

Analysis of cracking and breakage in dried pasta: a case study

A. Baiano^{1*}, A.G. Di Chio² and D. Scapola¹

¹Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente, University of Foggia, Via Napoli 25, 71122 Foggia, Italy;

²FrancescoTamma Industrie Alimentari, Corso del Mezzogiorno 15, 71122 Foggia, Italy; antonietta.baiano@unifg.it

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RESEARCH ARTICLE

Abstract

Cracks and broken pieces (crumbles) are among the main defects of dried pasta since they affect the quality perception of consumers already at purchase. They originate during drying as a consequence of non-uniform moisture and/or temperature distributions but also after drying due to the collisions among pasta pieces and with the plant surfaces. This work was aimed to highlight the critical points and to plan preventive solutions in order to reduce the frequency of these defects in *rigatoni*, *mezzi rigatoni*, *zitoni tagliati*, and *maccheroni* produced in an industrial factory. The results show that cracks and breakages significantly increased at pasta packaging (+335 and +100%, respectively) and cardboard box preparation (+60 and 30%, respectively), which represent the critical steps. The percentage of defects was higher in longer pasta (*rigatoni*) and inversely correlated with pasta thickness ($R=0.96$). No correlations were found between cracks/breakages and semolina protein content/gluten index or pasta moisture. An increase in % of cracks was observed in the packaging line equipped with a long and narrow loading hopper. The installation of a shutter in the drop cone of the multi-head scale dramatically reduced cracks and breakages.

Keywords: breakage, crack, defect, packaging, dried pasta, quality control

1. Introduction

Pasta is a staple product obtained through kneading of semolina and water, extrusion, pressing through a die, and drying (Del Nobile *et al.*, 2005).

Defects like stickiness, unevenness in size, broken pieces (crumbles) and cracks must be strongly avoided in pasta production in order to meet the consumer satisfaction. Since the visual inspection of food mass production as pasta is time-consuming, not very accurate, and expensive, the food industry is increasingly considering the use of image processing techniques in quality control (Higuchi and Yoshida, 2014; Mokhtar *et al.*, 2011; Ogawa and Adachi, 2017; Xing *et al.*, 2007).

The scientific literature has been focused on defects originating during drying, a sensitive process involving heat and moisture transfer throughout the food structure. During drying, stresses occur as a consequence of non-uniform shrinkage deriving from non-uniform moisture and/or temperature distributions (Liu *et al.*, 1997). When

stresses exceed a critical level, cracks can take place. Cracks in pasta pieces are due to improper dehydration of the gluten network that causes separation from the starch (Sung and Stone, 2005). The influence of drying on formation of cracking and broken pieces is so strong that the distribution of stress during drying has been investigated by applying mathematical models to the changes in shrinkage and other mechanical properties, in order to allow the prediction of these defects (Inazu *et al.*, 2005; Liu *et al.*, 1997; Sung and Stone, 2005). There are two critical periods concerning the risks of crack formation: at the beginning of drying on the pasta surface, and at the end of drying, in the pasta core (Andrieu *et al.*, 1988). The exposure of extruded pasta immediately to high temperatures is one of the main reasons for development of cracks and breakages in pasta due to rapid and uneven loss of water. When high temperatures are combined with very humid air, the formation of cracks can be hindered.

Crack and breakage defects can also occur after drying as a consequence of the intensification of previous stresses or creation of new stresses to an extent greater

than the threshold value. The defects that depend on the intensification of previous stresses generate in the axial directions of long pasta formats even if no abnormality was found in their appearances immediately after drying. The creation of new stresses is a consequence of collisions among pieces and with the surfaces of the plants (Higuchi and Yoshida, 2014). Ghaedniaa and Azizinaghsh (2011) published a simple algorithm using numerical methods to find the deformation and the fracture criteria of the collision of brittle materials such as spaghetti in collision with rigid surfaces. The collision contact time is small, thus the velocity of stress propagation caused by collision cannot be considered as infinite. This means that there is a concentration of stresses in the region near the collision point. The three kinds of stresses (shear stress, pressure and tension), which have their critical points in certain distances from the contact point, should be considered all together in order to find the fracture point. Just few patents concerning adoptable solutions for reducing the problem of damaging bulk pasta during transferring have been registered in the worldwide database (<https://tinyurl.com/yy9upqcu>).

The acceptability level of cracking depends on specifications specific of each factory while the normal level of breakage allowed in most specifications is below 2% (Turnbull, 2001).

This work was aimed to analyse the causes of the crack and breakage defects in pasta after drying, to highlight the process critical control points, and to develop a procedure to reduce the occurrence frequency of these defects.

2. Materials and methods

Materials

The study was performed in a factory producing drying pasta that is located near Foggia, in the South of Italy. The factory produces several types of pasta under various brands differing for protein content and gluten index of the starting durum semolina. The characteristics of the durum semolina samples and of the 4 types of pasta considered in this study are summarised in Table 1 and 2, respectively. The drying process was the same for the considered types of

Table 2. Characteristics of the dried pasta produced.

Pasta type	Length (mm)	Diameter (mm)	Thickness (mm)
<i>Rigatoni</i>	55.5±0.2	15.1±0.1	1.05±0.01
<i>Mezzi rigatoni</i>	39.0±0.2	15.1±0.1	1.10±0.02
<i>Zitoni tagliati</i>	39.0±0.2	9.8±0.1	1.10±0.02
<i>Maccheroni</i>	39.0±0.2	11.3±0.1	1.04±0.01

pasta. Protein content and Gluten Index were determined according to the AACC 46-19.01 and 38-12.02 (2010a,b) methods. Length, diameter, and thickness of pasta were measured through electronic caliper and micrometre (mod. Shopcal and IP54, respectively, Tesa, Renens, Switzerland). *Rigatoni*, *mezzi rigatoni*, *zitoni tagliati*, and *maccheroni* were chosen because they are considered as the more fragile types of pasta, due to their cylindrical shape (with the presence of streaks typical of striped pasta), high length-to-width ratio, and small thickness.

The factory works on 3 shifts (from 6 a.m. to 14 p.m.; from 14 p.m. to 22 p.m.; from 22 p.m. to 6 a.m.) and the pasta object of this study is packed in 3 different lines.

Control points of the process

In order to identify the critical points, namely the steps of the process after drying at which the cracks and breakages are likely to be higher, the following pasta sampling points were considered: conveyor belt that transfers the dried pasta from the silos to the vibrating sieve; vibrating sieve; loading hopper of multi-head scales; package after control by metal detector; package withdrawn from the carton box.

At each sampling point, 300 pieces of pasta were withdrawn. At package step and subsequent step, the sampling was performed in the following way: a number of packs representative of each production batches were opened, their content were gently extracted and put on a flat surface, and the sample was obtained by randomly picking the 300 pieces.

Defects detected

Two types of defects were considered:

- Crack, characterised by the presence of a fracture line from a few to many millimetre long depending on the violence of the impact of the piece on a hard surface. If the cracks are very extensive and deep or branched, the pieces of pasta can break during cooking.
- Breakage, more serious than crack because the piece of pasta is already broken, or chipped. The fracture point appears smooth, glassy and the inside is shiny.

Table 1. Characteristics of the durum semolina samples used.¹

Brand	Protein content (%)	Gluten index
A	13±0.2b	95±1b
B	14.5±0.3c	80±3a
C, D, E, F	12±0.3a	94±1b

¹ In column, different letters indicate significant differences at $P < 0.05$ by LSD multiple range test.

Cracks and breakage were visually detected. Defectiveness % was expressed as:

$$\frac{\text{number of cracked or broken pieces}}{\text{number of total pieces}} \times 100$$

Pasta moisture

The moisture of dried pasta was measured through a thermobalance (Sartorius, mod. 150 MA, Göttingen, Germany). Measurements were performed at 145 °C for 15 min.

Statistical analysis

Each analysis was replicated at least three times. For each replication, 100 pieces were evaluated. The averages and the standard deviations were calculated using Excel software V. 11.5.1 (Microsoft, Redmond, WA, USA). The effects on defectiveness of the characteristics of raw materials (protein content and gluten index) and pasta (% moisture), as well as those of packaging line, work shifts, and production batches were analysed. The least significant difference (LSD) test ($P < 0.05$) and the one-way analysis of variance (ANOVA) were performed using the package Statistica for Windows V. 8.0.

3. Results and discussion

Critical points of the process

The first step was the analysis of the trend of defectiveness along the path that the pasta follows from the outlet of the dryer to the insertion of the packs in cardboard boxes. The results of Table 3 highlight that significant increases of damages (particularly cracks) occurred in the path of pasta between the loading hopper of multi-head scales and pasta packaging and during the handling of packaged pasta and the cardboard box preparation. The low % of defects detected in the first 3 sampling points is explained by the short path that pasta makes from the dryer to the

Table 3. Trend of defectiveness throughout the production steps after drying of *rigatoni*.¹

Sampling point	% cracks	% breakages
Conveyor belt	2a	0a
Vibrating sieve	2a	0a
Loading hopper of multi-head scales	2a	0a
Package after control by metal detector	8.7±1.5b	1±0.5b
Package withdrawn from the carton box	14±1c	1.3±0.6b

¹ In column, different letters indicate significant differences at $P < 0.05$ by LSD multiple range test.

scales and by the delicate handling in loading, unloading, and sieving operations.

Analysis of the causes of cracking and breakage

Based on the described pieces of evidence, the study was focused on packaging operations, in particular on the samples taken from pasta packages, in order to identify the possible causes of cracks and breakages. The following factors were considered: protein content and gluten index of the starting semolina; types of pasta; pasta moisture; packaging lines; work shifts, and production batches. Table 4 concerns the % distribution of cracks and breakages in the 4 types of pasta and their moisture contents. The maximum percentage of total defects (cracks+breakages) was found, in an increasing order for *mezzi rigatoni* (8.5±1.5), *maccheroni* (22.3±2), *zitoni* (31.3±1.2), and *rigatoni* (32.6±1.2). The behaviour of *rigatoni* is related to their length that higher than those of other types of pasta and make them more fragile. The increasing defectiveness observed passing from *mezzi rigatoni* to *zitoni tagliati* is inversely correlated ($R = 0.96$, $P < 0.01$) to the thickness, all having the same length. These results are in agreements with the findings of Bruns and Bourne (1975), who found that the resistance to breaking is inversely proportional to the sample length and is proportional to the square of the thickness in symmetrical food bars with rectangular cross section and proportional to the cube of the radius in foods having cylindrical cross

Table 4. Defectiveness and moisture content of the four types of pasta.¹

Brand	% cracks	% breakages	% moisture
<i>Rigatoni</i>			
B	13.9±3.4a	1.3±1a,b	12.2±0.5c
C	17.5±1.5b	0.5±0.2a	12.2±0.5c
D	18.1±1.6b	1.6±0.5b	11.7±0.2b
E	30.3±1.2c	2.3±0.5c	11.3±0.3a
Mean values	20.2±2.2	1.5±0.4	11.9±0.3
<i>Mezzi rigatoni</i>			
A	1.6±0.5a	0	12±0.1b
B	4.8±1.6b	0	11.6±0.2a
C	5.5±1.5b	0	12.5±0.1c
Mean values	3.9±1.1	0	12.1±0.1
<i>Zitoni tagliati</i>			
A	30.3±2.1	1±0.5	12.2±0.3
<i>Maccheroni</i>			
B	2.3±1a	0.3±0.1a	11.7±0.5ns
F	19.6±1.4b	2.6±0.9b	11.6±0.5ns
Mean values	11±1.8	1.5±0.4	11.6±0.5

¹ In column, within each type of pasta, different letters indicate significant differences at $P < 0.05$ by LSD multiple range test. ns: not significant difference.

sections. Hence, a small change in thickness or radius value causes a large change in the breaking strength. No correlation was found between defectiveness and protein content or gluten index. This behaviour is only partially corroborated by literature which stated that, if product undergoes a high temperature-drying as in the present work, pasta quality is not dependent on gluten content and strength but is affected by the total amount of protein (Ames *et al.*, 2003; Bruneel *et al.*, 2010). Our findings are also opposite to results of Zweifel (2001), who concluded that the susceptibility of dried pasta to breakage during packaging and distribution can even be used to characterise the gluten strength and quality in semolina, although it is not directly related to textural properties of pasta. Nevertheless, the relationships among susceptibility to breakage and the protein composition of the starting raw materials are very complex and the absence of correlation between protein content and defectiveness in the present study could be due to the low difference in the protein percentages of the considered starting semolina samples (between 12 ± 0.3 and 14.5 ± 0.3). This lack of correlation is further confirmed by the finding, within the same type of pasta, of significant differences among defects among brands produced from the same durum semolina (see, for example, *rigatoni* C, D, E).

No correlations were found between defectiveness and pasta final water content in the considered narrow range of moisture values (11.0-12.7%). These findings are in agreement with the results of Zweifel (2001), but they are opposite to those of Voisey and Wasik (1978).

In order to check if the different defectiveness depended on the packaging line used, a further was focused on the more fragile type of pasta (*rigatoni*) (Table 5). In our case-study, *rigatoni* were packaged under flexible film in 3 different lines, namely lines 1, 2, and 3 differing from each other for length of the conveyor belt, shape and size of the loading hopper, and height of the scales. As a result, pasta packaged in line 1 shows a significantly higher % of cracks than the other 2 lines. The line 1 differed from the others for size and shape of the loading hopper, which was respectively higher and narrower, thus determining a bigger pasta jump. The line 1 also had larger weighing heads, thus increasing the risk and the number of more violent collisions. Instead, the incidence of breakages was the same in the three lines.

Since the steps involving human intervention are the weak links in the process, the analysis of the variance was applied to the defects detected during the 3 production shifts of *rigatoni* in order to verify if the human factor could represent a source of defects (Kieffer, 1998). The results of Table 5 showed the absence of significant differences among shifts for both cracks and breakages.

Table 5. Effects of packaging line, work shift, and production batches on defectiveness of *rigatoni*.¹

Packaging lines	% cracks	% breakages
Production lines		
Line 1	39.5±1.5b	1.5±0.2a
Line 2	18.6±5.5a	1.5±0.6a
Line 3	15.6±3.5a	1.8±0.8a
Work shifts		
First shift (from 6 to 14)	17.0±4.5a	1.6±0.2a
Second shift (from 14 to 22)	16.9±4.7a	1.5±0.4a
Third shift (from 22 to 6)	17.2±5.0a	1.6±0.3a
Production batches		
B1	22.9±7.3c	2.9±0.6d
B2	15.8±4.5bc	0.9±0.2b
B3	17.5±6.9bc	1.2±0.3b
B4	13.5±3.9b	1.1±0.4b
B5	23.3±7.1c	2.4±0.5c
B6	20.3±6.2c	2.3±0.5c
B7	8.8±2.4a	0.3±0.1a
B8	13.5±3.3b	0.9±0.2b

¹ In column, within each considered parameter, different letters indicate significant differences at $P<0.05$ by LSD multiple range test.

Concerning one of the brands of *rigatoni*, the analysis of variance was performed to highlight possible differences among production batches. The results showed that, even in the presence of a widespread variability, it assumes a random distribution (Table 5). In fact, in every production process there is an intrinsic variability independent on external causes (Van Kampen, 2007). It is considered a natural variability, originated by a series of internal fluctuations in the process as a result of numerous small causes that work randomly (called common or random causes) and that can't be attributed to machines, employees or suppliers.

In order to reduce the percentage of defectiveness in the path between the loading hopper of multi-head scales and the pasta packaging, a shutter was placed inside the drop cone of the multi-head scale. The shutter allowed a slowing down of the pasta fall in the forming tube and, consequently, reduced the number and the severity of the mechanical stresses suffered by the pasta pieces. The shutter consisted of two movable metal arms that allow the movement from top to bottom of a metal ring equipped with a rubber structure of about 10 cm long. The overall diameter is as large as the cone of the multi-head scale so as to block the pasta pieces in an optimal manner. The shutter divided the pasta fall into two different steps thus preventing severe

collisions. To guarantee the correct functioning of the shutter, the packaging system was slightly modified. In particular, it was necessary to slow down the sliding speed of the packaging film to allow the perfect synchronisation of the pasta fall into the pre-formed package. Table 6 shows the % of *rigatoni* defectiveness before and after installation. Cracks and breakages decreased of about 40 and 90%, respectively.

4. Conclusions

Cracks and breakages are two important defects of dried pasta. This study suggested the usefulness of adopting plant solutions to reduce the incidence of cracks and breakages occurring after the drying operation. Since one of the critical points is represented by the fall of pasta pieces from the loading hopper to the forming tube, a shutter installed in the drop cone of the multi-head scale contribute to slow the fall of the pasta pieces and to significantly reduce the defectiveness, especially in the case of types of pasta having lengths significantly greater than the other two dimensions or low thickness.

Conflict of interest

The authors have no conflict of interest to declare.

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Table 6. Defectiveness of *rigatoni* before and after modification of the packaging line.

Packaging lines	Before	After
% cracks	17.0±4.1b	10.7±1.9a
% breakages	1.4±0.5b	0.1a

¹ In row, different letters indicate significant differences at $P<0.05$ by LSD multiple range test.

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