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Original article

Novel high-quality takeaway Neapolitan pizza from unused dough balls: hedonic and textural properties, and carbon footprinting assessment

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Summary During home pizza delivery in cardboard boxes uncontrolled heat and mass transfer processes occur. This work aimed to evaluate how the textural and sensory properties change from the moment the pizza is taken out of the oven and the moment of its consumption at home. Such properties were also assessed for a novel takeaway pizza service involving pizza baking, freezing, packing, delivery and reheating at home to save leavened dough balls unused at the end of everyday working activity. Panellists preferred freshly baked pizza, but frozen pizza was more preferred over all pizzas kept in cardboard boxes for 10–30 min. The cradle-to-grave carbon footprint and cost of frozen pizza were finally assessed to show how such a food product, that would have been wasted, might be profitably converted into a high-quality alternative takeaway pizza service.

Keywords Carbon footprint, LCA, Neapolitan pizza, quick frozen pizza, reuse of unused dough balls, sensory properties, textural properties.

Introduction

The Neapolitan pizza is a world-wide renowned product of the Italian food tradition, that was recognised by the European Commission Regulation no. 97/2010 (CE, 2010) as one of the guaranteed traditional specialities (TSG). Even the art of the Neapolitan *pizzaiolo* was registered in the Representative List of the Intangible Cultural Heritage of Humanity (UNESCO, 2017).

Since 2020 the pizza market has been constantly growing in Italy, where about 8 million pizzas are baked every day, with an overall turnover of 15 billion € (Babetto, 2022). Eighty-six percent of Italians eat pizza at least once a week, while 40% even twice. The high frequency of consumption is a widespread habit, especially among 18- and 24-year-old, who consume it even three times a week (16%) (Pazzano, 2022). The market offers different ways of consuming pizza: full-service restaurants and pizzerias with or without home delivery or takeaway service, fast food and frozen pizza.

Italian people define pizza as comfort food. According to the various players in the Food Delivery market, pizza was the first ready-to-eat food among the most ordered dishes. In the last quarter of 2021, the number of pizzas ordered on the Deliveroo platform (https://deliveroo.it/en/, accessed 17 January 2023), which relies on more than 5000 pizzerias to order from all over Italy, grew by 70% as compared with the previous year (Accademia delle Professioni, 2022).

The home delivery or take-away pizza, as soon as it has been baked, is set into a cardboard box and delivered in no more than 30 min. The boxes mostly used for pizza transport are made from a central corrugated cardboard layer enclosed between two layers of thin pasteboard sealed with corn or potato starch adhesive (Conchione *et al*., 2020). Other boxes can be made of recycled corrugated cardboard, which is internally coated with an aluminium layer and a 12-μm polyethylene terephthalate (PET) layer. The latter is not only suitable for food contact applications, but also avoids oil leakage, prevents the pizza from tasting of cardboard, and keeps pizza warm for longer (Falciano *et al*., 2022a).

The time elapsed between the pizza preparation and its consumption affects its sensory characteristics,

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which decrease as the transportation time increases. The pizza cardboard boxes may represent a real risk if these are produced from recycled paper. Conchione *et al*. (2020) reported that, after being packed in such boxes for some time, the pizza resulted to be contaminated with traces of inks, glues, paints and other chemicals, such as phthalate, Bisphenol A, mineral oils hydrocarbons, and heavy metals. The main reason for these migration phenomena is the high-temperature inside the box (approx. 65 °C) and the presence of oil at the contact surface, enhancing the mass transfer. Despite numerous studies that have confirmed this migration process, the quantity of such compounds transferred to the food product has not been precisely assessed yet (Albu & Buculei, 2011).

Restaurants that also carry out home delivery or takeaway services certainly have greater profitability, but this activity interferes with their service quality (Roberts *et al*., 2022). To avoid such interferences and, what is more, prevent the leavened dough balls unused at the end of the day service from being disposed of in the organic garbage, such dough balls might be converted into the pizzas mostly ordered in the same restaurant (*i.e*., Marinara or Margherita pizza), baked in the wood-fired oven and immediately submitted to blast freezing before being stored in the restaurant freezer. Such frozen pizzas might be proposed as an alternative quick takeaway or home delivery service at lower selling prices than conventional services provided that their capability of being easily reheated in any domestic oven is properly claimed.

This work aimed to compare the quick-frozen and reheated pizza samples with freshly baked pizza samples, as served at the table immediately or after 5 min of queuing at the pizza counter or packed in cardboard boxes for 10, 20 or 30 min. The acceptability of samples was evaluated by conscious consumers of traditional Neapolitan pizza. In addition, such comparison was extended to a few relevant chemico-physical parameters, namely, the pizza thermal mapping, weight loss due to water vaporisation, and instrumental texture profile. Finally, the extra energy consumption associated with such a procedure was determined and used to perform a streamlined Life Cycle Assessment (LCA) to identify the related cradle-to-grave greenhouse gas (GHG) emissions in compliance with the Publicly Available Specification (PAS) 2050 standard method (BSI, 2011), and operating costs.

Materials and methods

Materials

The following ingredients were used: soft wheat flour type 00 with 12% (w/w) nominal water content kindly supplied by Mulino Caputo (Antimo Caputo Srl, Naples, Italy); brewer's yeast fresh (Lesaffre Italia, Trecasali, Parma, Italy); fine salt (Italkali, Petralia, Palermo, Italy); deionised water at 16–18 °C; sunflower oil (Mepa Srl, Terzigno, Naples, Italy) and tomato puree at 7.0 ± 0.2 °Brix (Mutti SpA, Parma, Italy). The wood-fired oven was fed with dry oak logs from the Royal Park of Portici (Department of Agriculture of the University of Naples – Federico II). Each pizza sample was packed in a 330-mm wide, 330-mm large and 38-mm high pizza box, its picture is shown in Figure S1 in the electronic supplement. Each pizza box weighed 168 ± 1 g, and was made of recycled corrugated cardboard, internally coated with an aluminium layer (its overall surface and weight being equal to 0.2925 m^2 and 11.1 ± 0.6 g, respectively) and a 12-μm polyethene terephthalate (PET) layer to be suitable for food contact applications (Cod. 1450041.07039-H, Artecarta Italia Srl, Scafati, Italy).

Pizza sample preparation

The Neapolitan pizza dough was prepared by mixing 60.0% soft wheat flour type 00 and 1.9% fine salt with 38.0% deionised water at 16–18 °C temperature, where 0.1% of fresh brewer's yeast had been previously added and dispersed under vigorous stirring for about 3 min (Falciano *et al*., 2022b). These ingredients were directly mixed in a spiral mixer (Grilletta IM5, Famag Srl, Milan, Italy) set at nominal speed 1 for 18 min. The dough was left resting at 25 °C for 20 min, then it was divided into balls weighing 250 g each. These were placed over 60 × 40 cm plastic trays (Giganplast, Monza and Brianza, Italy) and left leaven in a climatic chamber (KBF 240, Binder, Tuttlingen, Germany) at 22 °C and 80% relative humidity for 16 h. Thereafter, the dough balls were manually rolled to obtain a pizza base with a diameter of 28 ± 1 cm, which was topped with 70 g of tomato puree and 30 g of sunflower oil. Finally, the samples were baked in a traditional wood-fired pizza oven (manufactured by MV Napoli Forni, Naples, Italy, and previously described: Falciano *et al*., 2022b) for 80 s. By feeding the oven mouth with 1 kg of oak logs every 20 min for not shorter than 6 h, the oven was regarded as operating in pseudo-steady state conditions, the temperature of its floor and vault being approximately constant at 400 and 450 °C, respectively (Falciano *et al*., 2022b). To assure data reproducibility, the pizzas were made by a professional pizza maker (*i.e*., Mr. Enzo Coccia, Pizzeria *La Notizia*, Naples, Italy).

Table 1 shows the pizza samples examined.

Sample A was the freshly baked pizza, while sample R was the same pizza queuing on a plate at 25 ± 0.5 °C for 5 min to simulate the service of a crowded restaurant. The samples B_{10}, B_{20} or B_{30} were

Table 1 Pizza samples assayed in this work

Pizza samples	Service way
A	Freshly baked
R	5-min queuing in a plate
B_{10}	Kept in a cardboard pizza box for 10 min
B_{20}	Kept in a cardboard pizza box for 20 min
B_{30}	Kept in a cardboard pizza box for 30 min
F	Freshly baked, frozen and reheated

freshly baked pizzas after having been kept in cardboard boxes at an external temperature of 25 ± 0.5 °C for 10, 20 or 30 min, respectively, to simulate the takeaway or home delivery service.

Pizza freezing and reheating

Pizza sample F consisted of a freshly baked pizza that was rapidly frozen using the blast chiller ATT05 TH (Thermogel, Cardano al Campo, VA, Italy). Such equipment, available at the pizza restaurant (*i.e.*, Pizzeria *La Notizia*, Naples, Italy) previously examined (Falciano *et al.*, 2022a), was equipped with a refrigeration system of 1424 W. Its electric energy consumption was measured using an energy meter PM600 (RCE Srl, Salerno, Italy). As soon as the pizza was frozen, it was stored in a freezer for 24 h. Before testing, the frozen pizza was reheated using an Atlantic ATBO.30N4TX (Groupe Atlantic Italia SpA, Conegliano, TV, Italy) static built-in oven for energy class A domestic kitchen. The frozen pizza was then reheated for 4 min, once the oven had been preheated at 220 °C for 10 min. The effective energy consumption was monitored using the energy meter mentioned above.

Thermal mapping and water vapour loss in pizza samples

The temperature of the pizza samples was determined using a thermal imaging camera (FLIR E95 42°, FLIR System OU, Estonia) equipped with an uncooled microbolometer thermal sensor with dimensions 7.888 × 5.916 mm and a resolution of 464 × 348 pixels. The pixel pitch of the sensor is 17 μm, the lens 10 mm, and the field-of-view of 42° × 32°. The captured images were processed with the IRT Analyser 6.0 software (GRAYESS Inc., Bradenton, FL, USA) to assess the maximum (T_{max}), minimum (T_{min}) and average (T_{ave}) temperatures of the entire upper surface of each pizza assayed. All the temperature assessment using the IR camera were cross-validated using a thermocouple Squirrel data logger (Grant 600 series, Grant Instruments, UK).

The water vapour loss (WVL) was measured using an analytical balance (Gibertini, Milano, Italy) and calculated as follows:

$$\text{WVL}\ (\%) = \frac{(M_i - M_f)}{M_i} \times 100 \quad (1)$$

where M_i is the weight of any freshly baked pizza and M_f is that of the pizza when it was served, both expressed in g.

All these tests were repeated six times.

Texture profile analysis (TPA)

The textural properties of any pizza rim were determined using a TMS-Pro Texture Analyser (Food Technology Corp., Sterling, VA, USA), equipped with a 50-N load cell and an aluminium probe plate (25 mm in diameter). Three slices of 30 × 30 mm were randomly cut from the raised rim of each pizza sample and quickly analysed within a maximum time interval of 150 s. Each typology of pizza was assayed six times, thus involving an overall number of 18 TPA tests. Each Texture Profile Analysis (TPA) test was carried out by setting the probe speed at 1 mm/s. A first bite was performed by submitting each specimen to 80% compression. Then, the probe was lifted to its initial position. After a pause of 10 s, it was again lowered to submit the specimens to a second 80% compression and then raised to its initial position. According to Bourne (2002), the force peak on the first or second compression cycle was defined as the pizza hardness H_1 or H_2 at 80% deformation. The ratio of the positive force-vs.-time areas under the second and first compression cycles were defined as cohesiveness (Co). The distance that the specimen recovered its height during the time that elapsed between the end of the first bite and the start of the second bite was defined as springiness. Finally, it was estimated the gumminess (Gu), this parameter was defined as the hardness times cohesiveness.

Sensory evaluation procedure

Two experimental sessions were conducted. A total of 99 subjects (equally recruited for gender and aged >18 years old) consuming pizza at least once per week, participated in the study. They were recruited using social media, flyers and emails (from pre-existing databases) and chosen to be lovers of Neapolitan pizza (general liking for pizza on a 9-point hedonic scale: Average = 8.7; Standard Deviation = 0.6). Participants who indicated to like it <5 on the 9-point hedonic scale were excluded from the dataset. Participants signed two copies of the written informed consent according to the principles of the Declaration of

Helsinki (1964 and its later amendments) and the ethical standards of the University of Naples Federico II. In the first session, 45 subjects (average age = 40 ± 13; F = 54%) evaluated the pizza samples A, R, B_{10}, B_{20} and B_{30}. Each consumer received ¼ of each pizza sample in a randomised order. Drinking water was provided to consumers between sample tests. The pizza samples were first evaluated for overall acceptability and liking for sensory attributes like flavour, texture, and appearance and on a nine-point hedonic scale (1 = extremely dislike, 5 = neither like nor a dislike, 9 = extremely like). Secondly, subjects were asked to choose both the most preferred sample and the least preferred one. In the second session, 54 subjects (average age = 31 ± 10; F = 57%) evaluated the pizza samples A, B_{20} and F by using the same procedure described above.

Carbon footprint assessment

The streamlined LCA procedure was compliant with the Publicly Available Specification (PAS) 2050 standard method (BSI, 2011). The functional unit was specified as the preparation and consumption of a Neapolitan pizza of the Marinara type (EC, 2010).

Figure S2 in the electronic supplement shows the system boundary of this LCA study, which included the production of the Marinara pizza using all the leavened dough balls that were not converted into a pizza at the end of the pizzeria's daily service. To avoid disposing of such dough balls as organic waste, they were rolled and seasoned with the recipe for pizza marinara (EC, 2010), cooked in the restaurant's wood-fired oven, and immediately submitted to blast freezing. Thereafter, the frozen pizza was packed in a 4-g low-density polyethylene (PE) bag, which was put into a light cardboard box (90 g in weight). Such a box was assumed to be stored in the restaurant freezer for an average time of 7 days. Once the frozen pizza had been sold to the general consumer, it was transported to his/her house. Its consumption would ask for preheating the home electric oven at 220 °C for 10 min, followed by frozen pizza reheating for 4 min. By assuming to use the cardboard box as a tray for pizza consumption, it was neglected the use of any eating utensils, such as cutlery, glass, tablecloth and napkin, as well as the consumption of any beverage. Since the mass of a Marinara pizza was equal to 350 ± 4 g, and its average waste (*i.e.*, raised rim, burnt parts, *etc.*) was around 6% of its initial mass (Falciano *et al.*, 2022a), it was assumed to discard such a waste in the bin for organic waste, while the PE bag or light cardboard box in that for plastic or paper and cardboard waste, respectively. Such municipal solid wastes (MSWs) were separately collected and conveyed to the municipal waste collection center (WCC) by means of 21-Mg MSW collection service trucks. This system boundary did not include the GHG emissions arising from the production of capital goods (*i.e.*, wood-fired ovens, freezers, home ovens, *etc.*), as well as their cleaning and disposal (PAS 2050: Section 6.4.4), and the transport of consumers to and from the restaurant gate (PAS 2050: Section 6.5). To avoid including the subsystems related to the cultivation of raw materials (*e.g.*, soft wheat, tomatoes, garlic, oregano, *etc.*), and production of selected ingredients (*i.e.*, extra-virgin olive oil, table salt, *etc.*), the mean and standard deviation (SD) of the carbon footprint values of such products were extracted from the SU-EATABLE LIFE database (Petersson *et al.*, 2021), while the carbon footprint scores of the packaging materials (*i.e.*, PE bags, light cardboard pizza boxes, *etc.*) were extracted from the Ecoinvent v. 3.7 and Agribalyse v. 3.0.1 databases, both embedded in the LCA software SimaPro 9.2 (PRé Consultants, Amersfoort, NL), as reported previously (Falciano *et al.*, 2022a).

Statistical analysis

All the experimental data were submitted to analysis of variance (ANOVA) and expressed as Average (A) ± SD. ANOVA was performed by using the one-way analysis of variance procedure. Duncan's multiple range test was used to analyse the significant difference of means, and $P \leq 0.05$ was considered statistically significant.

ANOVA and Duncan's multiple range tests were also used to analyse the sensory data related to overall acceptability and liking for sensory attributes (flavour, texture and appearance) of the samples of session 1 and session 2, separately.

The preference data were analysed by the Kruskal–Wallis test with Bonferroni correction and the Dunn procedure for the multiple comparisons of values ($P \leq 0.05$).

The XLSTAT statistical software package version 2016.02 (Addinsoft) was used for data analysis.

Results and discussion

Thermal mapping

Temperature is the main factor affecting the physical–chemical changes that occur during pizza baking and cooling processes and may be regarded as the first index of quality (Manhiça, 2014). The images of the upper side of each pizza sample, as acquired with the thermal imaging camera and shown for instance in Fig. 1, were analysed with the IRT Analyser software to register the T_{max}, T_{min} and T_{ave} values for any pizza sample, as shown in Table 2.

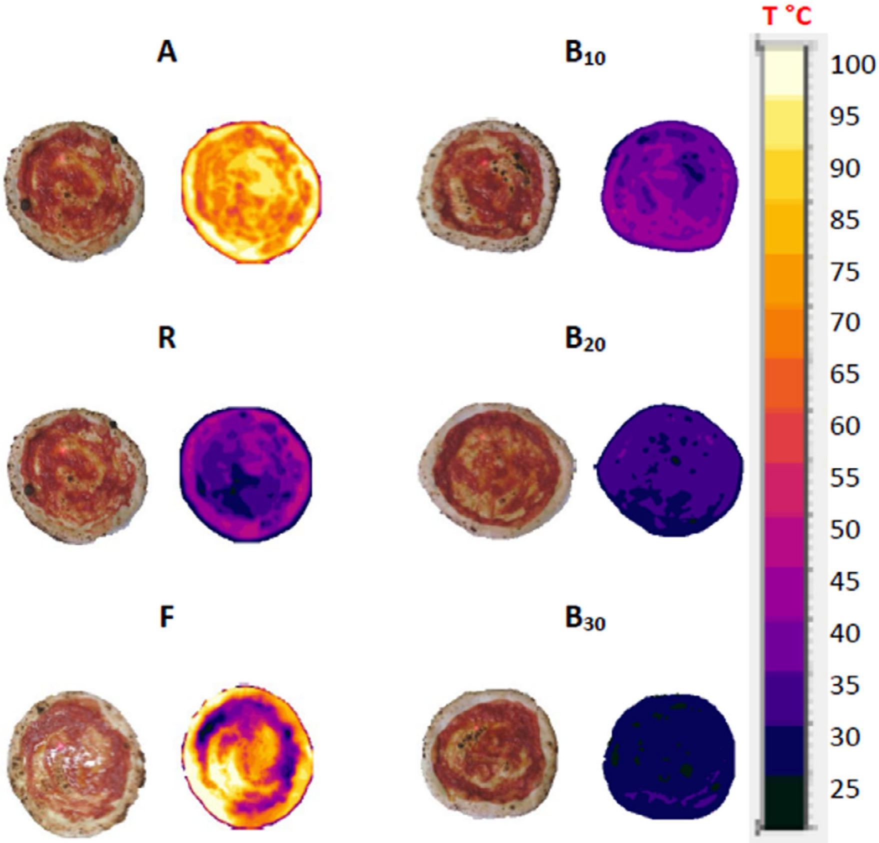

Figure 1 Visible and infrared (IR) images of the five pizza samples A, R, B_{10}, B_{20}, B_{30} and F (*cf.* Table 1), where their local temperatures can be roughly assessed using the IR thermometric scale shown on the right side.

The freshly baked pizza (sample A) was characterised by an average temperature of 82 ± 9 °C with a min–max interval ranging from 60.2 ± 0.4 °C to 99.2 ± 0.3 °C. When the pizza was let over a plate at room temperature for 5 min (sample R), T_{ave} was reduced to 42 ± 6 °C, this value being about the half of the sample A temperature. A similar temperature drop was observed in sample B_{10}, which was kept in a cardboard box for 10 min. As expected, the average temperature of the pizza samples further decreased as their residence time inside the cardboard boxes increased. T_{ave} was equal to 32.3 ± 1.6 °C for sample B_{30}. On the contrary, pizza sample F, that is the pizza quickly frozen and reheated for 4 min at 220 °C in a domestic oven, had a maximum temperature near to that of sample A. Unfortunately, the reheating process left some cold spots (T_{min} = 27 ± 2 °C), which reduced the average temperature to 69 ± 16 °C. The latter was smaller than that observed for sample A, even if their difference was not significantly different at $P = 0.05$. Since the best palatability range for pizza consumption was found to range between 80 and 65 °C as confirmed by 75 out of 100 panellists (Fava *et al.*, 1999), it can be noted that only samples A and F fell within such palatability range.

Water vapour loss

The fourth column in Table 2 lists the average VWL values observed in the different pizza samples tested.

When the freshly baked pizza was left queuing on a plate for 5 min (sample R), the average WVL value amounted to 3 ± 1% of its initial mass (*i.e.*, 350 g). Such a pizza weight loss was not statistically different from that referred to sample B_{10} (2.3 ± 0.7%) at 95% confidence level. Despite the great variability of these data, it would have been expected that the longer the residence time of pizza in the cardboard box the greater WVL became. A 30-min residence of pizza in the box increased the water vapour loss up to 3.9 ± 0.6% of the initial pizza mass, which was however not statistically different from the WVL values measured after a pizza residence time of 20 min (3.4 ± 1.0%). In the case of pizza sample F, the water

Table 2 Thermal mapping (maximum, T_{max}, minimum, T_{min} and average, T_{ave}, temperatures), water vapour loss and TPA parameters [hardness at the first (H_1) and second (H_2) compression cycles, cohesiveness (Co), springiness (Sp) and gumminess (Gu)] related to the pizza samples examined in this work

Samples	T_{max}[°C]	T_{min}[°C]	T_{ave}[°C]	WVL[%]	H_1[N]	H_2[N]	Co[−]	Sp[mm]	Gu[N]
A	99.2 ± 0.3^{e}	60.2 ± 0.4^{e}	81.9 ± 8.8^{d}	–	11.15 ± 0.54^{a}	9.90 ± 0.47^{a}	$0.52 \pm 0.09^{b,c}$	$7.17 \pm 2.25^{a,b}$	5.76 ± 0.93^{a}
R	55.7 ± 1.4^{d}	28.8 ± 1.1^{c}	42.2 ± 5.6^{c}	$3.0 \pm 1.0^{a,b}$	$13.45 \pm 5.33^{a,b}$	$11.48 \pm 4.48^{a,b}$	0.49 ± 0.06^{b}	8.57 ± 1.91^{b}	$6.40 \pm 2.50^{a,b}$
B_{10}	51.3 ± 1.1^{c}	30.6 ± 0.9^{d}	43.3 ± 3.3^{c}	2.3 ± 0.7^{a}	13.89 ± 3.28^{b}	12.04 ± 2.71^{b}	$0.51 \pm 0.06^{b,c}$	7.83 ± 1.37^{b}	7.04 ± 1.58^{b}
B_{20}	40.9 ± 0.9^{b}	$28.8 \pm 1.6^{c,d}$	36.4 ± 1.9^{b}	$3.4 \pm 1.0^{a,b}$	17.51 ± 3.13^{c}	14.70 ± 2.50^{c}	0.50 ± 0.03^{b}	8.35 ± 1.05^{b}	8.77 ± 1.63^{c}
B_{30}	37.2 ± 1.0^{a}	25.0 ± 0.2^{a}	32.3 ± 1.6^{a}	3.9 ± 0.6^{b}	17.51 ± 4.54^{c}	14.70 ± 3.64^{c}	0.55 ± 0.06^{c}	11.09 ± 2.56^{c}	9.51 ± 2.24^{c}
F	99.8 ± 0.2^{f}	26.8 ± 1.9^{b}	68.6 ± 15.7^{d}	†5.5 ± 0.7^{c}	$17.40 \pm 7.56^{b,c}$	14.53 ± 4.94^{c}	0.34 ± 0.03^{a}	6.03 ± 2.91^{a}	6.12 ± 2.88^{a}

Each value is expressed as mean ± SD (the number of tests, *n*, was equal to 6 or 18 for the thermal mapping and WVL or TPA assessment, respectively). Means with the same letters in the same column are not significantly different ($P < 0.05$) by the Duncan's multiple range test.

†This value refers to the overall WVL after the frozen samples had been reheated in a domestic oven, while the WVL at the exit of the blast freezer was 3.9 ± 0.4% of the initial pizza weight.

vapour loss reached the highest value (5.5 ± 0.7%). Since all the pizza samples had the same surface area and moisture content, the different WVL values detected here can be explained by accounting for the differences in terms of temperature and environment. Even if the water vapour loss observed in pizza samples R and B_{10} was found to be not statistically different at $P = 0.05$, some difference should have been derived from the fact that the former was exposed to free air while the latter was kept in a confined space. Since on the top of each pizza sample, there was free water, the water evaporation rate should have been almost constant, involving a linear WVL increase with time. The longer the pizza residence in a cardboard box, the lower the pizza temperature became. This resulted in a progressive water vapour saturation within the internal environment that should have lessened the local water evaporation rate. Moreover, sample F, as extracted from the blast freezer, exhibited a WVL (3.9 ± 0.4%) similar to that of sample B_{30}; thus, such higher experimental WVL was *a priori* expected as a result of its reheating in a domestic oven for 4 min.

Textural properties

The textural properties of bakery products mainly derive from their water content and distribution (Wagner *et al.*, 2007). The textural attributes of pizza samples were analysed by using texture profile analysis (TPA) tests. The raised rim sections of any pizza sample were compressed twice between the plates of the texture analyser to imitate the jaw action (Falciano *et al.*, 2022c). Figure S3 in the electronic supplement shows the typical TPA curves obtained when testing the A and F pizza samples, while Table 2 shows the main TPA parameters.

Owing to the aforementioned increase in the water vapour loss in the pizza samples tested, the rim force peaks during the first (H_1) and second (H_2) compression cycles increased with the following trend: A < R, and $B_{10} < B_{20}$, B_{30} and F. Actually, the difference in H_1 and H_2 for the pizza freshly baked (A) and that served at the restaurant table within 5 min (B) were not statistically significant at $P = 0.05$. Same statistically insignificant differences for the hardness values of the other pizza samples B_{20}, B_{30} and F.

Cohesiveness and springiness values were almost similar in all pizza samples except for sample F. Since cohesiveness measures how well the pizza rim regains its original form once submitted to 80% deformation (Bourne, 2002), it can be noted that the compression energy needed to perform the second bite was roughly 50% of that needed during the first bite in all pizza samples tested, except for the frozen and reheated pizza F. In fact, its cohesiveness reduced to 34%, probably because its structure was more damaged by the freezing process. Nevertheless, the pizza samples F exhibited the same gumminess value as samples A and R at $P = 0.05$, while the samples packed in cardboard boxes displayed an increasing trend for Gu, as their residence time increased from 10 to 30 min. This was probably a consequence of the reducing temperature and increasing water vapour loss of the pizza samples packed in cardboard boxes, this also favouring starch retrogradation as assessed by Aguirre *et al.* (2011). It can be finally noted that the difference in the Gu values for the samples stored in the cardboard for 20 and 30 min was not statistically significant at $P = 0.05$.

Sensory properties

The observed changes in the temperature and moisture content are expected to affect the sensory quality of the pizza samples examined here and in turn their consumer acceptability.

The first consumer test was carried out to compare the pizza samples A, R, B_{10}, B_{20} and B_{30}, and involved

45 subjects. Figure 2 shows the average scores for the different attributes, namely, overall acceptability (a), appearance (b), texture (c) and flavour (d), assessed by the subjects using nine-point hedonic scales.

While the appearance of the pizza did not change, all the other attributes were differently perceived from the sample freshly baked.

As shown in Fig. 3a statistical differences were found among the samples in terms of the most preferred one ($P < 0.0001$). In particular, pizza samples A and R were the most favourite ones. On the other side, no differences were found among the samples in terms of the least preferred one ($P = 0.11$), even though it was possible to observe that less response (%) increased as the time elapsed between baking and consumption enhanced.

Thus, a second consumer test was carried out to evaluate pizza samples A, B_{20} and F. Figure 4 shows the average hedonic scores. The appearance and flavour attributes were judged similarly by the 54 consumers whatever the samples evaluated. The largest discrimination among the three samples was observed in terms of texture. As expected, the highest score referred to the freshly baked pizza, this being followed

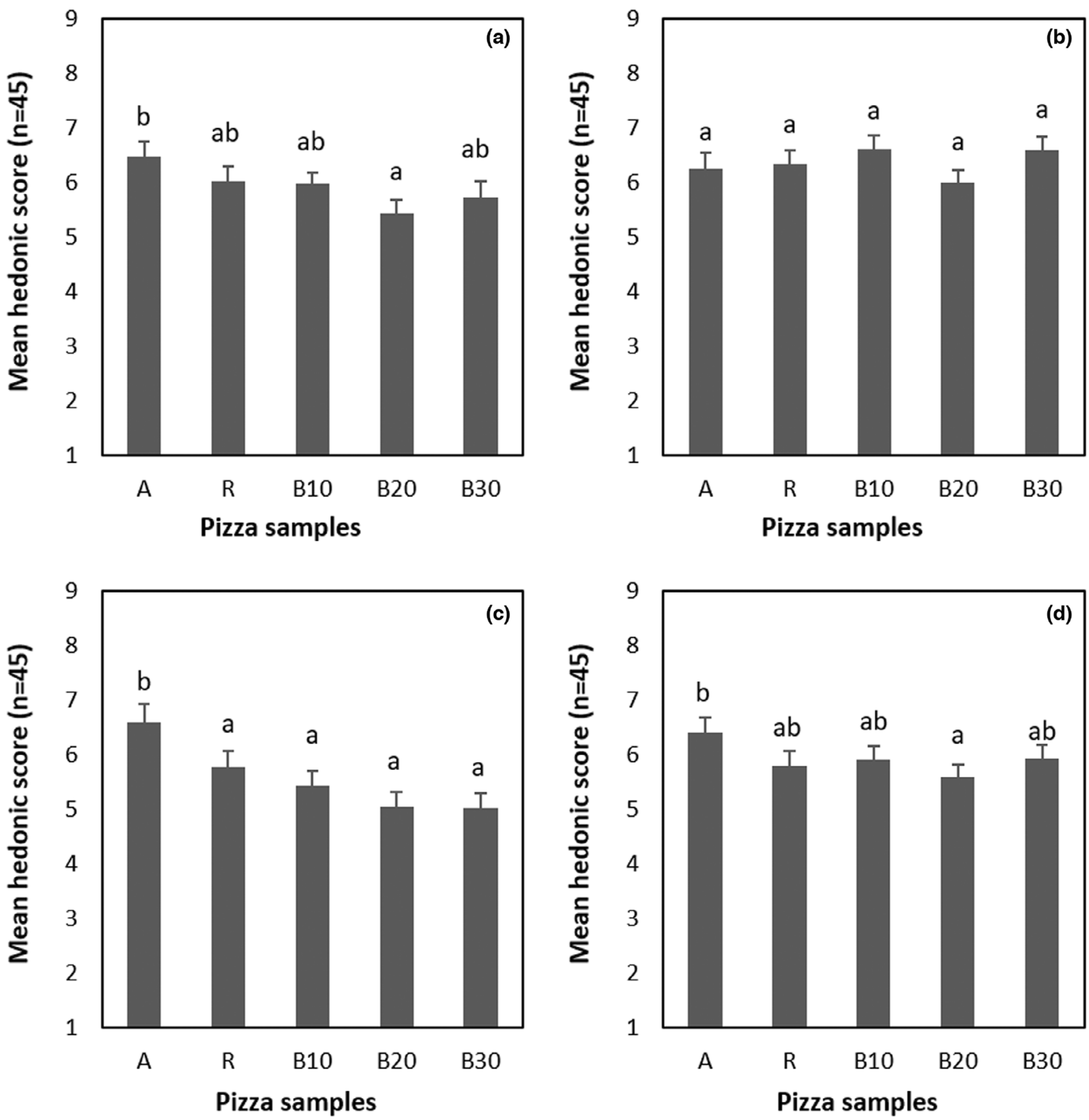

Figure 2 Average hedonic scores of pizza samples A, R, B_{10}, B_{20} and B_{30}: overall acceptability (a), appearance (b), texture (c) and flavour (d). Scores with the same letters are not significantly different ($P < 0.05$) by the Duncan's multiple range test.

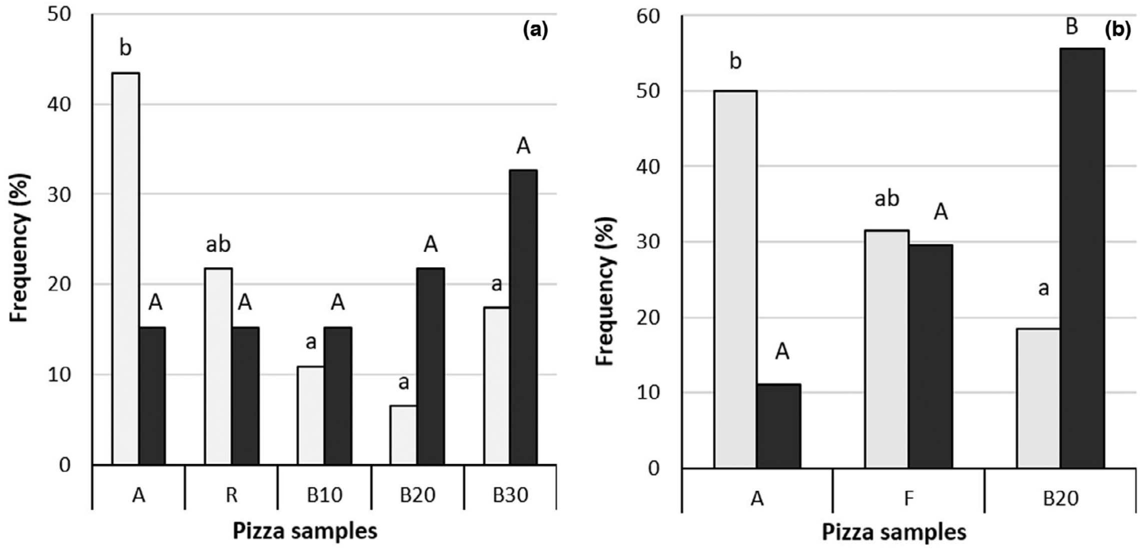

Figure 3 (a) Evaluation of the preference degree of pizza samples A, R, B_{10}, B_{20} and B_{30}. Favourite sample (statistical differences indicated with lowercase letters); ■ Not favourite sample (statistical differences indicated with capital letters, the Kruskal–Wallis test with Bonferroni correction and Dunn procedure for the multiple comparisons). (b) Evaluation of the preference degree of pizza samples A, B20 and F. ■ Favourite sample (statistical differences indicated with lowercase letters); ■ Not favourite sample (statistical differences indicated with capital letters, the Kruskal–Wallis test with Bonferroni correction and Dunn procedure for the multiple comparisons).

by the pizza quickly frozen and reheated in a domestic oven. The sample kept in the box for 20 min (B_{20}) obtained the worst score. This result agrees with the gumminess data obtained from the TPA test. In fact, gumminess values for the pizza samples A and F were 5.8 ± 0.9 N and 6.1 ± 2.9 N, respectively, while it reached a higher value (8.8 ± 1.6 N) for sample B_{20}.

The consumer opinion for the pizza prepared according to the procedure proposed in this study (sample F) can be easily seen by looking at the data shown in Fig. 3b. As one would expect, the most preferred sample was the freshly baked pizza (that is, the one usually consumed in a pizzeria or restaurant) ($P = 0.002$). However, no significant differences were found between sample A and sample F, whereas the pizza kept in a cardboard box for 20 min (B20) was significantly the least preferred one ($P < 0.0001$).

Carbon footprint assessment

To estimate the carbon footprint of the production and consumption of the frozen Marinara pizza according to the block diagram shown in Figure S2, it is worth noting that at the Pizzeria *La Notizia* (Naples, Italy) the number of dough balls (NP) unused at the end of any working week varied from 75 to 90, equivalent to 15–18 dough balls (DBs) per day. The energy consumption associated with their transformation in frozen pizzas should include three items related to the blast freezing, frozen storage and oven reheating of pizza, as estimated below.

Blast-freezing energy consumption

A few operations (*i.e.*, ignition, no-load operation at the service temperature, different freezing cycles) of the blast freezer used in this work were monitored.

Table S1 in the electronic supplement shows the time course of the electric voltage supplied (V), current (I) and power (P) absorbed, as well as the overall electric energy consumed (E) at the end of each operation of the blast freezer accounted for.

Thus, the overall electric energy needed to freeze NP Marinara pizzas was estimated as follows:

Blast freezer ignition:	0.191	kWh
Freezing of no. 3 pizzas/cycle:	0.135 × (NP/3)	kWh
Freezer reconditioning after pizza unloading-loading:	0.04 × (NP/3–1)	kWh

Therefore, for NP = 15 or 18 pizzas/day, the total electricity consumed (E) was equal to 1.03 or 1.20 kWh, this involving an average specific energy consumption for pizza freezing of 0.068 ± 0.001 kWh/pizza.

Energy consumption during frozen storage

In agreement with the most recent category rules for uncooked pasta (EPD®, 2022), such energy consumption was estimated as:

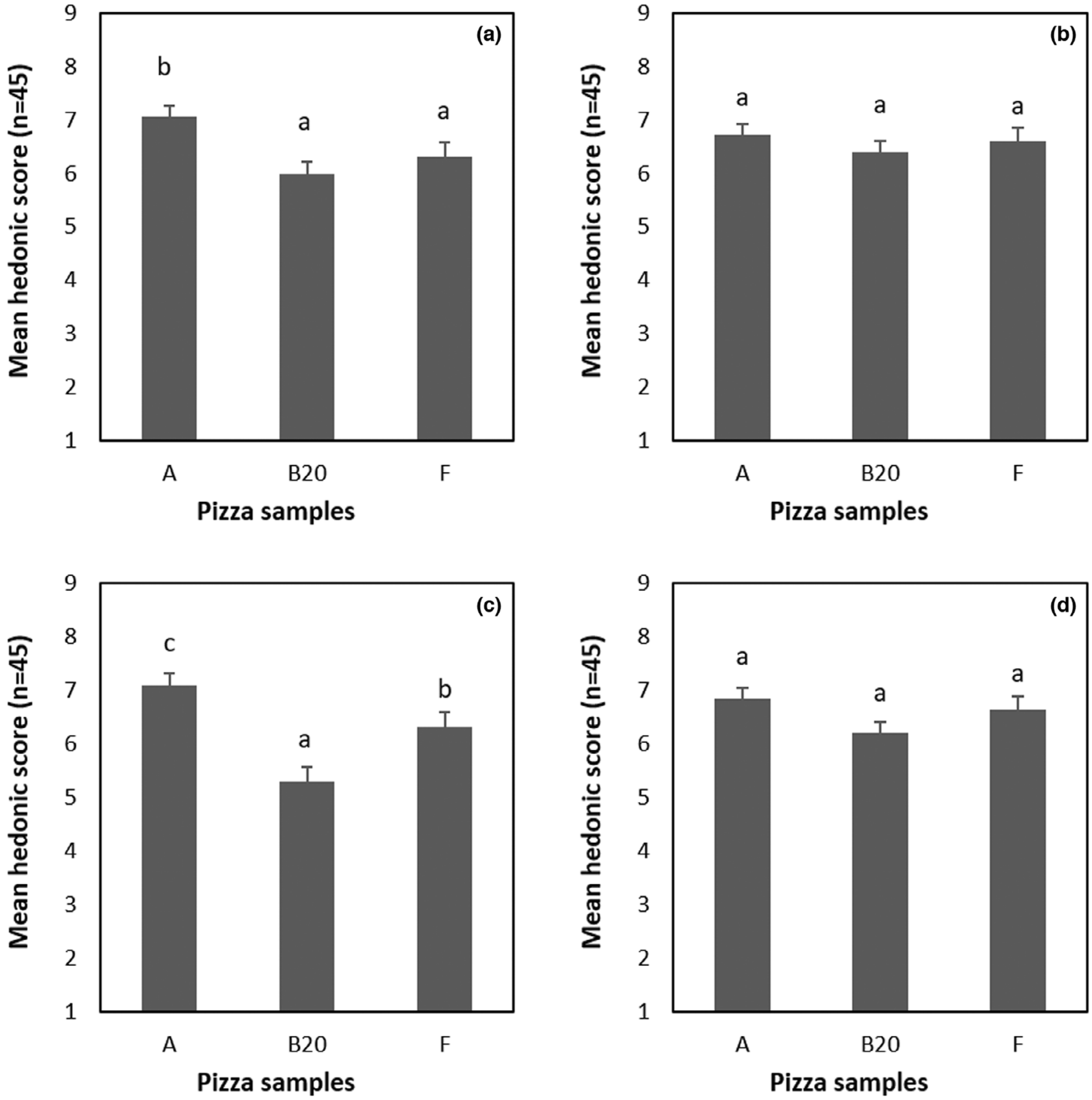

Figure 4 Average hedonic scores of pizza samples A, B_{20} and F: overall acceptability (a), appearance (b), texture (c) and flavour (d). Scores with the same letters are not significantly different ($P < 0.05$) by Duncan's multiple range test.

- Energy consumption by a class F freezer such as, for instance, Indesit UI6 F1T W1 (https://www.indesit.it/congelatore-verticale-a-libera-installazione-indesit-colore-bianco-869991609420/p, accessed 7 February 2023): 288 kWh/year.
- Net volume: 228 L.
- Average mass of frozen products storable in the freezer: 97 kg.
- Filling degree of the freezer: 75%.
- Daily specific energy consumption: 288 kWh/(365 days × 97 kg × 0.75) = 0.011 kWh/(day kg).
- Average residence time of frozen pizza in the freezer: 7 days.

Thus, the average energy consumed for preserving the frozen pizza was equal to 0.011 × 7 = 0.076 kWh/kg.

Energy consumption for pizza reheating

A few operations (*i.e.*, ignition, no-load operation at the service temperature, different reheating cycles) of the home oven used here were examined.

Table S2 in the electronic supplement shows the time course of the electric voltage supplied (V), current

(I) and power (P) absorbed, as well as the overall electric energy consumed (E) at the end of each operation of the home oven under study.

Thus, the overall electric energy needed to reheat a frozen pizza was estimated as follows:

Home oven ignition:	0.379	kWh
Reheating of no. 1 pizza/cycle:	0.104	kWh
Reheating of no. 2 pizzas/cycle:	0.133	kWh

The overall electricity consumed (E) was equal to 0.483 or 0.512 kWh if one or two pizzas per cycle were reheated, this involving a specific reheating energy consumption of 0.483 or 0.256 kWh/pizza.

Carbon footprint of frozen pizza

The production of a Marinara pizza at a typical Neapolitan pizzeria, just coming out of the wood-fired oven and before being served at the restaurant table or put in a cardboard box for home delivery or takeaway service, was characterised by a carbon footprint (*CF*) of about 1.7 kg CO_{2e}/kg, that is about 600 g CO_{2e}/pizza (Falciano *et al.*, 2022d).

For a detailed description, Table S3 shows the input and output sources and activities associated with the production of a Marinara pizza, freezing, storage and reheating in a home electric oven, as well as the production and transportation of the packaging materials used and disposal of biogenic and abiogenic waste according to the average urban solid waste disposal scenario in Italy, previously described by Falciano *et al.* (2022a). Thus, the operations of freezing and reheating had the effect of increasing the carbon footprint to 1056 g CO_{2e}/pizza.

If the maximum number of dough balls wasted per year (18 DB/day × 312 days/year = 5616 DB/year) in the reference Neapolitan pizza restaurant was wholly converted into frozen pizzas, the pizzeria would increase its overall direct and indirect GHG emissions (*i.e.*, 402 424 kg CO_{2e}/year, as estimated by Falciano *et al.*, 2022a) by as many as 5930 kg CO_{2e}/year, this represented <1.5% of the current GHG emissions.

By contrast, the disposal of the dough balls unused at the restaurant closing as organic waste would involve the wastage of the GHG emissions associated not only with the manufacture of their main ingredients (*i.e.*, soft wheat flour and dry yeast) and related packaging materials (*i.e.*, paper sacks, multilayer laminated foil) but also to their transportation to the restaurant gate and disposal as urban solid waste.

The GHG emissions associated with the disposal of a single unused dough ball would amount to 224 g CO_{2e}, 43% of which being due to the manufacture of the soft wheat flour used and 41% to landfilling of the organic waste (Table S4).

The reference pizzeria in 2019 had to dispose of about 27.7 Mg of MSW and consumed 2930 m^3 of drinking water (Falciano *et al.*, 2022a), their corresponding costs amounting to €3620 and €5245, respectively. Thus, the specific costs for MSW disposal or tap water consumption were equal to €0.13/kg and €1.79/m^3, respectively. Thus, the disposal of a single dough ball would cost about €0.129, 72.9% of which is represented by the soft wheat flour wasted and 26.5% by waste disposal (Table S5).

Since the selling price of a takeaway Marinara pizza is currently €7.00 (source Pizzeria *La Notizia*, Naples, Italy), such a novel takeaway pizza product might yield an additional gross revenue of k€23–29/year if it were sold at €4–5 at the restaurant cashier.

In principle, the leftover dough balls might be used as a sort of sour dough starter to prepare the next day's dough balls and, of course, this reuse would be much more environmentally friendly than that suggested in this work. However, when a dough ball is left on the pizza counter at room temperature waiting to be turned into a pizza, yeast continues to grow and ferment by converting free sugars into ethanol and carbon dioxide, the latter making the dough rise. If the dough is over-fermented, it will have a sour taste and a smell of alcohol. Moreover, its weakened gluten structure will no longer retain the gas bubbles, this yielding a dough excessively dense and flat that would give rise to a tough, chewy, solid, unappetizing crust. Even if dough over-proofing might be avoided by resorting to proper dough ball chilling or freezing, as for instance described by Charles (2022) and Lehmann (2013), in the typical Neapolitan pizzerias, such as that used as a reference in this work, the leftover dough balls are generally wasted, their direct reuse being regarded as inappropriate for assuring the high-quality standards of their Neapolitan pizza crust.

Conclusions

A good pizza should be eaten freshly baked, its quality decreasing as it cools. The cardboard pizza box used for home delivery or takeaway slows down the cooling rate of the pizza but reduces its texture quality as the residence time increases. A novel pizza takeaway product (sample F), which was freshly baked, quick-frozen and reheated in a home oven, exhibited a few textural properties, such as gumminess and springiness, similar to or near to the values of a just freshly baked pizza. As expected, consumers preferred freshly baked pizza, but its preference was not significantly different from that of pizza sample F. A life cycle assessment study yielded that the extra GHG emissions resulting from such a frozen product quite irrelevantly affected the overall amount of GHG emitted by a typical pizzeria every year. Thus, this novel product might, on one side, offer a better-quality pizza to consumers of home-delivery or takeaway pizza and, on the other side, reduce interference in crowded restaurants, as well as avoid the wastage of unsold dough balls with a net profit increase.

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Author contributions

Aniello Falciano: Formal analysis (equal); investigation (equal); visualization (equal); writing – original draft (equal). **Sharon Puleo:** Investigation (equal); methodology (equal); visualization (equal); writing – review and editing (equal). **Francesca Colonna:** Data curation (equal); formal analysis (equal); writing – review and editing (equal). **Mauro Moresi:** Conceptualization (equal); methodology (equal); supervision (equal); validation (equal); writing – review and editing (equal). **Rossella Di Monaco:** Methodology (equal); supervision (equal); validation (equal); writing – review and editing (equal). **Paolo Masi:** Conceptualization (equal); funding acquisition (lead); project administration (lead); writing – review and editing (equal).

Ethical approval

The study was conducted in agreement with the guidelines of the Declaration of Helsinki and the Italian ethical requirements on research activities and personal data protection (D.L. 30.6.03n. 196). Informed consent was obtained from all subjects involved in the study.

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Data availability statement

The authors do not have permission to share data.

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The frozen pizza samples exhibited the same gumminess value as the freshly baked and the 5-min queuing-in-a-plate samples, while the samples packed in cardboard boxes displayed an increasing trend for gumminess. The cited study reported the effect of bread storage temperature on starch retrogradation, which resulted as useful information to explain that result.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Operation of the blast freezer during ignition, no-load operation at the service temperature (−24.5 °C), and freezing of no. 1, 2 or 3 pizzas/cycle: internal temperature of the freezer chamber (T), and electric voltage (V), current (I) and power (P) as a function of the operating time (t), and overall electric energy consumed at the end of each operation (E).

Table S2. Operation of the domestic oven during ignition, no-load operation at the service temperature (200 °C), and reheating of no. 1 or 2 pizzas/cycle: Internal temperature of the oven chamber (T), and electric voltage (V), current (I) and power (P) as a function of the operating time (t), and overall electric energy consumed at the end of each operation (E).

Table S3. GHG emissions associated with the production and consumption of frozen and home reheated Marinara pizza.

Table S4. GHG emissions associated with the disposal of an unused leavened dough ball and related raw and packaging materials.

Table S5. Disposing costs for each dough ball (DB) unused.

Figure S1. Pictures of the empty open (a) and closed (b) pizza corrugated cardboard boxes used in this work.

Figure S2. System boundary of the streamlined LCA study carried out to assess the carbon footprint of a frozen Marinara pizza from unused leavened dough balls: EoL, end of life; PE, polyethylene; TR, transportation.

Figure S3. Typical texture profile analysis curves obtained from the TMS-Pro Texture Analyzer when testing the pizza samples, A () and F (): Compression force vs. time.