Waste Management 169 (2023) 301–309

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Research Paper

Quantification and economic assessment of surplus bread in Italian small-scale bakeries: An explorative study

Roberta Pietrangeli [a], Mattias Eriksson [b], Christina Strotmann [c], Clara Cicatiello [d,*], Marco Nasso [d], Luca Fanelli [e], Luigia Melaragni [e], Emanuele Blasi [d]

[a] Department of Economics, Engineering, Society and Business Organization, University of Tuscia, via del Paradiso 47, 01100 Viterbo, Italy
[b] Department of Energy and Technology, Swedish University of Agricultural Sciences, Box 7032, Uppsala SE-75007, Sweden
[c] Institute of Sustainable Nutrition (iSuN), Münster University of Applied Sciences, Corrensstr. 25, Münster 48149, Germany
[d] Department for Innovation in Biological, Agro-Food and Forest Systems, University of Tuscia, via san Camillo de Lellis snc, 01100 Viterbo, Italy
[e] Italian Confederation of Craft Trades and Small- and Medium-Sized Enterprises (CNA), Association of Viterbo and Civitavecchia, via I Maggio 3, 01100 Viterbo, Italy

A B S T R A C T

The generation of bread waste at suppliers and retailers is often linked to the production of surplus bread. This study reports the results of the first direct quantification and economic assessment of surplus bread conducted in Italy, involving a panel of 12 bakeries and their branches located in the Lazio region, which compiled a daily diary for 5 months. They are small-scale bakeries which reflect the typical structure of the Italian businesses in the bakery sector, producing fresh bread and selling it directly to consumers. The surplus bread measured during the study consists of 6,694 kg in total, with an average quantity of 4.83 kg/day per bakery. Studying the three main products (common bread, focaccia bread and bread rolls), the average rate of surplus is respectively 5.88 %, 3.99 % and 5.28 % of the production. The corresponding economic loss represents, on average, 5.44 % of the daily turnover. A set of factors seems to exert highest influence on the generation of surplus, as the range of production, location and number of customers. When surplus bread occurs, in 63 % of the cases it is managed on alternative routes to avoid disposal. Even if detected surplus bread does not necessarily become waste, it indeed represents a big loss for bakeries.

1. Introduction and objective of the study

Bread is one of the most frequently wasted foods. In the United Kingdom, 32 % of all bread bought is wasted at household level (WRAP, 2011). In Sweden, bread waste at bakeries and retailers represents over 50 % of total bread losses along the value chain, including waste at consumption (Brancoli et al., 2019). In Germany, 1.7 out of 4.9 million t of baked goods (~35 %) is wasted, and 36 % of that amount is generated by surplus products remaining unsold (Schmidt et al., 2019).

The Italian bread value chain is mostly made up of small-scale bakeries (defined as companies with <10 employees) that sell fresh bread directly to consumers. In 2019, 24,433[1] small-scale bakeries were operating in Italy, representing 91 % of total Italian bakeries. According to estimates published by the Italian Association of Bakery Ingredients (AIBI, 2022), 1.4 million t of bread was sold on the Italian market in 2021, of which 84.1 % was artisanal bread made by small-scale bakeries and 15.9 % was industrially produced bread. In a market survey conducted by Businesscoot (2021), 85 % of Italian respondents reported consuming fresh and artisanal bread, with total demand of 1.6 million t per year. Bread still represents 70 % of production volume for small-scale bakeries, whereas pizza and focaccia currently account for 23.5 % and cakes for 6.2 % of the total (Businesscoot, 2021). Most Italian small-scale bakeries sell bread directly to consumers via their own bakery outlet/s, located next to the baking facilities or elsewhere in town. The structure is very different in other countries. For example, in Sweden, there are many small-scale bakeries that produce only for their own bakery shop or café, but the national bakery supply chain is characterised by a small number of large bakeries with highly industrialised processing facilities, which supply retailers and dominate the market (Brancoli et al., 2017). In Germany, the traditional bakery trade has been undergoing a change in recent decades. In 2021, there were 9,965 bakeries selling their products in 45,000 stores, but the number has more than halved since 1990. The surviving companies have become larger and now employ an average of 24 people.

Previous studies suggest that the main hotspot of waste in the bakery sector is at the supplier-retailer interface (Brancoli et al., 2019), and mainly stems from surplus produce (Garrone et al., 2014). The last data from Eurostat reports 146 kg per capita of food waste generated in Italy

* Corresponding author.
E-mail address: cicatiello@unitus.it (C. Cicatiello).
[1] Source: https://dati.istat.it.

https://doi.org/10.1016/j.wasman.2023.07.017
Received 18 January 2023; Received in revised form 2 July 2023; Accepted 12 July 2023
Available online 24 July 2023

every year, which is slightly higher than the average level in EU27 (131 kg per capita).[2] However, there has been no complete quantification of bread waste along the Italian value chain, and most research focuses on waste at the consumption stage (Fanelli, 2019; Giordano et al., 2019).

This explorative study aims to fill this knowledge gap by performing a first assessment of surplus bread quantities (which may or may not become waste) at bakery level in Italy. This was done by directly measuring the quantity of surplus bread through daily diaries and calculating associated economic losses for bakeries.

2. Theoretical approach

2.1. Literature review on loss and waste of bread and bakery products

A literature review was conducted to assess general loss and waste of bread and bakery products. The results were applied to frame the field study of surplus bread in Italy. To obtain relevant literature for the review, the following string was used in searches in the Scopus database: (TITLE-ABS-KEY (“bakery” OR “bread”) AND TITLE-ABS-KEY (food AND waste) OR TITLEABS-KEY (food AND loss) OR TITLE-ABS-KEY (food AND surplus) AND TITLE-ABS-KEY (“food waste” OR “cause” OR “recycling” OR “reuse” OR “re-use” OR “prevention” OR “ valorisation” OR “disposal” OR “recovery”)). The search was conducted in April 2023 and considered articles published up to March 2023. Only studies conducted in Europe were selected, to ensure better comparability with data gathered in Italy during the field study.

The search yielded a total of 632 articles. After a first screening, the sample was reduced to 70 articles tackling quantification of bread and bakery loss and waste. Among these, 15 articles presenting empirical quantifications of losses and waste in the bakery sector were included in a meta-analysis. The meta-analysis (Table 1) covered the following items: reference, country, setting of the quantification, method used, direct measurements, results and sample size. Four of the selected articles described studies conducted at bakeries, two in supermarkets, one in a retail store and eight at households.

Based on findings reported in the selected papers, in Sweden bread waste comprises a total of 80,410 t/year, of which 40,240 t/year occurs in bakeries and retailers (Brancoli et al., 2019). In Austria, bread and bakery losses represent 4 % of bakery products at retail, but if the amount of bread and pastry returned to suppliers via take-back agreements is also considered, the level increases to 12.6 % (Lebersorger and Schneider, 2014). In Poland, around 10 % of bread produced is wasted at bakeries (Goryńska-Goldmann et al., 2021). Previous studies suggest that, in Italy, bread waste at bakeries is less than 2 kg/day per company (Lanfranchi et al., 2017) while, at the retail level, 31 % of all food waste generated at supermarkets consists of bakery products (Cicatiello et al., 2017).

The strategies used to manage surplus bread and bakery products were also analysed. Lebersorger and Schneider (2014) describe an interesting case in Austria, which has a food donation system for surplus bread and pastries. They quantified losses of 2.8 % for bread and pastries, while donations of these items comprised 7 % of the total. According to Brancoli et al. (2020) and Papargyropoulou et al. (2014), surplus bread should best be managed following the food waste hierarchy, where source reduction is the first priority, followed by donation for human consumption, feed production and recycling (such as using bread for beer or ethanol production), while anaerobic digestion and incineration should be avoided as far as possible.

2.2. Scope of the study

To clearly delimit the scope of the field study in small-scale Italian bakeries, the following definitions were applied (reflecting the steps of bread making and management from production to sale).

Baking process: The process of making bread from basic ingredients, using bakery facilities and machinery, and labour and energy inputs to derive a final product, the result of which is bread ready for human consumption. Production is manual, starting the day before and continuing overnight, to have fresh bread ready in the early morning. The dough is kneaded during the night and, after the leavening and rising steps, it is baked in an electric oven. After baking, fresh bread is left to cool and then delivered to bakery stores or supermarkets and displayed on the shelves to be sold.

Fresh bread: Under Italian law (Law n.248 of 04/08//2006), bread is considered “*fresh*” when it is baked in a continuous production process, without interruptions aimed at freezing or prolonged storage of raw materials, intermediate bakery products or mixtures, and presented for sale within 24 h of production. Otherwise, bread and bakery products can no longer be marked as “*fresh*” (Benozzo, 2011).

Surplus bread: Bread that is baked and put on sale directly in the bakery (or delivered to a bakery branch), but for various reasons not sold to a customer at the end of the day (Garrone et al., 2014). It is defined here as “*surplus*” because it can still be used for human consumption (i.e. donated or re-used as breadcrumbs), but cannot be sold as “fresh bread”. Surplus bread does not necessarily become waste, because it can be diverted to other uses. However, knowledge of the quantities involved and their economic value is essential in developing possible strategies and actions, at business or policy level, to prevent it from becoming waste.

Bread waste: Bread removed from the supply chain, to be recovered or disposed of. Bread donated or managed (for example, as breadcrumbs) in any other option is not considered waste in the present analysis, based on the official EU definition of food waste as “*any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans that has become waste*” (EU Directive 2018/851, amending EU Directive 2008/98 on waste).

3. Methodology

3.1. Assessment of surplus bread and waste at Italian small-scale bakeries

The quantity of surplus bread at Italian small-scale bakeries was assessed within the H2020 project LOWINFOOD, which included a specific task to establish a stakeholder dialogue in the bakery sector to increase the commitment of bakeries to food loss and waste prevention. One of the partners in the project, the Italian Confederation of Crafts and Small and Medium Enterprises (CNA, Association of Viterbo and Civitavecchia), identified a panel of 12 small-scale bakeries, with a total of 16 branches, all located in the north of Lazio region, Central Italy. These bakeries were asked to record their surplus bread for five months (February–June 2022) in a daily diary. The methodology used for quantification focused on three products: common bread, focaccia bread and bread rolls (e.g. “rosette”) (Fig. 1), typical types of Italian bread that together represent 80 % of total production in the participating bakeries.

At the beginning of each month, all participating bakery branches were provided with a diary, in which staff were asked to note the following parameters:

1. *Daily production of bread products* (kg) ready to be sold in the morning, with different rows for each kind of bread (common bread, focaccia bread and bread rolls). This information was recorded at the beginning of the working day.
2. *Surplus of bread products* (kg), with different rows for common bread, focaccia bread and bread rolls. This information was recorded at the end of the working day.

[2] Source: https://ec.europa.eu/eurostat/databrowser/view/env_wasfw/default/table?lang=en.

Table 1
Articles selected for a meta-analysis of published literature on quantification of bread and bakery losses and waste.

Product	Reference	Country	Setting	Method used	Direct measurement	Value + measurement unit	Sample size
Bread	Brancoli et al. (2019)	Sweden	Bakery	Database – data collection	No	National level: 80,410 t/year, 8.1 kg per per/y. Retail level: 28,220 t/year (55 %), TBA[a]: 15,510 t/year, during process: 12,040 t/year	380 retail stores and one bakery
	Brancoli et al. (2017)	Sweden	Super-market	Direct observation – supermarket database	Yes	30 % of relative mass	1 supermarket
	Goryńska-Goldmann et al. (2020)	Poland	Bakery	Internet survey	No	Raw material in the process (2017, 61.64 t; 2018, 54.11 t) Production phase (2017, 959.77 t; 2018, 804.76 t)Final product (2017, 11.93 t; 2018, 10.93 t)Transport phase (2017, 176.86 t; 2018, 166.30 t)	48 bakeries
	Goryńska-Goldmann et al. (2021)	Poland	Bakery	Monitoring the mass balance + telephone interview	Yes	Total bakery product loss: bakery A 10.023 %, bakery B 14.352 %, bakery C 9.719 % Total bread loss: bakery A 10.576 %; bakery B 13.401 %; bakery C 10.414 %	96 bakeries and pastry-makers – 9 businesses in monitoring of mass balance.
	Hanssen et al. (2016)	Norway	Household	Survey, waste collection	Yes	fresh bread: 0.44 kg/household/week, other bakery products 0.17 kg/household/week	220 households
	Østergaard and Hanssen (2018)	Norway	Household	Web-based Questionnaire (Likert model)	No	6.5 slices of bread/week for each household	1000 households.
	Scalvedi and Rossi (2021)	Italy	Household	Survey	No	68 g/family/week	1142 households
	Van Dooren et al. (2019)	Netherlands	Household	Survey	No	9.2 kg per person per year; 22 %	130 households (13 municipalities) + 763 consumer survey
Bakery products	Cicatiello et al. (2017)	Italy	Super-market	Direct recording	Yes	31 % of food waste is bakery products, 21,599 kg; € 21,854.00	1 supermarket
	Djekic et al. (2019)	Serbia	Household	Survey	No	qty food waste 482.1 + 329.2 (g/mL) and 37.2 % of sample	494 sample of citizen
	Herzberg et al. (2020)	Germany	Household	Data set diary	Yes	13.8 % of all food waste	6853 households
	Kasza et al. (2020)	Hungary	Household	Data set analysis – Fusion methodology	No	17.62 % (46.79 Kg)	165 households
	Lanfranchi et al. (2017)	Italy	Bakery/ household	Survey	No	<2 kg/day per company, 41 % of unconsumed bread becomes waste. Supply chain waste: production residuals and frying oil (30 %) and non-usable flour (10 %).	113 bakery company
	Lebersorger and Schneider (2014)	Austria	Retail	Company database	No	Bread and bakery loss 3.99 % by mass, 2.8 % of monetary value If returned bread is included, the food loss rate of bread & pastry is 12.6 %	612 retail stores
	Ratinger et al. (2016)	Czech	Household	Survey	No	63 % waste < 5 %, 76 % of households > 5 %	10 representative households + 251 questionnaires by household

[a] TBA: take-back agreement, meaning that bakeries in charge of forecasting, ordering, placing and removing products from supermarket shelves (if they are not sold) and are financially responsible for unsold products (including collection and waste management).

(1)  (2)  (3) 

Fig. 1. Bread products included in bread waste quantification at small-scale Italian bakeries. (1) Common bread, (2) Focaccia bread and (3) Bread rolls.

3. *Selling price* (€/kg) including VAT (which for these products is 4 % in Italy), with different rows for common bread, focaccia bread and bread rolls.
4. *Number of customers* purchasing at the bakery every day, derived from the number of receipts issued by each bakery in a single day.
5. *Destination of surplus bread*, with the possibility to select different options: reused (e.g. for producing breadcrumbs), donated to charity, sold or given away for animal feed, given away to customers, sold through the app "TooGoodToGo" (or similar apps), other options (that bakeries may have not mentioned above) or thrown away.

The completed diaries were collected on a monthly basis by the researchers and the data were entered manually in Microsoft Excel. Two different datasets were built, one relating to the quantity of surplus bread and one describing its economic value. In the first dataset, each observation was set in a row and comprised the data recorded for a single product, in a single bakery branch, in a single day. Therefore, for every bakery branch, three rows per day were reported in the first dataset: one for common bread, one for focaccia bread and one for bread rolls, with a total of 4,098 observations. In the second dataset, each observation set in a row represented a single day of observation in one bakery branch, considering the value of all three products, together. This second dataset comprised 1,385 observations.

3.2. Data analysis

Using the two datasets, the following key parameters describing the occurrence and magnitude of surplus bread were calculated:

Quantity of surplus bread as a proportion of total bread production (r_q) was determined based on the data collected on the quantities of surplus bread and total bread. For every observation in the dataset, the following equation was applied to calculate r_q, which is expressed as a percentage:

$$r_q = \frac{BSQ_{ij}}{BPQ_{ij}} \times 100 \quad (1)$$

where:

BSQ = daily quantity of surplus bread, kg.

BPQ = daily quantity of bread produced, kg.

i = type of bread considered (i = 1, 2 and 3 for common bread, focaccia bread and bread rolls respectively).

j = bakery branch considered (j = 1–16 for bakery branches included in the panel).

The value of r_q therefore represented the rate of surplus bread in each bakery branch, for each of the three products, in a single day of recording. Observations with missing values of BSQ or BPQ were excluded from the analysis, leaving a total of 4,058 observations. The mean, median and distribution of the 4,058 r_q values in the database were calculated to analyse this parameter.

Value of surplus bread ($r_€$) as a proportion of turnover was also assessed. First, value of surplus bread (BSV) and daily turnover (BTV) were calculated for each bakery branch and day of observation. BSV was calculated as the total value of surplus bread recorded on one day, at one bakery branch, considering all the three products studied:

$$BSV = \sum_{i=1}^{3} \left(BSQ_{ij} \times P_{ij}\right) \quad (2)$$

where P = sales price of bread including VAT (€/kg) and all other terms are as in eq. (1).

BTV was then calculated as the turnover resulting from the sale of the three products considered in this study on one day, at one bakery branch:

$$BTV = \sum_{i=1}^{3} \left(\left(BPQ_{ij} - BSQ_{ij}\right) \times P_{ij}\right) \quad (3)$$

where all terms are as defined for eqs. (1) and (2).

The economic dataset was therefore composed of 1,385 observations, representing the economic records of one bakery branch on a single day of the study period. For every observation in the economic dataset, the following equation was applied to calculate the ratio of value of surplus bread at one bakery branch on each single day, with respect to the turnover of the same day ($r_€$), expressed as a percentage:

$$r_€ = \frac{BSV_j}{BTV_j} \times 100 \quad (4)$$

The mean, median and distribution of the 1,385 $r_€$ values of the database were calculated to analyse this parameter.

The destinations of surplus bread were analysed as dummy variables; if the option was chosen, the variable assumed a value of 1, otherwise 0. Within the same day, respondents could choose more than one option.

The r_q and $r_€$ values were then used as dependent variables to assess the influence of different factors on the rates of surplus bread. The factors considered in the analysis were: geographical context where the bakery was located (medium-size town vs. small village), size of the bakery in terms of quantity of bread produced, daily number of customers purchasing at the bakery's branches, day of the week and decade of the month (first, second or third). A full list of the factors considered, with descriptive statistics, is reported in Table 2.

ANOVA and regression analyses were performed using the XLStat and STATA software, by entering the variables in Table 2 as factors contributing to the r_q and $r_€$ values.

4. Results

4.1. Quantity of surplus bread in small-scale Italian bakeries

The quantity of surplus bread generated at the 16 bakery branches during the five months of the study was 6,694 kg in total, with 70 % of this surplus consisting of common bread, 14 % focaccia bread and 16 % bread rolls. On average, the mass of surplus bread was 4.83 kg per day and bakery branch (considering all the three products studied), although the value showed significant variation across the panel of participating bakeries. Comparison of mean surplus against production range (PR) of the bakeries, divided into lower (mean total BPQ < 50 kg/day) and

Table 2
Descriptive statistics on factors considered in analysis (daily basis) of surplus bread as a proportion of total volume produced (r_q) and value of surplus bread as a proportion of total turnover ($r_€$).

Numerical variables

Variable	Units	Min	Max	Mean	Std. Dev.
BPQ	kg	3.00	370.00	41.72	42.39
BSQ	kg	0.00	30.00	1.65	2.49
P	€	2.80	12.00	5.91	2.88
Number of customers	n	35.00	400.00	132.75	48.69
r_q	%	0.00 %	75.00 %	5.06 %	6.37 %
$r_€$	%	0.00 %	93.23 %	5.44 %	7.51 %
BSV	€	0.00	180.00	7.05	9.21
BTV	€	31.05	2037.50	529.71	328.80

Categorical and dummy variables

Variable	**Type**	**Categories**	**Category description**	**Observations**	**%**
Location	Dummy	0	Small village	1,743	42.95 %
		1	Main city	2,315	57.05 %
Day of the week	Categorical	M	Monday	623	15.30 %
		Tu	Tuesday	689	17.00 %
		W	Wednesday	680	16.70 %
		Th	Thursday	656	16.20 %
		F	Friday	656	16.20 %
		Sa	Saturday	658	16.20 %
		Su	Sunday	96	2.40 %
Production Range (PR)	Categorical	Lower PR	Average production of common bread < 50 kg/day	2,981	73.46 %
		Higher PR	Average production of common bread > 50 kg/day	1,077	26.54 %
Surplus bread reused	Dummy	0	No	2,588	63.78 %
		1	Yes	1,470	36.22 %
Surplus bread given for free to feed animals	Dummy	0	No	3,604	88.81 %
		1	Yes	454	11.19 %
Surplus bread sold for animals	Dummy	0	No	3,614	89.06 %
		1	Yes	444	10.94 %
Surplus bread thrown away	Dummy	0	No	4,058	100.00 %
		1	Yes	0	0.00 %
Surplus bread given for free to customers	Dummy	0	No	3,634	89.55 %
		1	Yes	424	10.45 %
Surplus bread donated for charity	Dummy	0	No	3,577	88.15 %
		1	Yes	481	11.85 %
Surplus bread sold through the app “TooGoodToGo”	Dummy	0	No	3,562	87.78 %
		1	Yes	496	12.22 %
Other options	Dummy	0	No	4,000	98.57 %
		1	Yes	58	1.43 %
Disposed	Dummy	0	No	1,469	36.20 %
		1	Yes	2,582	63.80 %

higher (mean total BPQ > 50 kg/day) showed that the daily average bread surplus for bakeries with lower and higher PR was 4.01 and 7.16 kg/day, respectively.

Analysis of r_q (proportion of surplus bread in total quantity produced) was performed to compare the different bakery products and bakery branches. The value of r_q was found to be 5.88 % for common bread, 3.99 % for focaccia bread and 5.28 % for bread rolls (Fig. 2). The total mass of surplus bread of the three types generated over the five-month study period was 4,718 kg for common bread, 931 kg for focaccia bread and 1,044 kg for bread rolls.

The r_q values obtained showed wide variation across the 16 bakery branches analysed, with average values per branch ranging from a minimum of 0.92 % to a maximum of 13.94 %. The value of r_q also differed between bakeries with lower and higher PR (Table 3). The highest r_q was found for common bread.

Differences in r_q between months and between days of the week were also detected. During the five-month study period (February–June 2022), the lowest values of r_q were recorded in April (3.56 % for common bread, 2.05 % for focaccia bread, 4.89 % for bread rolls), while the values increased in May (5.08 %, 4.32 % and 4.54 %, respectively) and June (6.16 %, 3.20 % and 4.50 %, respectively), except for bread rolls. Analysis of r_q for the two PR groups revealed that r_q was systematically higher for bakeries with higher PR.

Regarding days of the week, the proportion of surplus bread was highest on Monday (mean r_q = 6.08 %) and lowest on Saturday (mean r_q = 4.21 %). ANOVA analysis confirmed that this difference was statistically significant.

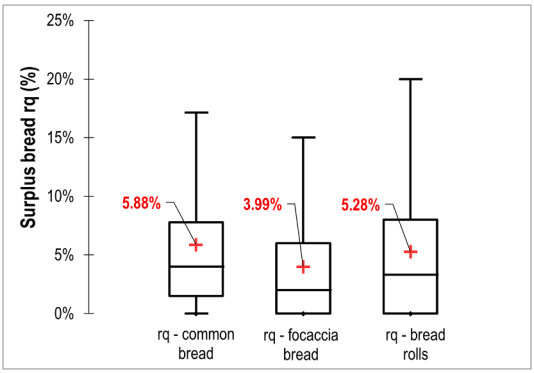

Fig. 2. Boxplot showing the proportion of surplus bread in total quantity produced (r_q) for common bread, focaccia bread and bread rolls. The red cross in each boxplot represents the mean value, green boxes indicate the second and third quartiles of the distribution, and the black horizontal line within each box represents the median value. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Proportion of surplus bread in total quantity produced (r_q) for common bread, focaccia bread and bread rolls, based on production range (PR) of the bakery branch (BPQ < 50 kg day (lower) or >50 kg/day (higher)).

Bread type	Lower PR	Higher PR
Common bread	4.94 %	8.55 %
Focaccia bread	3.08 %	6.49 %
Bread rolls	5.22 %	5.44 %

The influence of different 10-day periods in the month on r_q was also analysed, to detect any change related to the budget available to households from the beginning until the end of the month, but the results suggested that the rate of surplus bread was not linked to this factor.

A weather-related variable, mm rain per day, was also analysed, both as a quantitative variable (mm rain in a day) and as a qualitative variable (raining/not raining on a single day). In both cases, the results were not significant, indicating that daily rainfall did not affect the proportion of surplus bread.

The influence of bakery location on r_q was studied through a dummy variable (location) describing whether the bakery branch was located in the main city of the area (medium-sized city, ~60,000 residents) or in one of the surrounding small villages (1,000–12,000 residents). The analysis showed that r_q was slightly higher for bakeries located in small villages (5.83 %) than for those in the city (4.43 %).

Finally, the relationship between r_q and number of customers purchasing at the bakery branches in a single day was analysed. There was a strong negative relationship between the two variables (−2.36 %), i.e. the greater the number of customers, the lower the quantity of surplus bread at a bakery. However, it should be noted that this finding was based on only 2,837 observations (69 % of the total), because of missing data on number of customers in multiple cases.

Table 4 shows the results of the linear regression model for all factors found to influence the proportion of surplus bread, i.e. number of customers, day of the week, PR level, location and type of bread.

4.2. Economic value of surplus bread

The economic value of surplus bread was analysed by performing further calculations on the economic database, composed of 1,385 observations. Total value of surplus bread recorded during the study period was 28,589 €, of which 14,001 € referred to common bread. On average, the sales value of the surplus bread at each bakery branch was 20.64 € per day. In this case too there was a difference between bakeries with different PR levels. Those with lower PR reported an average value of 16.73 €/day for their surplus bread and those with higher PR an average value of 31.82 €/day.

On average, the proportion of value represented by surplus bread in daily turnover of the bakery branches ($r_€$) was 5.44 %. It was 4.63 % for bakeries with lower *PR* and 7.76 % for bakeries with higher *PR*. The value of $r_€$ also varied widely between the 16 bakery branches (range 0.9 %–14.6 %).

Analysis of the variation in $r_€$ between days of the week revealed no significant relationship. However, there was a tendency for the highest $r_€$ values to occur on Monday (6.95 % on average) and the lowest on Saturday (4.91 % on average).

Regression analysis of the relationship between $r_€$ and number revealed a negative relationship (−2.61 %) ($p < 0.01$, r-adjusted = 0.075), i.e. having fewer customers per day was related to higher $r_€$ and vice versa.

4.3. Analysis of extreme events in surplus bread generation

The surplus bread peaks (quantity, value) identified in previous sections were further analysed to determine factors causing extreme events in surplus bread generation. This analysis focused on the 4th quartile of the dependent variables r_q and $r_€$, for which four models were developed (Table 5). The variable r_q was calculated for each type of bread analysed (common bread, focaccia bread, bread rolls) and both r_q and $r_€$ were modelled against PR, day of the week and location. In the $r_€$ model, the variable number of customers was added.

As only cases with a high rate of surplus were considered, the factors influencing the generation of surplus bread emerged more clearly. PR level (higher, lower) was only significant for focaccia bread and bread rolls, while the location variable significantly influenced the quantity of the surplus for all three bread products studied. Surplus peaks also seemed to be more frequent in the bakery located in the main city of the area, regardless of day of the week, and day of the week did not influence the peaks in surplus overall. However, the number of customers was found to have high significance in the $r_€$ model, such that when there were many customers per day, the risk of a bakery having a higher economic loss associated with surplus bread decreased.

4.4. Management of surplus bread at bakeries

Management of surplus bread at the 16 bakery branches studied was also compared (Fig. 3). The data collected through diaries showed that surplus bread was managed by some strategy in 63 % of cases, while it

Table 4
Results of regression models with dependent variable r_q for the main influencing factors (number of customers, day of the week, PR, location, type of bread) (***p < 0.01, **p < 0.05, *p < 0.1).

r_q	Coef.	St. Err.	t-value	p-value	[95 % Conf	Interval]	Sig
Number of customers	−0.030	0.002	−13.570	0	−0.034	−0.026	***
Day of the week (base: Sunday)	–	.	.	.	.	.	
Thursday	1.607	0.644	2.500	0.013	0.344	2.869	**
Monday	2.348	0.651	3.600	0	1.071	3.626	***
Tuesday	1.653	0.643	2.570	0.010	0.392	2.915	**
Wednesday	1.451	0.642	2.260	0.024	0.191	2.711	**
Saturday	0.837	0.653	1.280	0.200	−0.443	2.118	
Friday	1.507	0.646	2.330	0.020	0.240	2.774	**
PR	−4.200	0.230	−18.230	0	−4.652	−3.749	***
Location	−3.456	0.233	−14.860	0	−3.913	−3.000	***
Type of bread (rel. to common bread):	–	.	.	.	.	.	
Bread rolls	−1.245	0.254	−4.910	0	−1.743	−0.747	***
Focaccia bread	−2.559	0.254	−10.080	0	−3.057	−2.062	***
Constant	18.405	0.797	23.090	0	16.842	19.969	***

Mean dependent variable: 5090; SD dependent variable: 6.186.
R-squared: 0.207; Number of observations: 2837.
F-test: 66.985; Prob > F: 0.000.
Akaike information criterion (AIC): 17755.887; Bayesian information criterion (BIC): 17827.293.

Table 5
Results of four models analysing the 4th quartile of the variables r_q and $r_€$, (three for bread types, one for $r_€$). Rows show factors considered in the models and columns the dependent variables used (*** p < 0.01, ** p < 0.05, * p < 0.1).

	r_q common bread	r_q focaccia bread	r_q bread rolls	$r_€$
Threshold 3° quartile	7.80 %	6.00 %	8.05 %	6.69 %
Number of obs.	N = 371	N = 356	N = 350	N = 257
R^2:	$R^2 = 0.030$	$R^2 = 0.154$	$R^2 = 0.087$	$R^2 = 0.373$
Factors				
PR	−0.955	−4.966***	−2.397*	−5.373***
Location	2.211**	−3.238***	−4.310***	−2.127***
Day of the week[a]				
Monday	1.286	−2.241	3.564	2.921
Tuesday	0.055	−2.978	2.758	1.117
Wednesday	0.089	−3.097	3.357	1.326
Thursday	−1.037	−1.256	3.544	2.134
Friday	0.164	−2.313	2.316	1.146
Saturday	−0.306	−1.048	3.042	1.409
No. of receipts	–	–	–	−0.158***
Constant	13.912***	22.887***	16.550***	19.881***

[a] Sunday was considered as a basis in the regression model.

was assumed that the remaining 37 % of surplus bread became waste. Among the surplus management options reported, the most frequent was re-using surplus bread to produce breadcrumbs (38 % of cases), particularly for surplus common bread. In some bakeries, the surplus was sold through the 'TooGoodToGo' app (13 % of cases) or for animal feed (12 % of cases). Other frequent options were giving bread surplus for free to customers (11 % of cases), as a donation to charities (13 % of cases) or for free to farmers for use in feeding animals (12 % of cases).

5. Discussion

This explorative study was the first to assess surplus bread generation at small-scale bakeries in Italy using direct measurement methods. The overall aim was waste reduction, since surplus bread is likely to become waste if no management options are implemented. Daily records for the 16 participating bakery branches revealed that, on average, 4.83 kg of surplus bread was produced every day at each branch, considering common bread, focaccia bread and bread rolls together. A previous study by Lanfranchi et al. (2017) reported around 2 kg/day of bread waste, measured by means of questionnaires administered to 113 bakeries in Italy.

Generation of surplus bread in the value chain is essentially due to inaccurate forecasting of demand for bread, which changes continually due to the influence of external factors (Brancoli et al., 2019) and also shows seasonal variation (Lebersorger and Schneider, 2014). The latter effect was observed in the present study, where the surplus varied considerably between months (April compared with May and June).

The proportion of surplus bread in the total quantity of bread produced (r_q) ranged from 3.99 % for focaccia bread to 5.28 % for bread rolls and 5.88 % for common bread. While there was some variation between the bakery branches (main city vs. small village, lower PR vs. higher PR), the r_q values obtained were rather low compared with literature values observed in other countries. In Germany, for example, return rates for bread and bakery products of between 2 and 23 % have been reported for six bakeries with 1–60 sales outlets (Schmidt et al., 2019) and return rates of between 3.8 and 16.7 % for six bakeries (Ritter et al., 2015).

On analysing extreme events, when more surplus bread was generated, we found that relevant factors explaining peaks in surplus were location and PR level of the bakery (although the latter did not apply for common bread).

The value of surplus bread as a proportion of daily turnover was 5.44 % on average, which is lower than, for example, in Sweden, where take-back agreements are common (Brancoli et al., 2019). It is also much lower than the mean value of 10.8 % reported for returned bread and bread products in Germany (Schmidt et al. 2019). This indicates that there is a different approach to bread in Italy, leading to better matching of supply and demand.

As expected, there was a negative relationship between the number of customers visiting the bakeries and surplus bread generation, where bakeries with a greater and more constant flow of customers tended to generate less surplus, as reported previously (Eling and Kiesenbauer, 2012). The value of surplus bread as a proportion of turnover was also negatively correlated with number of customers.

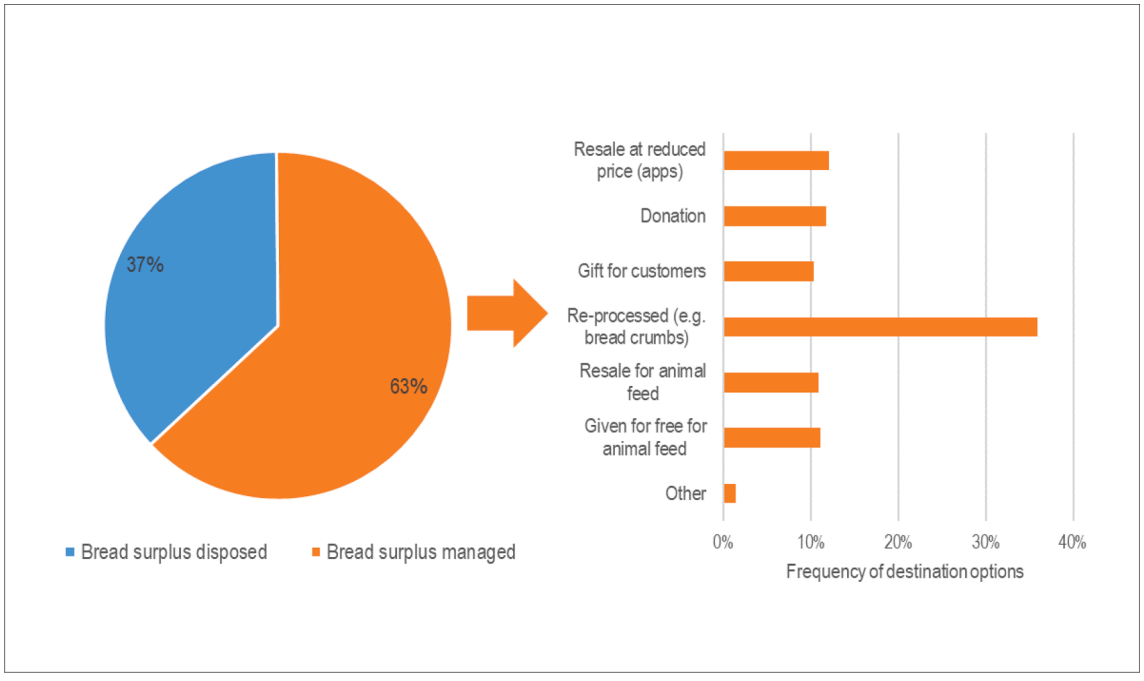

Fig. 3. Surplus bread management options employed on a daily basis by participating bakeries. Respondents could select more than one option per day, so the percentage frequency of choices in the right-hand part of the diagram exceeds 63 % for the option 'bread surplus managed'.

While the volume of waste in absolute terms increases with increasing size of operation, the opposite pattern is usually observed for relative waste, e.g. by Eriksson et al. (2020) for hospitals, Steen et al. (2018) for schools, Eriksson et al. (2014) for meat and dairy products sold in supermarkets and Brancoli et al. (2019) for bread products. This is due to the advantage of greater turnover in reducing food waste. However, in the present study, the smaller bakeries (with lower PR) performed systematically better than the larger bakeries for all three bread types considered. This might be due to the specifics of the larger bakery branches included, but it is also possible that efficiency with respect to surplus bread-related issues is higher for smaller businesses. The customer group of these businesses can be very local, enabling customer loyalty and communication, resulting in a stronger relationship between bakeries and customers. Small businesses may also have better knowledge about the preferences of their customers and greater flexibility to adapt. Indeed, flexibility in production and in connection with customers is a key factor in food loss and waste prevention in general (Forslund and Mattsson, 2021; Lostakova and Pecinova, 2014). When asked for feedback on the results of the present study, some of the bakeries replied they "*could write the name of the customer on each piece of bread*", because the communities served by these bakeries are very small. Lower bread surplus at smaller bakeries is consistent with findings by Schmidt et al. (2019) that single-branch bakeries have lower bread return rates than those with a medium number of branches. However, larger bakeries can also draw conclusions about future demand for their products by in-depth analysis of sales figures to produce sales forecasts (Takahashi & Goto, 2022). Therefore, it is of the utmost importance to make bakery managers aware of the problem of surplus bread in the first place. There are many possible solutions to reduce surplus, for example reducing the product range offered, discontinuing items that are difficult to sell or accepting empty shelves at the end of the day. Analysing which items are selling well or badly, and using past sales data to forecast the demand could help bakery managers predict future sales of individual items more accurately and adjust production to actual demand.

Take-back agreements are reported to be one of the main causes of bread losses and waste (Eriksson et al., 2017). However, none of the bakeries involved in this study reported using this practice, which became much less frequent in Italy after implementation of EU Directive 2019/633 in April 2019, which categorised take-back agreements as a potentially unfair trading practice.

Of course, the surplus bread produced at bakeries does not necessarily end up as waste. In the present study, surplus bread was directed to alternative destinations (63 % of cases). Reprocessing, e.g. to produce breadcrumbs, was reported as a very common option by participating bakeries, followed by donation and selling or giving surplus bread away for free for use as animal feed. Although it was not possible to quantify the actual amount or proportion of surplus bread reaching each of these destinations, this is a very interesting finding because it confirms that small-scale bakeries can perform very well in keeping the proportion of surplus bread low and in managing the surplus to avoid throwing it away.

6. Conclusions and implications

This first quantification of surplus bread in Italy, based on real data retrieved at bakery level, revealed that the proportion of surplus bread generated by small-scale bakeries (typical businesses of the Italian bakery sector) ranged from 3.99 % to 5.88 % of daily production by volume. In the absence of structured prevention and/or management actions by all stakeholders in the value chain, this surplus bread is likely to become waste.

The Italian bakery sector is unusual in that there are thousands of small-scale bakeries which produce bread and (mostly) sell it directly to the end-customer. This business model allows the sector to achieve rather lower rates of surplus than in other countries, since the small scale makes it possible to tailor production to customer preferences, which are well-known to the bakers. However, our results also showed that small-scale bakeries with more customers within the dataset were less likely to end up with a high rate of surplus bread. This is probably due to better product planning and forecasting to avoid the risk of producing surplus bread.

For small-scale bakeries in particular, preventing generation of surplus bread has significant economic implications. These bakeries typically have a small margin of revenue and their business is already at high risk due to increasing costs of ingredients (especially flour) and of energy.

To prevent the generation of surplus bread, it is important to involve bakers and other stakeholders in the bread value chain in joint efforts to make the chain more efficient and establish good collaborations in order to avoid surpluses or manage surpluses appropriately when they occur. Prevention and redistribution should be considered the most desirable options for surplus bread, while alternative destinations for surplus products should only be used when prevention is not possible. Dialogue among stakeholders, especially at the local level, is crucial to achieve a zero- or low-waste bakery value chain. Through dialogue, different actors could share their know-how to successfully match production and sales of bakery products and better understand customers and their demands. At small-scale bakeries, this dialogue can be facilitated by their stronger relationships with consumers.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Luca Fanelli reports a relationship with the Italian Confederation of Craft Trades and Small- and Medium-Sized Enterprises (CNA, Association of Viterbo and Civitavecchia) that includes: employment. Luigia Melaragni reports a relationship with Italian Confederation of Craft Trades and Small- and Medium-Sized Enterprises (CNA, Association of Viterbo and Civitavecchia) that includes: employment.

Data availability

Data will be made available on request.

Acknowledgements

This work is part of the H2020 project LOWINFOOD—Multi-actor design of low-waste food value chains through the demonstration of innovative solutions to reduce food loss and waste. LOWINFOOD is funded by the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 101000439. The views reflected in this article represent the professional views of the authors and do not necessarily reflect the views of the European Commission or other LOWINFOOD project partners.

References

Benozzo, M., 2011. Il reso del pane nei rapporti tra panificatore e rivenditori al dettaglio: alimento, mangime, rifiuto. Rivista di Diritto Alimentare 3.

Brancoli, P., Lundin, M., Bolton, K., Eriksson, M., 2019. Bread loss rates at the supplier-retailer interface–analysis of risk factors to support waste prevention measures. Resour. Conserv. Recycl. 147, 128–136.

Brancoli, P., Bolton, K., Eriksson, M., 2020. Environmental impacts of waste management and valorisation pathways for surplus bread in Sweden. Waste Manag. 117, 136–145.

Brancoli, P., Rousta, K., Bolton, K., 2017. Life cycle assessment of supermarket food waste. Resour., Conserv. Recycl. 118, 39–46.

Businesscoot, 2021. The bakery and pastry market Italy. https://www.businesscoot.com/en/study/the-bakery-and-pastry-market-italy#:~:text=In %20Italy %2C %20 bread %20plays %20a,of %20the %20total %2C %20are %20growing (accessed on 14 October 2022).

Cicatiello, C., Franco, S., Pancino, B., Blasi, E., Falasconi, L., 2017. The dark side of retail food waste: Evidences from in-store data. Resour., Conserv. Recycl. 125, 273–281.

Djekic, I., Miloradovic, Z., Djekic, S., Tomasevic, I., 2019. Household food waste in Serbia–Attitudes, quantities and global warming potential. J. Clean. Prod. 229, 44–52.
Eling, M., Kiesenbauer, D., 2012. Does surplus participation reflect market discipline? An analysis of the German life insurance market. J. Financ. Serv. Res. 42 (3), 159–185.
Eriksson, M., Strid, I., Hansson, P.-A., 2014. Waste of organic and conventional meat and dairy products: a case study from Swedish retail. Resour. Conserv. Recycl. 83, 44–52.
Eriksson, M., Ghosh, R., Mattsson, L., Ismatov, A., 2017. Take-back agreements in the perspective of food waste generation at the supplier-retailer interface. Resour. Conserv. Recycl. 122, 83–93.
Eriksson, M., Malefors, C., Bergström, P., Eriksson, E., Persson Osowski, C., 2020. Quantities and quantification methodologies of food waste in Swedish hospitals. Sustainability 12, 3116.
Fanelli, R.M., 2019. Using causal maps to analyse the major root causes of household food waste: Results of a survey among people from Central and Southern Italy. Sustainability 11 (4), 1183.
Forslund, H., Mattsson, S.A., 2021. Strategies for achieving customer order flexibility–supplier perspective. J. Manuf. Technol. Manag.
Garrone, P., Melacini, M., Perego, A., 2014. Opening the black box of food waste reduction. Food Policy 46, 129–139.
Giordano, C., Alboni, F., Falasconi, L., 2019. Quantities, determinants, and awareness of households' food waste in Italy: A comparison between diary and questionnaires quantities. Sustainability 11 (12), 3381.
Goryńska-Goldmann, E., Gazdecki, M., Rejman, K., Kobus-Cisowska, J., Łaba, S., Łaba, R., 2020. How to prevent bread losses in the baking and confectionery industry?—measurement, causes, management and prevention. Agriculture 11 (1), 19.
Goryńska-Goldmann, E., Gazdecki, M., Rejman, K., Łaba, S., Kobus-Cisowska, J., Szczepański, K., 2021. Magnitude, causes and scope for reducing food losses in the baking and confectionery industry—a multi-method approach. Agriculture 11 (10), 936.
Hanssen, O.J., Syversen, F., Stø, E., 2016. Edible food waste from Norwegian households—Detailed food waste composition analysis among households in two different regions in Norway. Resour., Conserv. Recycl. 109, 146–154.
Herzberg, R., Schmidt, T.G., Schneider, F., 2020. Characteristics and determinants of domestic food waste: A representative diary study across Germany. Sustainability 12 (11), 4702.
Kasza, G., Dorkó, A., Kunszabó, A., Szakos, D., 2020. Quantification of household food waste in Hungary: A replication study using the FUSIONS methodology. Sustainability 12 (8), 3069.
Lanfranchi, M., Giannetto, C., Dimitrova, V., 2017. Economic analysis and management of bread waste from producers: results of a survey conducted in Sicily (Italy). Bulgarian J. Agr. Sci. 23 (4), 544–550.
Lebersorger, S., Schneider, F., 2014. Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. Waste Manag. 34 (11), 1911–1919.
Lostakova, H., Pecinova, Z., 2014. The role of partnership and flexibility in strengthening customer relationships in the B2B market. Proc.-Soc. Behav. Sci. 150, 563–575.
Østergaard, S., Hanssen, O.J., 2018. Wasting of fresh-packed bread by consumers—influence of shopping behavior, storing, handling, and consumer preferences. Sustainability 10 (7), 2251.
Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N., Bin Ujang, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. 76 (2014), 106–115.
Ratinger, T., Tomka, A., Boskova, I., 2016. Sustainable consumption of bakery products; A challenge for Czech consumers and producers. Agric. Econ. (Czech Republic) 62 (10), 447–458.
Ritter, G., Friedrich, S., Heitkönig, L., 2015. Reduktion von Lebensmittelabfällen bei Brot und Backwaren Ein Konzept für Handwerk, Handel und Verbraucher. Institute of Sustainable Nutrition (iSuN), Münster, Germany.
Schmidt, T.G., Baumgardt, S., Blumenthal, A., Burdick, B., Claupein, E., Dirksmeyer, W., Hafner, G., Klockgether, K., Koch, F., Leverenz, D., Lörchner, M., Ludwig-Ohm, S., Niepagenkemper, L., Owusu-Sekyere, K., Waskowet, F., 2019. Wege zur Reduzierung von Lebensmittelabfällen - Pathways to reduce food waste (REFOWAS): Maßnahmen, Bewertungsrahmen und Analysewerkzeuge sowie zukunftsfähige Ansätze für einen nachhaltigen Umgang mit Lebensmitteln unter Einbindung sozio-ökologischer Innovationen. Volume 1, Thünen Report, No. 73,1, Johann Heinrich von Thünen-Institut, Braunschweig, p. 113. doi: 10.3220/REP1569247044000.
Scalvedi, M.L., Rossi, L., 2021. Comprehensive measurement of italian domestic food waste in a european framework. Sustainability 13 (3), 1492.
Steen, H., Malefors, C., Röös, E., Eriksson, M., 2018. Identification and modelling of risk factors for food waste generation in school and pre-school catering units. Waste Manag. 77, 172–184.
Takahashi, K., Goto, Y., 2022. Embedding-based potential sales forecasting of bread product. J. Adv. Comput. Intell. Intell. Inf. 26 (2), 236–246.
Torriani, L., 2022. Pane artigianale. I dati 2022 sulle vendite in Italia, Aibi Assitol. https://www.universofood.net/2022/03/18/pane-artigianale-dati-2022/#:~:text=I %20numeri %20pubblicati %20a %20marzo,ha %20riguardato %20il %20pane %20industriale (accessed on 18 October 2022).
Van Dooren, C., Janmaat, O., Snoek, J., Schrijnen, M., 2019. Measuring food waste in Dutch households: A synthesis of three studies. Waste Manage. 94, 153–164.
WRAP, H, 2011. Link Consumer Strategies and Campden BRI, WRAP, Waste and Resource Action Programme, Banbury, UK.