion of some high-quality studies in our analysis.

Suggestions for future direction

Further studies are needed to assess the extent of wastes in the other types of breads such as corn, rice, and sorghum breads. We also recommend a various array of studies to assess health, economic and environmental impacts of this

type of food waste, which threatens the environment and food security.

Conclusions

This study revealed that bread wastes have increased in recent years, particularly in European and Asian countries, despite a substantial number of individuals experiencing food insecurity and starvation. Bread waste poses a significant risk to global food security. To address this issue, governments must adopt a comprehensive approach that involves the entire society and government. In conjunction with local, national, and regional initiatives to improve food and nutrition security, governments should promote collaborations and partnerships among various stakeholders to redesign regulatory frameworks and policies. The ultimate objective is to alleviate the burdens of bread wastes and enhance community nutrition education.

Authors' contribution

RAB contributed in conceptualization, investigation and supervision. SL and RAB contributed to the literature search, data curation. RAB contributed to the formal analysis. RAB, SL, HB and S.SH did the data interpretation. SL and RAB did the original draft. S.SH worked as methodological advisors. writing - review & editing by RAB, SL, HB and S.SH. The corresponding author attests that all listed authors meet authorship criteria. RAB is guarantor.

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Declarations of interest

None

Appendix A. Supplementary material

Supplementary material related to this article can be found in the online version.

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