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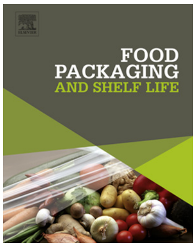

Influence of packaging on the quality maintenance of industrial bread by comparative shelf life testing

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A B S T R A C T

The research focuses on the evaluation of the effects of films with different thickness on the quality of industrial durum wheat bread. A comparative shelf life test was performed taking into consideration textural parameters, instrumental crumb colour parameters, crumb moisture and alkaline water retention capacity, considered as indirect indicators of bread staling. Sliced, durum wheat bread was packed into a system made of a thermoformed bottom, with thickness ranging from 225 to 275 μm, and a lid (121–125 μm), with comparable barrier properties. Results demonstrated that it is possible to reduce packaging by about 20% without affecting shelf life standards. The packaging systems showed comparable barrier performances, maintaining the modified atmosphere during 103 days. Texture profile analysis gave comparable results for packages at reduced thickness compared with conventional ones. Also, colour, alkaline water retention capacity and crumb moisture correlated well with bread ageing and did not significantly vary among packaging types.

1. Introduction

The shelf life of cereal products and derivates can be influenced by the packaging materials and technologies used and, with special regards for bread, it is mainly dependent on the staling rate (Cencic, Bressa, & Dalla Rosa, 1996; Del Nobile, Martoriello, Cavella, Giudici, & Masi, 2003; Fava, Limbo, & Piergiovanni, 2000; Lanza, Tomaselli, Muratore, & Pulvirenti, 2000; Latou, Mexis, Badeka, & Kontominas, 2010; Licciardello, Rizzo, Grillo, Venora, & Muratore, 2013; Pagani, Lucisano, Mariotti, & Limbo, 2006; Piergiovanni & Fava, 1997; Rodríguez, Medina, & Jordano, 2000). Shelf life testing can represent a tool for selecting the most suitable packaging systems. In turn, the staling of bread is a complex phenomenon, which cannot be described by one single parameter (Karim, Norziah, & Seow, 2000; Sidhu, Al-Saqer, & Al-Zenki, 1997). For this reason various tests are usually performed simultaneously, supplying complementary information which can be directly or indirectly associated with staling. Karim et al. (2000) reviewed the methods for the study of starch retrogradation, which include those based on the changes in physical and chemical properties.

In the last years, consumers and producers have become more sensitive towards the sustainability of food productions, with special regards for the role of packaging. Estimates of the impact of packaging are in the range of 5–10% of the total environmental impact of a food item (Hanssen, 1998). It is sometimes necessary to increase the packaging environmental impact in order to reduce food losses (Wikström & Wilson, 2010), however this is not always true and new packaging solutions at lower environmental impact can be able to guarantee certain shelf life standards.

Indeed, packaging users often make unsuitable choices due to scarce knowledge of the materials characteristics and performances and of the product requirements: such choices generally rely on standardized solutions for certain product categories, as it is the case for bakery products. On the other hand, the optimization of packaging would be desired.

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Moreover, packaging users tend to maintain the same materials, not considering that the progress in materials science continuously offers new solutions with lower thickness but higher performances in terms of barrier and mechanical properties. As a consequence, the packaging materials adopted are not optimized for the specific product to be packed, and very often they exceed the product requirements: this phenomenon is known as "overpackaging", that is the excessive use of packaging material (Piergiovanni & Limbo, 2010). On the other hand, the difficulty for small and medium food industries to carry out reliable shelf life studies results in a prudential evaluation of the "best-before end" for their products, which underestimates the product shelf life. Such discrepancy causes huge quantities of products to be discarded and disposed well in advance compared to the actual commercial life.

The aim of the present research was to assess the effect of films with different thickness on the quality of an industrial, durum wheat bread, evaluating the possibility of reducing the amounts of plastic materials used without affecting the shelf life standards. This objective was addressed by the comparative study of the shelf life of bread packed with materials having a lower thickness than the conventional one, taking into account texture, crumb colour parameters, crumb moisture and alkaline water retention capacity, considered as indirect indicators of bread staling.

2. Materials and methods

2.1. *Sample preparation*

Commercially available bread was prepared by Valle del Dittaino Società Cooperativa Agricola a.r.l. (Assoro, EN, Italy), following a consolidated industrial process. In particular, the base ingredient was semolina obtained from durum wheat cultivated in the centre of Sicily, and leavening was performed by the use of sourdough. Two-piece packages were obtained from a bottom film and a lid film possessing the same shape and area ($\approx$280 cm^2). The bottom film was thermoformed into a bowl before inserting the bread. Packages contained 450 g sliced bread and were obtained with different plastic materials, listed and described hereafter with reference to thickness, water vapour transmission rate (WVTR, g/m^2/24 h) and oxygen transmission rate (OTR, cc/m^2/24 h):

- *Package A.* Bottom film: T6011B, thickness: 275 μm, WVTR $\leq$ 10, OTR = 1; Lid film: T9250B, thickness: 125 μm, WVTR < 10, OTR < 3;
- *Package B.* Bottom film T6090B, thickness: 225 μm WVTR $\leq$ 10, OTR = 1; Lid film: T9250B, thickness: 125 μm, WVTR < 10, OTR < 3;
- *Package C.* Bottom film T12HBL – 230, thickness: 230 μm, WVTR = 3.5, OTR = 1; Lid film: HF00159-A, thickness: 121 μm, WVTR = 6, OTR = 2.

Films for packages A and B were supplied by Cryovac Sealed Air S.r.l. (Passirana di Rho, MI, Italy). Films for packages C were supplied by Hafliger films S.p.a. (Rozzano, MI, Italy).

As conventionally done by the producer, food-grade ethanol (3 mL) was sprayed into the packages, whose atmosphere was replaced with a 70:30 N_2:CO_2 gas mixture. Samples were stored for up to 103 days at 25 °C and the determination of quality parameters was performed at regular intervals on 3 replicates for each batch.

2.2. *Headspace gas composition analysis*

The internal O_2 and CO_2 composition of packages was monitored during the shelf life testing by a Dansensor Checkpoint portable gas analyzer (Dansensor, Ringsted, Denmark) on three replicates at 2-week intervals, analyzing 10 mL of the package headspace.

2.3. *Texture profile analysis*

The rheological properties of crumb were evaluated at 2-week intervals by cyclic compression tests using an Instron 3344 Texture Analyzer (Instron, Norwood, MA, U.S.A.), supplied with a 2000 N load cell and a cylindrical probe (diameter: 5 cm) for compression purposes. For each of the three replicated loaves, two samples sized 5 cm × 5 cm × 2.2 cm were obtained from the first two slices. Compression tests were carried out until 40% sample deformation at 5 mm/s speed, with no delay between first and second compression. The following data were stored and elaborated by the Bluehill® 2 software (Instron, Norwood, MA, U.S.A.): maximum force at first and second compression, cohesiveness, springiness and chewiness.

Crumb firmness was fitted to the modified Avrami equation (Armero & Collar, 1998):

$$\theta = \frac{F_\infty - F_t}{F_\infty - F_0} = \exp(-kt^n)$$

where θ is the fraction of the total change in the crumb firmness still to occur. F_0, F_t and F_∞ are experimental values of the property at times zero, t, and infinite (or limiting value), k is a rate constant, and n is the Avrami exponent. All parameters were obtained from the modelling process.

2.4. *Colour parameters*

The first slice of each sample was scanned by a scanner Canoscan N650U (Canon Computer System, Inc., Costa Mesa, CA, U.S.A.). Images sized 3 cm × 3 cm were acquired at 150 dpi resolution and processed by the software Image Color Summarizer v0.5 © 2006–2011 (Martin Krzywinski, http://mkweb.bcgsc.ca) obtaining the r, g, b (respectively: red, green and blue indexes) and h, s, v (respectively: hue, saturation and lightness indexes) colour coordinates.

2.5. *Alkaline water retention capacity (AWRC)*

Alkaline water retention capacity was determined according to the method described by Yamazaki (1953), conveniently modified for the analysis of bread crumb as follows. One gram of bread crumb, previously dried until constant weight, was put in 15-mL tubes (W_1), added with 5 mL 0.1 N $NaHCO_3$ and vortexed for 30 s, then let at room temperature for 20 min. The slurry was centrifuged at 3000 rpm for 15 min, the supernatant was discarded and tubes were let drip for 10 min upside down with an inclination of 15°. Dried tubes were then weighed (W_2).

AWRC (%) was calculated as $[(W_2 - W_1)/W_1] \times 100$, where W_1, weight of tube containing the dry sample; W_2, weight of tube containing the dripped sample.

Analyses were conducted in duplicate.

2.6. *Statistical analysis*

Data were submitted to one-way analysis of variance (ANOVA) and post hoc comparison of means was performed by the Tukey test ($p < 0.05$) through the statistical package IBM® SPSS® Statistics 13.0 (Armonk, NY, USA).

3. Results and discussion

3.1. *Headspace gas composition analysis*

The CO_2 level inside packages (Table 1) slightly decreased during storage time: this could be attributed both to the dissolution of the gas into the food matrix and to permeability through the packaging material. The materials tested showed comparable barrier performances, as no statistical significance was observed among CO_2 values relative to different packages. Also, O_2 inside packages was not detectable through the whole duration of the shelf life test, this result confirming the high barrier properties of the three materials used, irrespective of their thickness.

3.2. *Crumb moisture content*

Freshly packed bread showed an average crumb moisture of 44.7%. This value decreased significantly ($p \leq 0.05$) with ageing, until steady values around 33–35% (Table 1). An increase in the crust moisture was observed (data not shown), thus indicating that moisture loss from crumb is to be attributed to its migration to the crust. The moisture loss from crumb determines its hardening, due to its plasticizing effect on the crumb network (Hug-Iten, Escher, & Conde-Petit, 2003); conversely, the moisture increase in the crust causes its softening. This event is, together with starch recrystallization, one of the major factors involved in bread staling (Baik & Chinachoti, 2000; He & Hoseney, 1990; Piazza & Masi, 1995). Similarly, Raffo et al. (2003) studied the effect of durum wheat cultivar on the staling rate of bread as determined by crumb water loss and firming. For what concerns the comparison among packaging materials, no significant difference was observed: this confirms the similar performances of the materials tested, irrespective of their thickness, especially regarding the moisture barrier which is essential for the quality maintenance of bakery products. As it can be inferred, different packages were able to guarantee the same steady-state crumb moisture, but none of the tested materials could slow down the moisture loss from crumb, this event depending only on the food matrix properties.

3.3. *Alkaline water retention capacity*

This parameter gives an indirect measure of the degree of starch crystallization; in particular, higher values are related to gelatinized starch, while lower AWRC indicates a higher fraction of starch which has lost the capacity to bind water, i.e. retrograded starch. AWRC has successfully been used for the indirect evaluation of crystallized starch, giving good correlations with the degree of retrogradation and with overall quality (Indrani, Rao, Sankar, & Rao, 2000; Sidhu et al., 1997). Indeed, the principle of such correlation relies on the fact that gelatinized starch possesses higher water-binding capacity which, conversely, decreases in crystallized starch. Bread samples showed a decrease of AWRC during ageing, starting from 383% for the fresh bread crumb, and significantly decreasing after 61 and 75 days, slightly increasing at the last stage of storage (Table 1). Similar results were obtained by Sidhu et al. (1997) who recorded AWRC values of 346 and 369% for fresh arabic bread, which decreased to 217.80–209.04% after 4 days of storage. In any case, no significant difference was observed among the different packaging materials.

3.4. *Texture profile analysis*

The cyclic compression tests showed a progressive increment of the maximum force relative to the first and second compression cycles. The maximum force required to compress the crumb (Table 2) was 8.1 N for the fresh samples, increasing significantly ($p \leq 0.05$) at each sampling time, until values ranging from 20 to 29.5 N after 103 days of storage. As it can be inferred from Table 2, sample C showed a higher increase for the compression force. A similar trend was observed for the maximum force at the 2nd compression

Table 1 – Headspace gas composition, crumb moisture and alkaline water retention capacity (AWRC) of differently packaged industrial bread during storage.

Time (days)	CO_2 level (%)			Crumb moisture (%)			AWRC (%)		
Packaging	A	B	C	A	B	C	A	B	C
0	30.0^{cd}	30.0	30.0^{d}	44.72^{c}	44.72^{c}	44.72^{d}	382.7^{c}	382.7^{c}	382.7^{b}
7	30.6^{d}	30.3	30.6^{d}	40.32^{bc}	40.06^{bc}	41.15^{cd}	378.4^{c}	378.9^{c}	378.0^{b}
21	$29.8^{c,B}$	30.1^{B}	$29.1^{cd,A}$	38.53^{b}	38.18^{ab}	39.20^{bcd}	$365.8^{bc,AB}$	$359.4^{bc,A}$	$358.4^{b,A}$
48	$29.0^{b,B}$	28.9^{B}	$27.8^{bc,A}$	38.19^{ab}	38.53^{ab}	36.03^{abc}	$339.3^{b,B}$	$327.3^{ab,A}$	$335.8^{ab,B}$
61	$28.8^{b,B}$	28.8^{B}	$27.3^{ab,A}$	33.87^{a}	38.56^{ab}	33.08^{a}	$308.5^{a,A}$	$326.8^{ab,B}$	$327.5^{ab,B}$
75	28.8^{b}	29.0	26.9^{ab}	33.71^{a}	34.31^{a}	35.25^{abc}	$319.3^{ab,AB}$	$306.9^{a,A}$	$300.9^{a,A}$
103	27.8^{a}	30.1	25.9^{a}	35.90^{ab}	34.81^{a}	35.09^{ab}	359.4^{bc}	344.9^{b}	341.2^{ab}

Different small letters, in columns, and different capital letters, in lines, indicate significantly different ($p \leq 0.05$) values. Absence of letters indicates no statistical significance of differences.

Table 2 – Textural parameters for differently packaged industrial bread during storage.

Time (days)	Max. force 1st cycle F1 (N)			Resilience (F2/F1) (N)			Springiness (mm)			Chewiness (N)		
Packaging	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
0	8.1^{a}	8.1^{a}	8.1^{a}	0.918^{a}	0.918^{a}	0.918^{a}	3.78^{cd}	3.78^{c}	3.78^{c}	22.4^{a}	22.4^{a}	22.4^{a}
7	12.1^{a}	12.6^{a}	13.9^{b}	0.931^{ab}	0.928^{b}	0.928^{b}	$2.98^{ab,A}$	$3.27^{a,AB}$	$3.27^{ab,AB}$	$28.8^{ab,A}$	$32.5^{a,AB}$	$35.8^{ab,B}$
21	19.8^{b}	21.7^{b}	18.9^{bc}	0.924^{b}	0.926^{ab}	0.927^{b}	3.24^{ab}	3.26^{a}	3.21^{a}	51.2^{c}	56.5^{b}	49.1^{bc}
48	18.2^{b}	23.5^{b}	19.2^{c}	0.932^{b}	0.932^{b}	0.940^{c}	3.36^{bc}	3.09^{a}	3.17^{a}	50.2^{c}	57.1^{b}	50.6^{bc}
61	20.9^{b}	21.0^{b}	22.6^{c}	0.931^{b}	0.934^{b}	0.931^{b}	3.25^{ab}	3.50^{ab}	3.18^{a}	55.5^{c}	60.0^{b}	58.8^{c}
75	22.1^{b}	23.5^{b}	21.7^{c}	0.931^{b}	0.930^{b}	0.928^{b}	$4.24^{d,BC}$	$4.31^{d,C}$	$3.25^{ab,A}$	55.5^{c}	60.0^{b}	58.8^{c}
103	$19.7^{b,A}$	$22.8^{b,A}$	$29.1^{d,B}$	$0.932^{b,B}$	$0.927^{b,AB}$	$0.928^{b,AB}$	$2.87^{a,A}$	$3.55^{ab,B}$	$3.66^{bc,BC}$	$46.5^{bc,A}$	$64.4^{b,B}$	$83.0^{d,C}$

Different small letters, in columns, and different capital letters, in lines, indicate significantly different ($p \leq 0.05$) values. Absence of letters indicates no statistical significance of differences.

Table 3 – Avrami parameters for crumb firming kinetics of sliced durum wheat bread packed in different systems (*A*, *B* and *C*); F_0 and F_∞ are the initial and limiting firmness values, respectively, *k* is the rate constant and *n* is the Avrami exponent.

	F_0	F_∞	k	n
A	8.09 ± 1.65	20.23 ± 0.83	0.0094 ± 0.026	1.9319 ± 1.27
B	8.09 ± 1.17	22.69 ± 0.58	0.011 ± 0.014	1.7967 ± 0.53
C	8.42 ± 2.52	5806.62 ± 845	0.00348 ± 0.0051	0.4753 ± 0.075

(data not shown), which always scored slighly lower values than for the 1st compression. Comparable textural values were obtained by Raffo et al. (2003) and Pasqualone, Summo, Bilancia, and Caponio (2007) who observed maximum compression force ranging between 7 and 11 N for fresh durum wheat bread, which increased rapidly with storage in microperforated films.

Compression data were modelled using the Avrami equation: Fig. 3 shows the best fit of the model to experimental data, while Table 3 resumes the model parameters.

Resilience showed a significant increase after 7 days of storage, and remained almost unchanged during the rest of the storage period for each of the tested packages. Springiness did not provide noticeable changes and could not be related with bread staling. Finally, chewiness, which corresponds to the force required to chew the sample, increased from 22.4 N for the fresh bread, to 46.5, 64.4 and 83.0 after 103 days of storage in packaging *A*, *B* and *C*, respectively. For what concerns the comparison between the tested materials, it can be observed that packaging *C* differentiated samples at the latest stages of storage, showing the highest textural parameters. On the other hand, packaging *B* performed similarly to *A* as far as textural parameters were concerned. Taking textural parameters as indirect indices of bread staling, it can be concluded that packaging *C* offered lower performances in terms of quality maintenance of bread.

3.5. *Colour parameters*

Crumb colour was measured by scanning image analysis on the first slice of loaves, on fresh bread and samples stored for 103 days, in order to assess whether the different packaging had any influence on the appearance of the packaged produce. A preliminary analysis (data not shown) showed significant differences ($p \leq 0.05$) for the r, g, b, s and v colour parameters between fresh bread and samples which had exceeded the labelled shelf life. As it can be inferred from Figs. 1 and 2, the r,

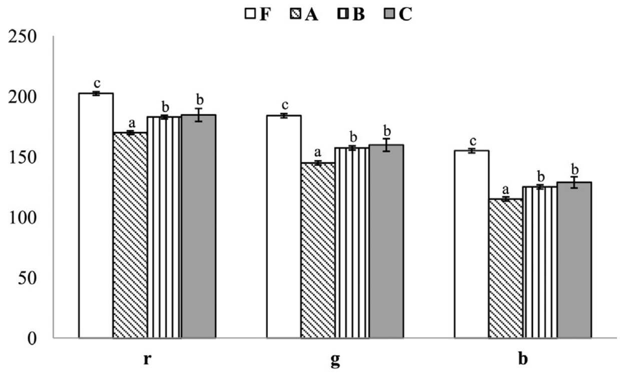

Fig. 1 – Red (*r*), green (*g*) and blue (*b*) colour parameters in freshly produced (F) and differently packaged durum wheat industrial bread after 103 days of storage.

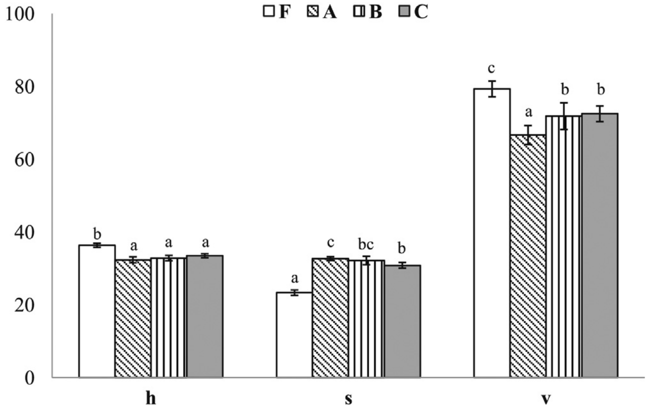

Fig. 2 – Hue (*h*), saturation (*s*) and lightness (*v*) colour parameters in freshly produced (F) and differently packaged durum wheat industrial bread after 103 days of storage.

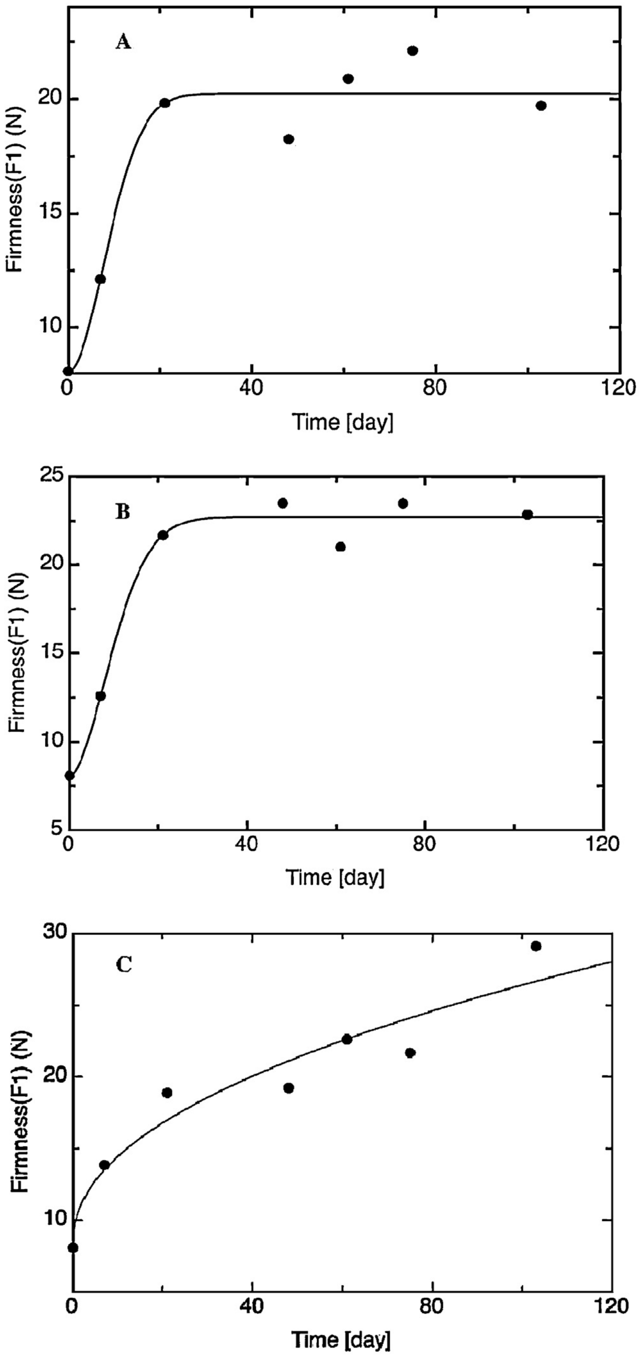

Fig. 3 – Best fit of Avrami equation to experimental firmness data.

g, *b* and *v* colour parameters decreased significantly ($p \leq 0.05$) with bread ageing, while *s* significantly increased and *h* remained substantially unchanged. For what concerns the comparison among packaging materials, it is worth noting that *B* and *C* showed significantly higher values for *r*, *g* and *b* indexes and for *h* compared with the reference packaging A: this means that the colour of samples B and C was more similar to that of freshly produced bread; *h* and *s*, on the contrary, did not vary significantly among treatments. Previous studies have considered colour changes to describe bread quality loss: Pająk, Habryka, and Fortuna (2012) observed a loss in the yellow index in mixed wheat-rye bread during 5 days of storage; similarly, Popov-Raljić, Mastilović, Laličić-Petronijević, and Popov (2009) observed a lighter colour in bread from different cereals after 3 days of storage. Ghoshal, Shivhare, and Banerjee (2013) also confirmed that bread possessing slower staling kinetic was characterized by lower colour changes (expressed as ΔE) during shelf life. No study available has investigated the mechanisms that lead to colour changes during the ageing of bread, however we can hypothesize that the changes observed are the result of moisture loss, which might affect the colour lightness, and of the oxidation of carotenoids which characterize durum wheat. Further research is needed to assess which factors contribute to the colour change of bread crumb.

4. Conclusions

Texture profile analysis, together with colour, alkaline water retention capacity and crumb moisture correlated well with bread ageing and did not significantly vary among packaging types. The selection of materials with lower thickness for the packaging of an industrial bread allows to maintain the shelf life standards and would carry several advantages for the producer, such as the reduction of packaging volumes (with improvements in the in-house materials stocks management) and costs, and in terms of sustainability of the whole life cycle of the product. In the case study, the comparative shelf life test highlighted that it is possible to reduce packaging by about 20% compared to the conventional packaging system. Results confirm the tendency, by small and medium food industries, to overpack goods. Moreover, the investigated quality indices of industrial durum-wheat bread did not change significantly after 21 days and until 103 days of storage (labelled "best-before" date is 40 days from production), and this could encourage food producers to abandon their prudential approach to shelf life in favour of an empirical approach, which would supply reliable data on the real product quality maintenance.

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