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Changes in pasta properties during cooking and short-time storage

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A b s t r a c t. The fundamental aim of this research was to study changes in the physical properties of spaghetti during cooking and after the first hour of storage. In addition, the research evaluated the cooking properties of pasta. For testing purposes, eight samples of spaghetti, produced using semolina and common wheat flour, were used. After cooking, the samples of spaghetti were stored for 2, 5, 10, 20, 30, 40, 50 and 60 min. After storage, the samples of cooked spaghetti were cut, and both the cutting force (hardness) and the cutting energy (firmness) of the samples were determined. It was found that, after storage, the cutting force and energy of cooked pasta decreased, in average terms, from 1.0 to 0.44 N and from 0.84 to 0.43 mJ, respectively. The statistical analysis showed a significant correlation between the storage time and the textural parameters of pasta. The hardness and firmness of pasta, which was *al dente* after cooking, were found to decrease about twice during storage, as a result of water migration. The hardness of pasta stabilised after 50 min of the storage of cooked spaghetti. Moreover, the obtained data revealed that the diameter increase index of spaghetti could indicate the quality of pasta.

K e y w o r d s: pasta, diameter, texture, cooking, storage

INTRODUCTION

Pasta is one of the most popular corn products, due to its ease of preparation, acceptable texture, low cost and long expiration date (Martinez *et al*., 2007; Krishnan and Prabhasankar, 2012). The best-quality pasta is made from durum wheat semolina; however, many kinds of pasta are produced from common wheat (Fuad and Prabhasankar, 2010) or from flour enriched with some functional components (Micale *et al*., 2018). The quality of pasta could be estimated from its colour, cooking attributes, such as weight increase, cooking loss, texture (Lee *et al*., 2002; Ozyurt *et al*., 2015) and sensory properties (Micale *et al.*, 2017). The cooking quality of pasta mostly depends on its kind and the ingredients used (Fares *et al.*, 2015; Biernacka *et al*., 2017). Moreover, cooking time has a strong influence on quality (Martinez *et al*., 2007). During cooking, the product becomes hydrated by a diffusion-controlled process, and the temperature-moisture conditions induce the gelatinisation of starch (Larrosa *et al*., 2015). As a result, starch absorbs water and swells. On the contrary, if the protein network lacks elasticity, or its formation is delayed, starch granules easily swell, and a part of the starchy material gets mixed up with the cooking water, resulting in a product characterised by stickiness and poor consistency. This increases the volume and causes pressure on the protein network (Delcour *et al*., 2010). In addition, cooking time has an influence on the texture, chemical composition and nutritional values of pasta (Sobota *et al*., 2013). Dziki and Laskowski (2005) revealed that extending the cooking time leads to a decrease in the firmness of pasta, which is expressed as cutting work. Extending the cooking time also causes an increase in cooking loss. De La Pena *et al*. (2015) found that when the cooking time of pasta was extended to 18 min, the total starch content decreased up to 5.7% units, starch damage increased up to 11.7% units, and both pasting

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parameters and protein solubility decreased significantly. The capacity of pasta to absorb water during cooking was found to determine the value of the weight increase index of the product after cooking (Sobota *et al.*, 2013).

The evaluation of mechanical properties is the most objective method to assess the texture of pasta, and it includes a series of tests, such as the cutting test (Larrosa *et al.*, 2016) and the compression test (Bouasla *et al.*, 2017). In literature, only a few studies refer to the characteristics of water migration in pasta and link it to quality. Besides, the textural characteristics of food products play essential roles in the final acceptance of these products by consumers. The basic test used to evaluate the textural characteristics of pasta is the cutting test (Rosenthal, 1999). According to literature (Dziki and Laskowski, 2005), the strength of cutting can be an indirect factor determining the hardness and firmness of pasta. Carini *et al.* (2014) studied changes in the physicochemical properties of ready-to-eat pasta that occurred during storage. They found that the hardness and crystallisation of amylopectin increased when the macroscopic water status indicators, such as the moisture content and water activity, and the mobility of the protein translation, remained constant during storage. Changes that occur during short-time storage after cooking also affect the quality of pasta (Sanguinetti *et al.*, 2016). However, the number of studies concerning this aspect is limited.

The aim of the present research was to determine the influence of both cooking time and short-time storage on the physical properties of spaghetti, with particular emphasis on its mechanical properties and the diameter.

MATERIALS AND METHODS

Eight different samples of commercial spaghetti – produced by different producers using durum (DWF) semolina and common wheat flour (CWF), and having similar diameters – were used (Table 1). Pasta samples were purchased in large supermarkets, paying attention to avoiding products with damaged packaging and short expiration dates. The moisture content and the chemical composition of the pasta samples were determined by drying performed according to the AACC Approved Methods (2000). In addition, the total protein content (AACC, Method 46-08), the ash content (AACC, Method 08-01) and the fat content (AACC, Method 30-26; using hexane solvent) of the samples were determined.

For the evaluation of the cooking properties, 100 g of each sample of pasta was cooked in 1 l of boiling distilled water. The optimum cooking time of pasta was determined as the time of disappearance of the white central core of pasta (Sobota *et al.*, 2015). Cooking loss (%) was measured as the amount of cooking water evaporated to dryness, using the oven-dry method (AACC, Method 44-15A). The water absorbed during cooking was measured as the weight increase of pasta after cooking, and the weight increase index was calculated by dividing the weight of pasta after cooking by the weight of uncooked pasta (Bonomi *et al.*, 2012). The cooking properties of pasta were evaluated with respect to the optimum cooking time. These analyses were performed in triplicate.

Changes in the diameter of pasta were measured using a computer vision system (Różyło *et al.*, 2015). Measurements were conducted on five strands of each sample of spaghetti. The diameter was measured at three different places of each sample. The samples were cooked as mentioned previously, and the diameter was measured at 2 min intervals during 20 min of cooking. The kinetics of changes in the diameter of individual samples of pasta was expressed as changes in the diameter index (D_i):

$$D_i = \frac{d_a}{d_b}, \tag{1}$$

where d_a is the diameter of pasta after cooking and d_b is the diameter before cooking.

The mechanical properties of pasta were evaluated using a universal strength testing machine Zwick ZN20/TN2S (Germany). For every sample of pasta, 10 measurements were taken. Soon after cooking, the pasta samples were dipped in cool water and brought to room temperature (Larrosa *et al.*, 2016), and then measurements were taken with respect to the optimum cooking time. Single samples of pasta were put on the bottom plate of a resistance testing machine Zwick Z020, and cut with a knife (1-mm thick) at a crosshead speed of 10 mm/min until the distance between the knife and the plate reduced to 0.1 mm. This test was used to determine the maximum force and shear work needed to cut a single sample of cooked pasta (Biernacka *et al.*, 2018). The cutting force indirectly indicated the hardness of pasta, whereas cutting work indicated its firmness (Bouasla *et al.*, 2016). These parameters are the key determinants of the textural features of the product (Wójtowicz, 2006).

Storage stability of the pasta samples was studied under normal conditions by storing them in polyethylene bags with minimum possible airspace. After cooking, the samples were cooled to room temperature using tap water. Their texture was investigated after 2, 5, 10, 20, 30, 40, 50 and 60 min of storage at room temperature (22°C). In addition, the sensory evaluation was performed on cooked pasta. The sensory parameters included taste, smell, colour, stickiness and texture (firmness of the bit) (Biernacka *et al.*, 2017). A semi-trained panel of 42 members assessed the acceptability of each sample, using a 5-point scale, from 1 point (the least acceptable) to 5 points (the most acceptable) (Wójtowicz and Mościcki, 2014). The sensory evaluation of pasta was performed directly after cooking and after 60 min of storage at room temperature. The room in which the assessment was carried out met the requirements of the adequate visibility and cleanliness, and was free from extraneous odours. Each sample was evaluated in triplicate with respect to different storage times.

The process of cooking was performed three times for each sample of pasta. The results were expressed as mean ± S.D. A one-way analysis of variance and Tukey's post hoc test were used to compare the groups. A regression analysis was also performed. The root mean square error (RMSE) and the coefficient of determination (R^2) were calculated (Rudy *et al*., 2015). The statistical analysis was performed at a significance level of $\alpha = 0.05$ using Statistica 13.0 from StatSoft.

RESULTS AND DISCUSSION

The characteristics of the raw spaghetti and the results of the chemical composition analysis are shown in Table 1. The initial moisture content of the pasta samples ranged from 8.84% (sample V) to 10.30% (sample VII). The highest protein content was found in sample VIII (15.41%), and the lowest content was observed in sample I (11.04%). Generally, pasta made from semolina was characterised by a higher protein content compared to products made from common wheat. A similar tendency was observed by Sobota and Skwira (2009) in their study. The fat content of the pasta samples ranged from 0.21% (sample VIII) to 0.30% (sample I). Pasta obtained from common wheat flour was characterised by a significantly lower content of mineral components, in comparison to products obtained from durum wheat. The ash content of the pasta samples ranged from 0.46% (sample II) to 0.95% (sample VI). Most of the analysed pasta samples had a similar diameter (about 1.86 mm), and only sample VII had a lower diameter (1.52 mm).

The results of the analysis of cooking properties of the tested pasta, with respect to the optimum cooking time, are shown in Table 1 and in Fig. 1. The optimum cooking time of the pasta samples ranged from 9.5 min (sample VII) to 13.5 min (sample VIII). The weight increase index ranged starch content varied from hydration-driven gelatinisation in the outer layer to heat-induced crystallite melting in the centre (Delcour *et al*., 2010). It should be noted that, besides cooking time, the weight increase index can also be affected by many different factors, such as raw material and processing conditions (Scanlon *et al*., 2005; De Noni and Pagani, 2010). Slightly higher values of this index were observed for pasta made from durum wheat; however, significant differences in this index were only found between sample

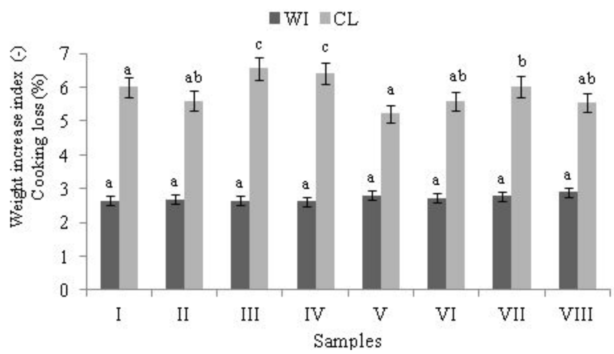

Fig. 1. Weight increase index (WI) and cooking loss (CL) of pasta for the optimum cooking time t_o, I-IV – common wheat pasta, V-VIII – durum wheat pasta, Mean ± SD, n = 3. Values followed by the same letter in the same columns are not significantly different ($p < 0.05$).

VIII and samples I–IV. The cooking loss varied from 5.22% (sample V) to 8.06% (sample I) (Fig. 1). Generally, similar values of cooking loss were found for pasta made from common wheat flour and from semolina. This index is one of the basic parameters used to predict the cooking quality of pasta. It depends on, *inter alia*, the quantity and quality of gluten (Marti *et al*., 2013), the degree of damage caused by amylolytic enzymes or starch (Fardet *et al*., 1999), and the method used for pasta drying; in particular, starch gelatinisation occurring during pasta drying makes a major contribution to the quality of pasta (Guler *et al*., 2002).

In literature, only a few studies have focused on the geometric changes that occur in pasta during cooking. The obtained results revealed that the major changes in the diameter occurred in the first 3-5 min of cooking (Table 2). For most of the tested samples, a proportional increase in the diameter was observed up to approximately 15 min of cooking. Thereafter, for some of the tested pasta (mainly for common wheat spaghetti), the values of the diameter increase index stabilised, whilst for the majority of durum wheat pasta stabilisation occurred only after a long time of hydrothermal treatment. Figure 2 presents the average values of the diameter increase index for common wheat pasta and durum wheat pasta. It was observed that as the cooking time increased, the differences between the values of diameter increase index of durum wheat pasta and

Table 1. Physical and chemical characteristics of pasta samples

Sample	Main component	Produced	Initial moisture (% wb)	Diameter of raw pasta (mm)	t_o (min)	Protein	Ash	Fat
						Content (%)		
I	CWF	Poland	9.84 ± 0.18^c	1.82 ± 0.04^b	11.4 ± 0.5^d	11.04 ± 0.19^a	0.55 ± 0.04^b	0.30 ± 0.01^c
II	CWF	Poland	10.24 ± 0.09^{de}	1.86 ± 0.05^b	13.1 ± 0.3^f	12.31 ± 0.10^c	0.46 ± 0.03^a	0.26 ± 0.02^b
III	CWF	Poland	9.72 ± 0.21^{bc}	1.81 ± 0.04^b	10.5 ± 0.5^d	12.81 ± 0.22^c	0.54 ± 0.03^b	0.26 ± 0.02^b
IV	CWF	Poland	8.78 ± 0.22^a	1.85 ± 0.03^b	11.2 ± 0.2^{ef}	11.77 ± 0.19^b	0.59 ± 0.07^b	0.25 ± 0.01^{ab}
V	DWF	Italy	8.84 ± 0.16^a	1.86 ± 0.06^b	11.8 ± 0.1^e	14.61 ± 0.19^e	0.94 ± 0.06^d	0.26 ± 0.01^b
VI	DWF	Italy	9.57 ± 0.23^b	1.88 ± 0.05^b	11.5 ± 0.1^e	15.31 ± 0.23^f	0.95 ± 0.03^d	0.23 ± 0.02^a
VII	DWF	Poland	10.30 ± 0.07^e	1.52 ± 0.04^a	9.8 ± 0.5^d	13.56 ± 0.11^d	0.73 ± 0.08^c	0.24 ± 0.02^{ab}
VIII	DWF	Poland	10.02 ± 0.20^d	1.85 ± 0.03^b	13.2 ± 0.3^f	15.41 ± 0.18^f	0.68 ± 0.04^c	0.21 ± 0.02^a

CWF – common wheat flour, DWF – durum wheat flour, t_o – optimum cooking time; mean ± SD, n = 3. Values followed by the same letter in the columns are not significantly different ($p < 0.05$).

Table 2. Changes in the spaghetti cooking diameter index, depending on the cooking time and pasta samples

Time (min)	Sample							
	I	II	III	IV	V	VI	VII	VIII
0.01	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}	1.00±0.01^{a}
2	1.30±0.03^{b}	1.28±0.03^{b}	1.31±0.03^{b}	1.35±0.03^{b}	1.36±0.03^{b}	1.35±0.03^{b}	1.33±0.03^{b}	1.28±0.03^{b}
4	1.42±0.03^{c}	1.43±0.03^{c}	1.42±0.03^{c}	1.43±0.03^{c}	1.46±0.03^{c}	1.44±0.03^{c}	1.42±0.03^{c}	1.39±0.03^{c}
6	1.45±0.03^{c}	1.48±0.03^{d}	1.46±0.03^{c}	1.47±0.03^{cd}	1.52±0.03^{d}	1.51±0.03^{d}	1.56±0.03^{d}	1.45±0.03^{d}
8	1.49±0.03^{d}	1.52±0.03^{e}	1.55±0.03^{e}	1.49±0.03^{d}	1.58±0.03^{e}	1.60±0.03^{e}	1.64±0.03^{e}	1.55±0.03^{e}
10	1.55±0.04^{e}	1.55±0.04^{ef}	1.57±0.04^{fg}	1.53±0.04^{e}	1.62±0.04^{f}	1.66±0.04^{f}	1.68±0.04^{ef}	1.66±0.04^{f}
12	1.58±0.03^{ef}	1.57±0.03^{fg}	1.60±0.03^{g}	1.57±0.03^{e}	1.63±0.03f	1.70±0.03^{g}	1.71±0.03^{fg}	1.72±0.03^{g}
14	1.61±0.04^{fg}	1.60±0.04^{g}	1.62±0.04^{f}	1.65±0.04^{f}	1.71±0.04^{g}	1.73±0.04^{g}	1.73±0.03^{g}	1.82±0.04^{h}
16	1.63±0.04^{g}	1.61±0.05^{g}	1.61±0.04^{fg}	1.66±0.04^{fg}	1.75±0.04^{gh}	1.79±0.04^{h}	1.75±0.04^{g}	1.85±0.04^{h}
18	1.62±0.04^{g}	1.60±0.04^{g}	1.60±0.04^{g}	1.68±0.04^{fg}	1.76±0.04^{gh}	1.82±0.05^{h}	1.75±0.04^{g}	1.91±0.04^{i}
20	1.62±0.06^{g}	1.60±0.06^{g}	1.58±0.04^{ef}	1.70±0.04^{g}	1.77±0.04^{h}	1.84±0.06^{h}	1.74±0.04^{g}	1.92±0.05^{j}

I-IV – common wheat pasta, V-VIII – durum wheat pasta.

common wheat pasta became higher. Common wheat pasta was characterised by a smaller value of the diameter increase index, compared to durum wheat products. A significant correlation was found between the protein content of pasta and the diameter increase index (D_i), recorded after 20 min of cooking (r = 0.75). Moreover, significant negative correlations were found between the values of the diameter increase index and cooking loss (r = –0.67). Sung and Stone (2003) found that the swelling of pasta during cooking occurred mainly due to the hydration of gluten, and not due to the gelatinisation of starch. Durum wheat semolina is usually characterised by a higher efficiency of hydration of gluten, compared to the flour obtained from the milling of common wheat (Kim *et al.*, 2016; Sissons *et al.*, 2007).

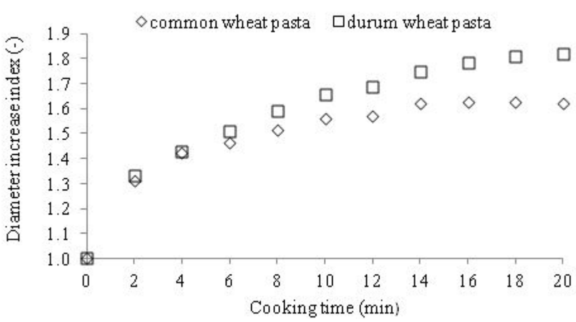

Fig. 2. Average values of the diameter increase index (D_i) for pasta produced from common wheat flour and durum semolina.

For describing changes in the diameter increase index (D_i) in pasta during cooking, we derived the following equation:

$$D_i = a\tau^n + b, \qquad (2)$$

where *a* and *b* are the coefficients of the equation, *n* is an exponent and τ is the time of cooking.

The results of the regression analyses of the model used to describe the kinetics of an increase in the diameter increase index are presented in Table 3. It should be noted that a very good fit of the experimental data was observed for the proposed model. All the calculated values of R^2 fell in the range of 0.977-0.998, whereas the RMSE changed from 0.000104 to 0.000978. The calculated coefficients of the proposed equation are listed in Table 3.

Table 3. Coefficient values in the models describing the increase in the pasta diameter index during cooking

Sample	a	n	b	Loss function	R^2	RSME
I	0.389	0.235	0.865	0.003	0.990	0.0003
II	0.464	0.195	0.805	0.007	0.980	0.0006
III	0.533	0.170	0.751	0.011	0.969	0.0010
IV	0.359	0.265	0.898	0.007	0.983	0.0006
V	0.372	0.287	0.902	0.002	0.996	0.0002
VI	0.307	0.362	0.943	0.001	0.998	0.0001
VII	0.410	0.271	0.873	0.013	0.977	0.0012
VIII	0.187	0.548	0.987	0.005	0.994	0.0005

Explanations as in Table 2.

The results revealed that the storage of pasta after cooking significantly affected its texture. The results of the analysis of changes in the cutting force and the cutting energy, with respect to the storage time, are shown in Table 4. The cutting force of durum wheat pasta decreased during storage (average) from 1.02 to 0.53 N, whereas the cutting force of common wheat pasta decreased (average) from 1.00 to 0.44 N. Usually, a higher cutting force is observed for durum wheat pasta; however, in our study, a lower cutting force was observed in sample VII, as a result of a lower diameter. Changes in the cutting energy during the storage of pasta directly after cooking showed a similar trend as changes in the cutting force. In all the tested samples, a decrease in the cutting energy of pasta was observed after storage. The values of this parameter reduced to about 50-60% of the initial value obtained for pasta directly after cooking. In the case of spaghetti from semolina, the values of the cutting energy ranged from 0.84 to 0.52 mJ, whereas in the case of spaghetti from common wheat, these values ranged from 0.72 to 0.44 mJ. The highest decrease in both the cutting force and the cutting energy of pasta was observed after about 30 min of storage, and these parameters stabilised after about 50 min of storage. These changes indicated that, if cooked beyond the optimum time, pasta displayed about a twofold loss of its hardness and firmness. This information is very important for consumers. Moreover, longer cooking time is not

Table 4. Changes in the pasta cutting force and the cutting energy with respect to storage time

τ_S (min)	Parameter	Sample							
		I	II	III	IV	V	VI	VII	VIII
2*	F_c (N)	1.02±0.11^{f}	1.06±0.06^{f}	0.94±0.10^{f}	1.00±0.17^{d}	1.07±0.03^{g}	1.21±0.12^{e}	0.42±0.01^{f}	1.29±0.11^{e}
5		0.78±0.03^{e}	0.93±0.04^{e}	0.69±0.02^{e}	0.83±0.07^{c}	0.95±0.02^{f}	1.05±0.06^{d}	0.35±0.02^{e}	1.13±0.05^{d}
10		0.72±0.03^{de}	0.80±0.03^{d}	0.64±0.02^{de}	0.66±0.04^{b}	0.87±0.01^{e}	0.89±0.02^{c}	0.31±0.01^{d}	0.99±0.08^{c}
20		0.63±0.05^{cd}	0.65±0.04^{c}	0.59±0.03^{ad}	0.59±0.04^{ab}	0.81±0.02^{d}	0.83±0.04^{c}	0.27±0.01^{c}	0.90±0.09^{c}
30		0.54±0.06^{bc}	0.61±0.04^{c}	0.53±0.05^{a}	0.58±0.02^{ab}	0.67±0.05^{c}	0.72±0.02^{b}	0.25±0.01^{bc}	0.76±0.03^{b}
40		0.48±0.05^{ab}	0.51±0.02^{b}	0.51±0.01^{ac}	0.52±0.06^{a}	0.59±0.04^{b}	0.63±0.04^{ab}	0.23±0.01^{ab}	0.71±0.02^{ab}
50		0.45±0.02^{a}	0.44±0.01^{ab}	0.43±0.02^{b}	0.48±0.04^{a}	0.54±0.03^{ab}	0.61±0.02^{a}	0.21±0.02^{a}	0.69±0.06^{ab}
60		0.44±0.03^{a}	0.41±0.03^{a}	0.44±0.03^{bc}	0.46±0.02^{a}	0.50±0.02^{a}	0.54±0.03^{a}	0.21±0.02^{a}	0.63±0.04^{a}
2	W_c (mJ)	0.74±0.05^{f}	0.74±0.04^{f}	0.69±0.07^{d}	0.72±0.06^{e}	0.83±0.05^{d}	0.92±0.11^{b}	0.32±0.02^{f}	1.11±0.08^{c}
5		0.70±0.03^{ef}	0.68±0.03^{ef}	0.61±0.04^{a}	0.63±0.03^{d}	0.73±0.04^{c}	0.88±0.04^{ab}	0.27±0.02^{e}	0.90±0.12^{b}
10		0.66±0.05^{de}	0.66±0.02^{be}	0.57±0.03^{a}	0.56±0.02^{b}	0.69±0.03^{bc}	0.85±0.08^{ab}	0.23±0.02^{d}	0.81±0.10^{ab}
20		0.62±0.02^{cd}	0.60±0.03^{ab}	0.57±0.02^{ab}	0.53±0.03^{b}	0.59±0.06^{b}	0.83±0.06^{abd}	0.23±0.02^{d}	0.78±0.04^{ab}
30		0.57±0.04^{bc}	0.59±0.04^{ab}	0.56±0.06^{ab}	0.50±0.03^{bc}	0.45±0.06^{a}	0.77±0.03^{acd}	0.19±0.02^{c}	0.76±0.08^{ab}
40		0.52±0.04^{ab}	0.57±0.02^{ad}	0.54±0.02^{ab}	0.46±0.01^{ac}	0.42±0.06^{a}	0.72±0.04^{cd}	0.18±0.02^{bc}	0.74±0.04^{a}
50		0.49±0.05^{a}	0.51±0.04^{cd}	0.49±0.05^{bc}	0.44±0.02^{a}	0.44±0.07^{a}	0.66±0.04^{ce}	0.15±0.01^{ab}	0.72±0.08^{a}
60		0.48±0.06^{a}	0.44±0.06^{c}	0.45±0.05^{c}	0.41±0.02^{a}	0.40±0.05^{a}	0.59±0.05^{e}	0.14±0.02^{a}	0.68±0.06^{a}

* Directly after cooking and cooling of pasta, τ – time after cooking, I-IV – common wheat pasta, V-VIII – durum wheat pasta, F_c – cutting force, W_c – cutting energy, mean ± SD, n = 10. Values followed by the same letter in the columns are not significantly different ($p < 0.05$).

recommended for those who prefer less hard pasta because extended cooking time increases cooking loss and leads to higher energy requirements for cooking.

For describing changes in the pasta cutting indices (*CI*) during storage, we derived the following equation:

$$CI = a\tau^n, \qquad (3)$$

where: *CI* is the pasta cutting parameter (force or cutting energy), *a* is the coefficient of the equation, *n* is an exponent and τ is the time of storage.

The results of the regression analyses of the model used to describe the kinetics of a decrease in the cutting indices during storage are presented in Table 5. It should be noted that a good fit of the experimental data was observed for the proposed model. All the calculated values of R^2 fell in the range of 0.917-0.995 and 0.855-0983 for the cutting force and the cutting energy, respectively, whereas the RMSE changed from 0.000025 to 0.003085 and from 0.000076 to 0.00173 for the cutting force and the cutting energy, respectively. The calculated coefficients of the proposed equation are listed in Table 5.

Changes in the texture of pasta after cooking can be explained by water migration during storage. In general, the moisture content, and its spatial and temporal distribution, are important factors that determine the textural properties of foods (McCarthy *et al*., 2002). Moisture redistributes from the outer parts of spaghetti to the inner zone during storage, and reduces the moisture gradient as well as the firmness of pasta. Similar relationships were found by Gonzalez *et al.* (2000). The textural changes in pasta during storage also depend on its chemical composition, and in particular on the protein content (Del Nobile *et al*., 2005).

The results of sensory evaluation of spaghetti, both performed directly after cooking and after 60 min of storage, are presented in Table 6. Similar scores for the smell

Table 5. Coefficient values in the models describing the decrease in the pasta cutting force and the cutting energy during pasta storage

Sample	Parameter	a	x	Loss function	R^2	RSME
I	F_c (N)	1.199	-0.239	0.0050	0.982	0.0006
II		1.326	-0.252	0.0184	0.952	0.0023
III		1.053	-0.211	0.0074	0.961	0.0009
IV		1.166	-0.223	0.0031	0.988	0.0004
V		1.287	-0.199	0.0247	0.917	0.0031
VI		1.443	-0.214	0.0120	0.968	0.0015
VII		0.486	-0.203	0.0002	0.995	0.0000
VIII		1.518	-0.201	0.0036	0.990	0.0005
		a	n	Loss function	R^2	RSME
I	W_c (mJ)	0.838	-0.123	0.0054	0.919	0.0007
II		0.825	-0.116	0.0093	0.855	0.0012
III		0.732	-0.096	0.0049	0.869	0.0006
IV		0.813	-0.155	0.0013	0.983	0.0002
V		1.005	-0.211	0.0138	0.927	0.0017
VI		1.005	-0.097	0.0054	0.920	0.0007
VII		0.378	-0.218	0.0006	0.976	0.0001
VIII		1.164	-0.131	0.0079	0.940	0.0010

I-IV – common wheat pasta, V-VIII – durum wheat pasta, F_c – cutting force, W_c – cutting energy.

and taste of pasta were obtained for all the spaghetti samples tested. Most of the pasta samples showed similar texture and stickiness. Only in the case of common wheat pasta (sample IV), lower scores for these attributes were obtained. The overall quality of durum wheat pasta was slightly higher than that of spaghetti made from common wheat, mainly due to the higher scores for pasta colour. Storage for 60 min had no influence on the smell, taste and

Table 6. Results of the sensory evaluation of pasta

Sample	Sensory attributes											
	Smell		Taste		Colour		Texture		Stickiness		Overall quality	
	DS	ST60	DS	ST60	DS	ST60	DS	ST60	DS	ST60	DS	ST60
I	4.8 ± 0.21^{bA}	4.6 ± 0.32^{abA}	4.7 ± 0.25^{aA}	4.5 ± 0.18^{aA}	4.2 ± 0.32^{aA}	4.1 ± 0.36^{aA}	4.5 ± 0.22^{bA}	3.5 ± 0.15^{bB}	4.6 ± 0.15^{cA}	4.2 ± 0.20^{bB}	4.2 ± 0.19^{bA}	3.7 ± 0.22^{bB}
II	4.6 ± 0.17^{abA}	4.4 ± 0.25^{aA}	4.6 ± 0.18^{aA}	4.6 ± 0.23^{aA}	4.2 ± 0.18^{aA}	4.0 ± 0.44^{aA}	4.8 ± 0.18^{cA}	3.4 ± 0.26^{abB}	4.5 ± 0.32^{cA}	4.1 ± 0.22^{abB}	4.3 ± 0.34^{abA}	3.5 ± 0.25^{bB}
III	4.7 ± 0.35^{abA}	$4.60.31^{abA}$	4.5 ± 0.31^{aA}	4.4 ± 0.15^{aA}	4.1 ± 0.24^{aA}	4.2 ± 0.42^{aA}	4.4 ± 0.38^{bA}	3.2 ± 0.32^{abB}	4.0 ± 0.16^{aA}	3.9 ± 0.28^{aB}	4.1 ± 0.31^{aA}	3.5 ± 0.14^{abB}
IV	$4.5\pm0.12aA$	4.6 ± 0.40^{abA}	4.5 ± 0.23^{aA}	4.6 ± 0.23^{aA}	4.1 ± 0.23^{aA}	4.0 ± 0.47^{aA}	4.0 ± 0.12^{aA}	3.0 ± 0.27^{aB}	4.3 ± 0.11^{bA}	4.0 ± 0.13^{aB}	4.1 ± 0.25^{aA}	3.4 ± 0.15^{aB}
V	4.5 ± 0.18^{aA}	4.4 ± 0.18^{abA}	4.6 ± 0.26^{aA}	4.6 ± 0.17^{aA}	4.5 ± 0.16^{bA}	4.6 ± 0.36^{bA}	4.5 ± 0.21^{bA}	3.9 ± 0.25^{cB}	4.5 ± 0.18^{bcA}	4.2 ± 0.15^{bB}	4.3 ± 0.18^{bA}	3.9 ± 0.12^{cB}
VI	4.5 ± 0.29^{aA}	4.3 ± 0.25^{aA}	4.6 ± 0.19^{aA}	4.5 ± 0.31^{aA}	4.7 ± 0.21^{abA}	4.5 ± 0.38^{bA}	4.5 ± 0.26^{bA}	4.0 ± 0.24^{cB}	4.5 ± 0.07^{bcA}	4.2 ± 0.19^{bB}	4.6 ± 0.15^{cA}	3.7 ± 0.19^{bB}
VII	4.7 ± 0.13^{abA}	$4.50.37^{abA}$	4.5 ± 0.28^{aA}	4.3 ± 0.28^{aA}	4.7 ± 0.25^{abA}	4.6 ± 0.32^{bA}	4.6 ± 0.27^{bcA}	3.6 ± 0.22^{bB}	4.3 ± 0.33^{bA}	$4.1.\pm0.21^{abA}$	4.6 ± 0.30^{cA}	3.9 ± 0.26^{cB}
VIII	4.5 ± 0.28^{aA}	4.6 ± 0.22^{bA}	4.6 ± 0.34^{aA}	4.5 ± 0.21^{aA}	4.8 ± 0.27^{bA}	4.8 ± 0.24^{bA}	4.8 ± 0.15^{cA}	4.0 ± 0.18^{cB}	4.6 ± 0.24^{cA}	4.2 ± 0.15^{bB}	4.7 ± 0.21^{cA}	4.2 ± 0.14^{dB}

I-IV – common wheat pasta, V-VIII – durum wheat pasta, DR – directly after cooking, ST60 – after 60 min of storage; mean ± SD, n = 3. Values followed by the same small letter in the columns are not significantly different ($p < 0.05$); mean ± SD, n = 15. Values followed by the same capital letter in the lines are not significantly different ($p < 0.05$).

colour of pasta, but it changed the pasta texture and caused stickiness. Stored pasta was characterised by significantly lower scores for texture and stickiness. Also, the overall quality of all the stored pasta samples was lower than the quality of spaghetti evaluated directly after cooking. These results were in agreement with the results of the evaluation of instrumental texture which showed a decrease in hardness and firmness of pasta. Other researchers have also observed that the storage of cooked and pre-cooked pasta deteriorates the sensory properties as the water distribution becomes even, and thus it reduces the firmness (McCarthy *et al.*, 2002; Wood, 2009). Summing up the results of the qualitative assessment, it can be said that durum wheat pasta had the highest quality and retained its culinary properties to the best extent, both directly after cooking and after 60 min of storage.

CONCLUSIONS

1. The analysis of the kinetics of an increase in the diameter of pasta during cooking showed that the largest changes in the diameter occurred during the first 3-5 min of cooking. In the case of spaghetti made from common wheat, these changes stabilised after 15 min of hydrothermal treatment, but for most of the semolina pasta samples, stabilisation occurred after a longer cooking time. There was a statistically significant and positive correlation between the protein content of pasta and the increase in its diameter.

2. The statistical analysis showed a significant decrease in both the hardness and firmness of pasta during storage. Major changes in these parameters were found during the first 15 min of storage, and the parameters stabilised after nearly 50 min of the storage of cooked spaghetti. The hardness of spaghetti, which was al dente after cooking, decreased about twice. Thus, the cooking of pasta beyond the optimum time is not recommended as it not only increases the loss of dry substances but also leads to higher energy requirements for preparation.

3. The sensory analysis confirmed that the storage of cooked pasta had a negative influence on its texture and caused stickiness. Durum wheat pasta had better quality after storage than common wheat spaghetti.

Conflict of interest: The authors declare that they have no conflict of interest.

Compliance with ethical requirements: This study does not contain any experiment involving human or animal subjects.

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