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Effects of raw material, technological process and cooking procedure on quality of pasta from durum wheat semolina.

Docente tutor:

Chiar.ma Prof.ssa Silvana Cavella

Candidato:

Dott. Angelo Sicignano

Docente cotutor:

Chiar.ma Prof.ssa Rossella Di Monaco

XXVII CICLO

To all my loved ones

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0. Preface

The present work was carried out during the activity of PhD enterprise, financed by Por Campania Fse 2007-2013, and conducted in collaboration between the Agriculture Department of University of Naples Federico II and the pasta factory "Pastificio Artigianale Leonessa". The object was to evaluate the effect of raw material, technological processes and cooking methods on pasta overall quality. Moreover, certain research activities were carried out at Instituto Politécnico Nacional of Mexico City where a study on the possibility of reducing glycemic index in pasta by substitution of semolina with other ingredients was conducted. Part of the work was also done in collaboration with the University of Foggia and the University of Copenhagen, which have contributed respectively to the physical-chemical characterization of durum wheat semolina from different wheat cultivar and in the development of a new sensory analysis method. The most innovative aspects of this work were: study of alternative drying method; physico-chemical and sensory characterization of new pasta cooking methods; use and development of an innovative sensory method.
Other additional activities as a support to the enterprise were also carried out; adaptation to EU labeling regulation *N. 1169/2011, optimization of new products, testing of shelf life and other activities have not been addressed in the following text although part the training path.*

1. State of art

Pasta is a traditional Italian cereal-based food, popular worldwide, because of its convenience, versatility, sensory and nutritional value; its consumption is recommended by Mediterranean dietary guidelines where it is considered a fundamental food . Nowadays eating pasta is perceived as one of the "healthy options", since it is supremely versatile as a base to a meal, easy to prepare in a way to satisfy both our notions of "healthy eating" and our appetite. Prevalently constituted by carbohydrates (70 g/100 g) and proteins (11.5 g/100 g), pasta is considered to be a slowly digestible starch food; a nutritional quality ruled by its structure, as well as its composition.

1.1. Historical and economic comments

Pasta is a generic term addressed to the whole range of products commonly known as spaghetti, macaroni, and tagliatelle. Sources suggest that noodles existed in China since 5000 B.c. and then spread to Japan around 1600 B.c. Evidence indicates that some types of wheat and water mixtures were used in prehistoric Mesopotamia and in ancient Greek and Roman cultures as well.

Many centuries B.c, Greeks and Etruscans commonly produced and consumed the first types of pasta. The first evidence of the existence of something similar to pasta goes back to the first millennium B.c.; the Greek word "laganon" was used to indicate a large sheet and plate of pasta cut into strips. From "laganon" derives "laganum" in Latin, quoted in the writings of Cicero. However, the Arabs were the first to dry pasta in order to consume it during their peregrinations in the desert. The first historical production of dried pasta in a small-scale industry dates back to the eleventh century in Sicily. In the fourteenth century Boccaccio in his 'Decameron' described pasta production as "…stava gente che niun'altra cosa faceva che fare maccheroni e raviuoli, e cuocerli nel brodo di capponi" (…there were people who did nothing other than make macaroni and ravioli and cook them in capon broth).

In 1501 pasta was so widespread in Palermo that its price was among those controlled. In the eighteenth century the main production and consumption of dry pasta shifted from Palermo to Naples, this because of strong population growth and technological innovations, which reduced production costs. Pasta production was concentrated in the two municipalities of Gragnano and Torre Annunziata, favored by particular climatic conditions. In the same years, thanks to the initiative of master pasta makers who had gained experience in Naples and Genoa, small local pasta factories in the rest of Italy grew up (Serventi & Sabban, 2002).

Thereafter the Italian pasta industry quickly developed and spread rapidly to France and elsewhere in Europe. From the last century a gradual spread of consumption and production of pasta, throughout the peninsula, gave impulse to advanced industrial production systems. The automation of production processes, the increased knowledge of food chemistry, preservation and packaging, development of marketing strategies, contributed to remarkable developments in the food industry, producing industrial-scale products that had been limited previously to domestic and artisanal production.

On July 30, 2010 a public hearing was held to approve the first pasta PGI in Italy "Pasta di Gragnano" for pasta produced in the area of Gragnano. Today pasta is considered one of the leading sectors of 'Made in Italy' with an ever expanding international market. Italy is the first European producer of durum wheat and the world leader in pasta production. In Italy, more than 300 pasta shapes are marketed: this variety is the result of many traditional shapes and continuous research for new ideas. The most produced shape is spaghetti, although short pasta - in all its forms - represents 70% of the market. The annual production of pasta in Italy is 3.4 million tons, with a turnover of more than €4.6 billion and over 7.500 people employed in the pasta sector. Over the past years the trend of exports has recorded significant growth rates, reaching €2 billion (MIPAAF, 2015).

1.2. The Italian choice: pasta from 100% durum wheat semolina

Despite the fact that numerous variations of ingredients for different pasta products are known today, commercial manufacturing and labeling of pasta for sale as a food product in Italy is highly regulated (Presidential Decree No. 187 February 9, 2001, and amendments). Italian regulations recognize only three categories of dried pasta as well as fresh and stabilized pasta:

- Durum wheat semolina pasta (Pasta di semola di grano duro)
- Low grade durum wheat semolina pasta (Pasta di semolato di grano duro)
- Durum wheat wholemeal pasta (Pasta di semola integrale di grano duro).

Pasta made under these categories must be made only with durum wheat semolina, low grade durum wheat semolina or durum wheat whole-meal semolina and water. The use of soft wheat flour with an allowance of 3% for dry pasta manufacture in Italy is not permitted except for pasta produced for sale in other countries. In addition, pasta destined for sale must have the characteristics expressed in Table 1.

Type and de nomination	Maximum humidity (%)	Per hundred parts of dry substance			
		Ash		Minimum protein (nitrogen x 5.7)	Maximum acidity (degrees)*
		minimum	maximum		
Durum wheat semolina pasta	12.50	-	0.90	10.50	4
Low grade durum wheat semolina pasta	12.50	0.90	1.35	11.50	5
Durum wheat wholemeal semolina pasta	12.50	1.40	1.80	11.50	6

Table 1. - Types of dry pasta and product characteristics. * *The level of acidity is the number of cubic centimetres of normal alkaline solution required to neutralise 100 grams of dry substance.*

The Italian choice for 100% durum wheat pasta can be summarized as (Milatovic & Mondelli, 1990):

• top quality from gastronomic point of view

• higher nutritional value

• the great production of durum wheat in Italy

Pasta obtained exclusively from durum wheat is generally of superior quality with regard to the texture, taste, cooking performance and color (Irvine, 1978; Milatovic & Mondelli, 1990). The laws relating to Italian pasta production certainly contributed to the recognition of our product as of superior quality, favoring export to other countries. With the exception of Greece and France, other countries in the world allow the use of soft wheat flour in pasta manufacturing.

1.3. Unconventional raw material for special pasta production

To improve nutritional quality and /or make special pastas, some ingredient can be added to semolina (Padalino et al., 2014). Indeed, today pasta is also used to convey nutraceutical substances (Chillo et al., 2008).
Due to its widespread use across the world, ease of use, its preservation (Antognelli, 1980), pasta can be used with the most varied integrations, to provide important nutrients. The increase in the protein, dietary fiber, vitamin and mineral content could make pasta an interesting nutrient vehicle. Indeed, pasta was one of the first foods approved by the Food and Drug Administration (FDA) for its enrichment with vitamins and iron in 1940. Flour with high protein content can be used to increase pasta protein content from 10-12% up to 15% and, at the same time, improve the biological value of the proteins and its "chemical score”.
A variety of non-wheat and no-cereal products have been used to lower the glycemic index (GI) or to improve the nutritional quality of pasta. Both low-carbohydrate and slowly-digested carbohydrate food products are considered nutraceuticals (Osorio-Díaz et al., 2008). Several studies have indicated the possibility of adding legume flour to semolina in pasta preparation, although the results are controversial as regard to the effects of such additions on the sensory properties of pasta (Wood, 2009; Gallegos-Infante et al., 2010).
However, it should be noted, that the amount of other flour added to the semolina is a compromise between improved nutritional quality and organoleptic and sensory characteristics of the new product obtained.

1.4. Durum wheat quality

Evaluation of a good potential to make pasta starts from the grain. Aspects of importance include test weight, weight of 1000 kernels, physical defects, vitreousness, moisture content, weather damage and grain protein percentage (Sissons, 2004). The most appropriate wheat for making pasta products is durum *Triticum turgidum*. It is one of the hardest wheat and from milling produces coarse particles called semolina, ideal for making pasta. The variation in grain hardness is one of the most important traits that determines end-use quality of wheat. Hard wheat meals are coarser, they flow and bolt more easily than soft wheat flour. Grain texture classification is based primarily on either the resistance of kernels to crushing or on particle size distribution of ground grain or flour (Morris, 2002). It impacts significantly on the milling process influencing among other things milling yield and particle size. The hardness in wheat is largely controlled by genetic factors but it can be affected by the environment and factors such as moisture, lipid, and pentosan content(Tumbull & Rahman, 2002). The puroindoline proteins a and b are the molecular genetic basis of grain hardness or texture. When both proteins are in their ‘functional’ wild state, grain texture is soft. When either one of the puroindolines is altered by mutation or absent, then the result is a hard texture (Morris, 2002).
Hardness, intense yellow color and nutty taste are the most important features of durum wheat for pasta with good cooking quality and stability to overcooking with unmatchable eating quality (Sissons, 2008). The role of starch in the

determination of the rheological characteristics of durum wheat dough is sometimes underestimated in comparison with the role of gluten. Nevertheless, the surface characteristics of the starch granules may affect the type of protein-starch interaction and the viscoelastic behavior of pasta (Edwards et al., 2002). Although wheat gluten proteins, which are water-insoluble storage proteins, comprise a smaller part of the endosperm (≈7 -20%), they constitute the 85% of the endosperm proteins (Posner, 2000). Gluten proteins serve as carbon, nitrogen and sulfur source for the immature plant (Shewry et al., 2002). The most abundant amino acid is glutamine and together with proline and glycine they constitute about 50% of the amino acid residues in gluten (Hoseney, 1998). Additional characteristics of gluten proteins include a large number of hydrophobic amino acid residues (≈35%), while methionine, tryptophan, and lysine are the nutritionally limiting amino acid in gluten (Lásztity, 1996; Hoseney, 1998; Shewry et al., 2002)
According to the protein classification of Osborne (Osborne, 1907) proteins of durum wheat can be fractioned into albumin (water-soluble), globulin (soluble in salt solution), gliadin (extractable in aqueous ethanol solution) and glutenin (soluble in dilute acid). Albumins and globulins represent the lower percentage (20%) as compared to monomeric gliadins and polymeric glutenins (80%).The Osborn parting procedure was a step forward in the identification of major groups of wheat protein. Thanks electrophoresis, subsequently has been clarified that gliadin and glutenin are two major groups of proteins, each composed of several individual subunits. We now know four fraction gliadinas (α, β,γ, ω) range in molecular mass from ≈15 to 60 kDa and account for about 50% of gluten proteins (Lásztity , 1996). The α, β,and γ are know as sulfur rich and generally range from 25 to 40 kDa. The ω-gliadins are considered to be sulfur poor and have molecular masses that are approximately twice those of the other gliadins (Lásztity , 1996). Otherwise polymeric glutenin complexes weight range from 100 to > 10 milion (Wieser et al., 2006).
The two main glutenin fractions are low molecular weight glutenin subunits LMW-GS and high molecular weight glutenin subunits HMW-GS; it was estimated that the molecular weight of HMW-GSat ≈70-136 kDa and that of LMW-GSat ≈20 -45 after reduction of intermolecular disulfide bonds (Shewry et al., 2002; D'Ovidio & Masci, 2004). The sulfur poor MMW-Gs are constituted by a mix of a periodic and α-helical structures at both termini, with a β-spiral central repetitive region and two to five free Cystein residues (Shewry et al., 2002). The sulfur rich LMW-GS are not as well characterized but are thought to consisting of an α-helical structure at the C terminal, with irregular β-turns near the N terminal region; one or two free Cystein participate in intermolecular disulfide bonds (D'Ovidio & Masci, 2004).
The protein matrix entraps starch granules during cooking, thereby conferring pasta its special structure and reducing the loss of solids in the cooking water and thereby reducing surface stickiness (Sissons, 2008). Wheat with low levels of protein produces extremely fragile pasta with low firmness. High protein durum wheat allows pasta to swell when cooked, reduces cooking loss and improves texture with a better retention of firmness in overcooking which is also associated with less stickiness (Dexter et al., 1983).
Durum wheat breeding programs have continued to make protein and gluten quantity the main objectives due their importance in marketing and quality determination of pasta. Relating protein composition to quality requires an investigation at different levels. Ratio of glutenin to gliadin and ratio of HMW to LMW glutenins subunits are the main studied factors.
It is generally accepted that glutenins confer elasticity and gliadins are responsible for the viscosity and extensibility of the gluten, with the interactions between the two protein fractions determining the ultimate gluten quality of one cultivar (Weegels et al., 1996). It is also accepted that, of the two fractions, the glutenins are still the main one responsible of the gluten strength (Subira et al., 2014). Both HMW-glutenins and LMW-glutenins, but mainly the latter, have a great influence on gluten strength and on the pasta-making quality of durum wheat (Martinez et al., 2005), stressing the need to obtain cultivars with the optimal HMW-glutenins and LMW-glutenins combinations to boost gluten quality.
Especially LMW glutenins contain a specific number and distribution of cysteine residues that confer the ability to form inter-molecular disulphide bonds with other LMW-glutenins or with HMW-glutenins, thus contributing to the formation of the glutenin polymers. Conversely, the number and distribution of cysteine residues in gliadins allows them to form only intra-molecular disulphide bonds, with the result that they are monomeric components of thegluten (D'Ovidio & Masci, 2004).
Several models have been suggested over the years to describe the gluten network structure. The current widely recognized model was proposed by Shewryet al. (2001). In this model, HMW-GS constitute the main backbone via head-to-tail disulfure cross-links, with a limited extend of lateral disulfide bonding between HMW-GS chains. LMW-GS participate by acting as chain connectors or terminators as a function of the number of free suphydryl groups availablefor disulfide bond formation. Gliadins interact non covalently with HMW-GS chains, conferring a modulatory role in terms of glutenin elasticity (Bock & Seetharaman, 2012).
The ratio of polymeric glutenin to monomeric gliadin can be directly related to the balance between tenacity and extensibility. The effect of variation on the ratio of HMW to LMW is less clear(Wrigley et al., 2006). One important aspect to define protein quality is gluten strength, an indicator of the gluten viscosity and elasticity. It is accepted that weak and inelastic gluten produce pasta with low cooking quality but how much strength is optimal is not known.
One of the commonly strategy employed by millers in Italy to increase gluten strength in weak semolina, is the blending with a high strength semolina which enhances pasta texture. It is thought that gluten strength is relate to the balance between viscosity and elasticity (Shewry et al., 2002). Generally it has been accepted that semolina from extra strong durum varieties is thought to produce firmer pasta and as a result gluten strength has become sought after in many markets where a higher price can be commanded.

Wheat starch is composed from two different size of granules; small spherical B-type granules (average diameter 1–10 µm) and larger lenticular A-type granules (average diameter 15-40µm) (Buléon et al., 1998). Structure of starch granules and amylose content was found to influence pasta characteristics. Spaghetti made from semolina samples at 32-44% of B granules exhibited higher cooked firmness and lower stickiness compared with the control sample (22.7% B-granules). Pasta cooking loss decreased with elevated B-granule content which is a positive feature. A larger portion of small size granules allows a more uniform distribution of protein during kneading in comparison with large size granules; this can affect the loss of amylose, reducing cooking loss (Soh et al., 2006).

As far as the lipids, despite being only 1-3% (dry matter) of the grain, they are an important components of wheat. There are the starch bound and non-starch lipids in semolina. The first ones interact with the amylose helix and exist asamylose-inclusion complexes in the starch granules (Morrison, 1978). Non-starch lipids are all the other lipids in the grain. They are divided further into free components (soluble in non polar solvents) and bound ones (soluble in cold polar solvent mixtures). Free lipids represent 64% of total lipids (Sissons, 2008). During the dough mixing process, they interact with proteins to provide a beneficial influence on gluten strength. Sisson et al. (2008) found that removal of total lipids from semolina had detrimental effects on pasta quality such as an increase in stickiness, whereas by adding lipids the samples showed a lower stickiness.

Lipids are also important in determining the color of pasta due to pigments and lipoxygenase (LOX). Yellow color is mainly determined by the amount of carotenoid pigments in grain, resulting from the balance between pigment synthesis and degradation by lipoxygenases (Garbus et al., 2009). Semolina LOX activity was found to be highly correlated with the extent of decrease in pigments (Sissons, 2008) and a reduction of LOX activity during pasta processing is of interest for technological and commercial purposes. LOX reaction could be inhibited by beta-carotene and a lower semolina bleaching was observed in samples having a higher carotenoid content (Trono et al., 1999); so it is suggested that a high carotenoid content of semolina is desirable to impart a better color preventing carotenoid bleaching during pasta processing. The presence of other enzymes such as Amylases and Polyphenol Oxidase (PPO) in wheat, are other important factor that can affect pasta quality. Amylases activity (AA) is lower in semolina than in whole kernel because amylases are mainly present in the outer layer of the kernel that is discarded during milling. In the industrial milling process, in order to increase the extraction rate, some of these fractions are added to "core streams" and at the same time increase the potential AA in semolina and hence the amount of reducing sugar and the extent of Maillard reaction (MR) that potentially will take place during pasta drying (De Noni & Pagani, 2010).

Otherwise, PPO catalyse the oxidation of a large number of phenols which occur in the grain. These enzymes reside mainly in the pericarp and grain layers, and can cause the enzymatic browning in food material through an initial oxidation of phenols into quinones that readily undergo self-polymerisation or condensation with amino acids or proteins via their amino groups to form complex brown polymers (Milatović & Mondelli, 1991). Since the source of PPO is the bran layers, excess bran in the semolina arising from poor purification could produce brownness in the pasta made from such semolina (Milatović & Mondelli, 1991).

1.5. Physicochemical changes during processing and cooking

1.5.1. Semolina particle size and mixing operation

Durum wheat milling is a complex procedure of progressive grinding and sieving. The very hard durum grain must be tempered to the right moisture content from about 10% to 17% before grinding it on corrugated break rolls (Ruini et al., 2013). The grinding step is aimed to break up wheat kernels and to separate the endosperm from the bran, preserving grain quality. Semolina possesses irregularly shaped particles with variable sizes characterized by sharp edges. When observed under SEM, semolina shows a compact structure, with few visible starch granules entrapped in a protein matrix (Alami et al., 2007). At room temperature semolina proteins and starch behave as a glassy material. After the addition of some water, protein becomes rubbery and elastic becoming able to form strands and sheets via inter-molecular bonds during mixing. The gluten network formed helps to trap the starch granules in pasta and hold pasta shape during cooking (Sissons, 2008).

Semolina particle size is a quality key factor in pasta making. Semolina used for pasta processing typically ranges in particle size from 550 to 150 µm (Manthey & Twombly, 2006; De Noni & Pagani, 2010). Pasta manufacturers choose the particle size distribution of semolina according to the desired final product characteristics and the production requirements. The underlying principle is that the more even the particle size more uniform hydration of the semolina during the mixing. Hydration of semolina with a wide range of particle size result in a over-hydration for the finer fraction and a under-hydration for the coarser fraction. The non uniform hydration will adversely affect dough development and pasta quality (Manthey & Twombly, 2006). There is, however, no ideal granulometry as this requirement refers to the method of mixing used by the pasta maker. The tradition was for a higher particle size (mainly consisting of particles in the size range 250-350µm), but now modern pasta making plant require finer semolina (<300µm) that hydrate quicker. Finer, floury particles were associated with poor quality pasta but if milled correctly, particle size range, akin to flour, can be used successfully, giving good quality pasta at increased milling yield and faster mixing speeds (Kill & Turnbull, 2008). Modern high speed extrusion processes are characterized by limited dough residence time and finer semolina is particularly suitable avoiding the appearance of white spots due to poor

hydration of the particles; it confers to pasta a highly homogeneous color with a higher yellow color saturation than coarser semolina (Milatović & Mondelli, 1991).
Differently from the modern high speed and temperature plants, small manufacturers usually prefer the traditional way to produce pasta, using high particle size semolina. Coarser semolina show on one hand higher hydration times, and on the other handless starch damage. The re-grinding operation required for fine semolina making, could determine adverse effects on quality of starch that is easily hydrolized by amylases. During the kneading and extrusion steps, the pH (slightly acidic) and temperature of (40-50°C) condition are optimal for amylases and occur an increase of reducing sugar content from semolina mixing to dough extrusion accelerating the MR during drying with adverse effects on both color (browning) and nutritional value (loss of lysine) (D'Egidio, 2001).
The damage of starch increases also granule swelling and solute dispersion from starch granules during cooking (Mok & Dick, 1991); finally the starch damage reduces the gelatinization enthalpy of wheat that can affect the cooking quality of pasta from fine semolina (Stuknytė et al., 2014).
The right amount of water to be added to semolina, generally, ranges from 25 to 34 kg per 100 kg depending from the initial moisture content of semolina and from the resulting pasta shape (Stuknytė et al., 2014). Usually, for extruded spaghetti, 26.5kg (per 100kg of semolina) of water is added to semolina in order to obtain a dough with 32% of water content. The mixing stage is performed under vacuum to remove air from dough and avoid air bubbles in pasta. During the mixing operation, heterogeneous hydrated pea-sized lumps (2-3 cm dia.) are formed in the mixing chamber (Petitot et al., 2009). The right mixing time depends from semolina particle size, the absence of non-hydrated particles in the final dough is very important since it could induce in pasta defect. As water absorption takes place below 50°C, starch granules show no important structural changes (Vansteelandt & Delcour, 1998), and no indication of gluten network formation is apparent (Bruneel, 2011) due also to the limited hydration level and low energy input (Icard-Verniere & Feillet, 1999).

1.5.2. Die material and extrusion operation

Wet mix passes into the vacuum screw and to the extruder, forming a dough and due the application of mechanical work causes protein aggregation and form the glutennetwork (Sissons, 2008). Extrusion step is conducted at lower temperatures than those required to cause the insolubilization of proteins. When the extrusion temperature exceeds 50°C starch granules begin to undergo abnormal swelling and coagulation of protein occur (De Noni & Pagani,2010). However, in the extrusion worm, pressure builds up and the dough temperature can rises locally; structural transformations are the consequence of both shearing stress and thermal energy involved during extrusion (Kruger et al., 1996). The screw rotation pushes the dough towards the die where it takes its final shape (Petitot et al., 2009). The extrusion pressure is essential to give the product the necessary texture to preserve its shape during cooking (Kruger et al., 1996); as the dough progress toward the screw pressure increase. The pressure at the die generally range about 10MPa (extruding and drying pasta) but depending on die material, pasta final shape, and type of plant, this may be up 13-14 MPa. When compared to semolina, freshly extruded pasta conducted at low temperature (35-40 °C) does not significantly ($P < 0.05$) affect protein solubility (Icard Verniere, 1999).
Concerning the starch fraction, mechanical forces concomitant with a local increase in temperature (>60°C) can lead to moderate damage to starch granules. DSC measurements detect a higher gelatinization enthalpy of semolina compared to extruded pasta (Vansteelandt & Delcour, 1998) that could be explained by the presence of some gelatinized starch granules and/or damaged starch granules in pasta. The high pressure occurring in dough extrusion was found promote amylases inactivation and only a small further increase in reducing sugar amount was observed during the subsequent drying step (De Noni & Pagani, 2010).
Freshly extruded pasta, observed under SEM, possesses a compact internal structure with irregular size and shape starch granules deeply embedded in a protein matrix and aligned along the direction of the flow (Matsuo et al., 1978).
Other important variables that can affect pasta characteristics are associated to the use of die insert from different materials. The most widely used die insert are made from Teflon or Bronze. With regard to the appearance of the pasta surface, Teflon gives a smooth and bright yellow appearance to the product, whereas bronze gives a rough surface to the pasta. The use of bronze dies has the disadvantages of a lower production yield of the press and a faster wear of the die insert (Manthey & Twombly, 2006). Fresh pasta extruded with bronze has higher water content and larger diameter and it expands more than Teflon die pasta after extrusion. Those results indicate that the use of different die materials would lead to different matrix structures (Mercier et al., 2011).
By using the same raw material and adopting the same process steps, bronze die samples appeared more fragile than Teflon one: statistically lower forces are required for breaking the samples prepared with both fine and coarse semolina (Lucisano et al., 2008).
The rough surface of the bronze inserts produces large pores on pasta surface, with a porous gradient that gradually decreased towards the center of the product (McNabb & Anderssen, 2007); the higher porosity probably is consequence of the rough surface of the pasta, resulting in a decrease in apparent density. An higher volumetric fraction of air present in the matrix of bronze-extruded pasta can explain the lower breaking strength that has been associated to it (Lucisano et al., 2008).
As a result of an higher porosity, bronze die induces an increase in effective moisture diffusivity compared to Teflon die, while equilibrium moisture content is not affected (Mercier et al., 2011). From the measured effective moisture

diffusivity and equilibrium moisture content, by using the model derived from Fick's law, the time required to dry a 2.5mm pasta from 50.0 to 20.0g-water 100g-dry matter-1 at 80°C would be 97 ± 2min for a Teflon die extrusion and 71 ± 2min for a bronze die extrusion (Andrieu & Stamatopoulos, 1986).

Ultra structure images magnified the differences in term of smoothness between Teflon extruded spaghetti and bronze extruded ones that could be already evidenced by visual inspection. SEM observations show that Teflon extruded spaghetti have a very compact structure in which the starch granules and the protein matrix are fused together and no longer clearly distinguishable while the surface of the bronze die spaghetti is characterized by the presence of gluten strands that only partially cover the starch granules, thus leaving many small cavities between them (Lucisano et al., 2008). The product roughness makes bronze die pasta more suitable to bind the sauce than Teflon die pasta, but at the same time facilitates insects attack. Clinging of the product, the insects gnaw its surface and make a small hole in which to lay its eggs helped from a reduced mechanical strength of the material extruded by bronze die (Pagani et al., 2007).

1.5.3. Drying operation

The assessment of internal water profiles during pasta drying is a critical point for tailoring the pasta properties, minimizing the possibility of crack formation and achieving uniform glass transition conditions (Mercier et al., 2014). Since the 1970s, technological improvements have induced an increase in drying temperatures of pasta: from low temperatures (LT, 40-60 °C), to high temperatures (HT, 60-84 °C), and very high temperature (VHT) (>84 °C), reducing drying times and improving hygienic standards. Moreover, the use of higher temperatures is also beneficial for the overall cooking performance of pasta (Zweifel et al., 2003). High temperature-short time (HT-ST) drying conditions were first used commercially in 1974. Since then there has been continuous increase until 90 °C and even higher, allowing pasta to be dried within 2-3 hours (Kill & Turnbull, 2008).

Weegels (Weegels et al., 1994) studied the reactivity of gluten and found that major changes occur when gluten with a moisture content of 25-30% (w/w) is heated at 80°C. A decrease in protein solubility was found due mainly to the glutenin fraction. This situation can be compared to the conditions applied during pasta drying at high temperature. Heating to 90 °C conformational changes of glutenins exposed unavailable areas containing free SH-groups and, next, polymerized with oxidation of most SH-groups (Lagrain et al., 2006). Over 90 °C, the remaining free SH-groups of glutenin can induce a covalent linkage with gliadin through a heat-induced SH-SS exchange mechanism catalyzed by SH-groups. It is probable that for gliadin–glutenin cross-linking are necessary conformational changes caused by high temperature in the gluten proteins (Guerrieri et al., 1996).

Durum wheat semolina is characterized by a high fraction of SDS soluble proteins (80-83%), a low fraction of dithioerythritol (DTE) soluble proteins while dried pasta has a higher protein aggregation, as shown by the decrease in SDS-soluble proteins in favor of DTE-soluble proteins (19,17%), and no traces of unextractable proteins (Stuknytė et al., 2014). This phenomenon suggest a protein aggregation through the formation of additional disulphide bonds and rise with the increase of drying temperatures, particularly when the very high temperature (≥90°C) is applied at a low pasta moisture content (VHT-LM) (Petitot et al., 2009).

According to different authors, generally higher drying temperatures improve pasta cooking performance even though high drying temperature applied to high pasta moisture can determine an excessive swelling of starch granules with the consequent break down of the proteic network and a decrease in the overall cooking performance (Resmini et al., 1988). The best results are obtained using a preliminary low drying temperature in the first step to reduce pasta moisture, followed by high drying temperature (Resmini & Pagani, 1983). However, drying at high temperature promotes extensive heat damage in pasta, correlated to the appearance of off-color and off flavor (Reineccius, 1990), damaging the nutritional value of protein (Friedman, 1996), and forming unnatural compounds (Resmini & Pellegrino, 1994). The high drying temperature cycle induces new macromolecular interactions, lowering the role of semolina quality in pasta cooking performance (Marti et al., 2013); if pasta is dried at high temperature the quality of the raw material could be considered a non-critical parameter (Cubadda, 1989).

Zhang et al (2011), demonstrated that moisture distribution in samples depends on drying temperature and that pasta, dried below the gelatinization temperature, absorbs better water. Pasta dried with an higher drying temperature (≥ 70°C) absorbs in the inner part less water, conversely pasta dried with lower drying temperature (≤ 50°C) behave in the opposite way. When drying step temperature are above gelatinization temperature, the dependence of moisture distribution on drying temperature is not longer found. This phenomenon can be attributed to starch granules arise in the surface of pasta dried at higher temperature. The higher drying temperature allows starch granules gelatinization preventing the diffusion of water to the inside. LT-dried pasta shows an highest water absorption than HT-dried pasta under any cooking condition (Zhang et al., 2013). Increasing the drying temperature, the swelling of starch granules is hindered by the formation of a more aggregated gluten network during process (Bruneel et al. 2010). Moreover the higher drying temperature increased the hydrophobic properties of the gluten network; higher levels of amylose–lipid complexes are observed with higher drying temperatures. The increase of amylose-lipids complex contributes to lowering water absorption (Zhang et al., 2013). It is demonstrated that drying temperature also influences pasta *in vitro* digestibility. If compared to a low drying temperature, the application of a VHT-LM drying, decreases starch and protein digestibility *in vitro* with a greater effect on the latter (Petitot et al., 2009); this findings could be explained by the presence of highly aggregated proteins stabilized by covalent protein as gliadin-glutenins aggregates and Maillard

reaction products (Petitot et al., 2009). Indeed, a development of MR compounds occurs during pasta drying, especially at high and very high temperatures (Anese et al., 1999).
The application of high-temperature treatments enables an improvement in pasta cooking properties, with an increase in plant productivity and a reduction of microbial contamination (Manser, 1990), but the development of uncontrolled reactions, such as the MR, could be induced too (Resmini & Pellegrino, 1994). During high temperature-low moisture drying, pasta reaches Aw value of 0.70-0.80, that is recognized to be optimal for Maillard reaction (Rockland & Stewart, 1981). Pagani et al. (1996) found the highest value of MR products in samples manufactured according to an high extraction rate milling cycles and using semolina having small size, drying at temperature up to 75°C when pasta presents low moisture. The MR early stage may affect the nutritional value of pasta protein reducing nutritionally-available lysine and methionine and inducing an excessive browning due to the formation of colored compounds and the loss of carotenoids (Hidalgo et al., 2010). In the MR advanced stages, can also occur the formation of flavor compounds from free sugars (Resmini & Pellegrino, 1994) as well as important changes in flavor composition due to Strecker degradation (Hayashi et al., 1990) and thermal oxidation of lipids components (Sayaslan et al., 2000).
In the last years the research about pasta drying continues to move in the direction of time-reducing and productivity increase. It would seem that the use of microwaves might meet these expectations, also reducing the size of dryer plant.
Several advantages have been highlighted for the first time after the joint work of a processor pasta in Canada (Lipton) and an equipment manufacturer in the USA (Cryodry), who were engaged to adapt a microwave stage on an existing industrial conventional process. In an article by Maurer, Tremblay and Chadwick (Maurer et al., 1971) several factors to consider when evaluating the economics of the process compared with conventional microwave are described.
Otherwise from conventional methods of heating whereby heat is transported from the surface to the center, heating of foods exposed to a microwave field is 10-20 times faster (De Pilli et al., 2009). As compared with the conventional drying, the use of microwave assisted by hot air involves two main advantages: an higher production speed and a lower space utilization. Berteli et al. (2005) stated that using a combined microwave assisted hot air rotary dryer, drying time is reduced by more than ten times meaning a considerable saving in time compared to conventional process, without being harmful to the appearance of pasta getting a final product without fissures. As far as physical and texture properties of pasta dried with combined hot air/microwave, this pasta is equal or better than that conventionally dried (Altan & Maskan, 2004). Generally, an increase in pasta firmness and a reduced cooking loss is observed with microwave application. The investigators observe that the shorter microwave drying time would be caused from the additional energy input and by the rapid heat penetration of microwave. Anyway not yet exist industrial plants that use this drying method; it would be necessary to perform a more precise economical analysis that considers the potential advantages and disadvantages of microwave drying compared to traditional techniques in order to evaluate the costs and benefits of this potential innovation in pasta drying.

1.5.4. Cooking procedure

During the cooking time, water concentration increases at the boundary of pasta and moves toward internal regions showing a sort of discontinuity in concentration that progressively disappears when the overcooking phase advances. As the cooking time proceeds, lots of structural transformations occur, also dependent from those occurred during the previous processing steps; the final structure of pasta is the result of all the changes occurred in pasta making process and this is mainly affected by the starch and protein fractions (Petitot et al., 2009).
Modification of process parameters impacts also pasta nutritional properties; indeed, as discussed in the following section, the nutritional properties of pasta are closely linked to its structure (Colonna et al., 1990; Granfeldt & Björck, 1991).
In traditional consuming countries consumers assume that cooking performance is the main attribute related to pasta quality followed by the capability of binding the sauce and yellow color, while stickiness is indicated as the main defect (Di Monaco et al., 2004).
Starch gelatinization and protein coagulation are the main events that occur during the cooking time. Protein coagulation and interaction lead to a formation of a continuous and strengthened network which traps starch granules while the latter by swelling and gelatinization, occludes all free interspaces giving to pasta its special structure.
A decrease of protein solubility in SDS is observed during cooking. Depending on the previous drying temperature applied, the loss of protein solubility during cooking step can be more or less accentuated. If one compares the solubility of proteins in pasta submitted to different drying temperatures, it appears that the higher temperature leads to less marked changes in pasta protein solubility during cooking compared to lower temperature because most of the proteins have been aggregated during the drying step (Petitot et al., 2009). Starch and proteins transformations are in the same range of temperature and moisture conditions (proteins react at a little lower moisture level) (Cuq et al., 2003); both components are competing for water and the swelling of starch granules is antagonistic to the formation of protein network during cooking step (Bornet et al., 1990). When protein network is not strong and elastic, the starch swells and gelatinizes before protein coagulation; amylose goes mainly in cooking water and amylopectin fragments move to the pasta surface reducing pasta cooking quality. On the contrary, when protein interactions prevail, starch granules, which hydrates slowly, are trapped within the protein network and the resulting cooked pasta will be firm with no stickiness and clumpiness (De Noni & Pagani, 2010).

Both transformations are mediated by water uptake during cooking. As the cooking time proceeds, water absorption rate depends on water ability to diffuse through the matrix and on the melting kinetics of domains (Pagani et al., 1986). Water acts as a plasticizer and increases polymer mobility, penetrates towards the centre as the cooking time proceeds. The lower moisture content in the inner parts of pasta generates a greater competition for water between proteins and starch, leading water to be not evenly distributed among components (Petitot et al., 2009). A higher hydration of proteins locally may cause the formation of the protein network before starch swelling.
When pasta is dried at low temperature the cooking quality is mainly a function of protein content and gluten properties. In the case of HT drying cycles, assume a primary role the only amount of protein. The gluten coagulation before cooking induced by temperature higher 60°C reduces the need for a strong gluten network in semolina (Casiraghi et al., 1992). Different authors (D'Egidio et al., 1990; Cubadda et al., 2007) described the role of drying temperature in determining pasta cooking quality, almost regardless of the protein content; there is a general agreement indicating that the low-temperature dried pasta gave a lower cooking performance when compared to the higher dried pasta.
Observing the surface of cooked pasta under SEM, protein and starch are no longer distinguishable from one another, forming a thin film with some small cracks and open areas (Heneen & Brismar, 2003). Moving the observation inwards, the structure of cooked pasta can be divided into three different concentric regions; an external region, an intermediate region, and a central region (Heneen & Brismar, 2003; Petitot et al., 2009). In the outer region, starch granules are widely deformed, swollen and it is difficult to differentiate them from proteins observing under SEM (Fardet et al., 1998; Heneen & Brismar, 2003). The intermediate and central regions of cooked pasta are clearly distinguished from the external regions; intermediate region is characterized by partly swollen granules embedded in a dense protein network (Fardet et al., 1998; Heneen & Brismar, 2003), while the centre of pasta presents a low starch granules swelling with a limited degree of gelatinization, due to limited water absorption (Cunin et al., 1995).
Recently, in order to reduce the cooking times and automate the cooking process, the use of microwave cooking (MWC) as alternative way to cook pasta has been proposed. By using a sensory panel of trained judges no differences were observed between traditionally cooked pasta and microwave cooked pasta, except for yellow color intensity (Cocci et al., 2008). As the cooking time proceeds, pasta cooked by microwave shows a lower weight increase (WI) kinetic than tradition alone, showing an initial diffusion-like step, followed by a linear increase of weight. At the same level of water uptake, pasta cooked by microwave shows a significant higher gel degree and lower firmness than traditional cooked pasta (TRC).Chemical method show for TRD and MWC a rate of gelatinization of 13% and 16.1%, respectively, while the value from DSC measurement was 96.2% and 99.8%; observing by SEM, microwave cooked pasta shows a morphological modification of starch granules, that take the shape of a flatted disk (Cocci et al., 2008). According to Cocci et al. (2008), at the same weight increase we observed in MWC an higher morphological modification of the starch granules, (Fig. 1 A) compared to TRC where the shape of flatted disk was less expressed (Fig.1 B). Probably, the higher extent of gelatinization is due to the effect of the dielectric heating on the inner food polar molecules during microwave cooking; microwaves reach the inner pasta layer affecting temperature profile inside the food material (Cocci et al., 2008).
Observed under SEM, external surface of MWC pasta shows a more compact gluten network (Fig. 1 C) than TRC pasta (Fig. 1 D). TRC pasta appear with the typical honey comb-like network, observed also by other authors (Cocci et al., 2008).
Microwave application could induce an higher protein denaturation that generates the more compact gluten network (Altan & Maskan, 2004).

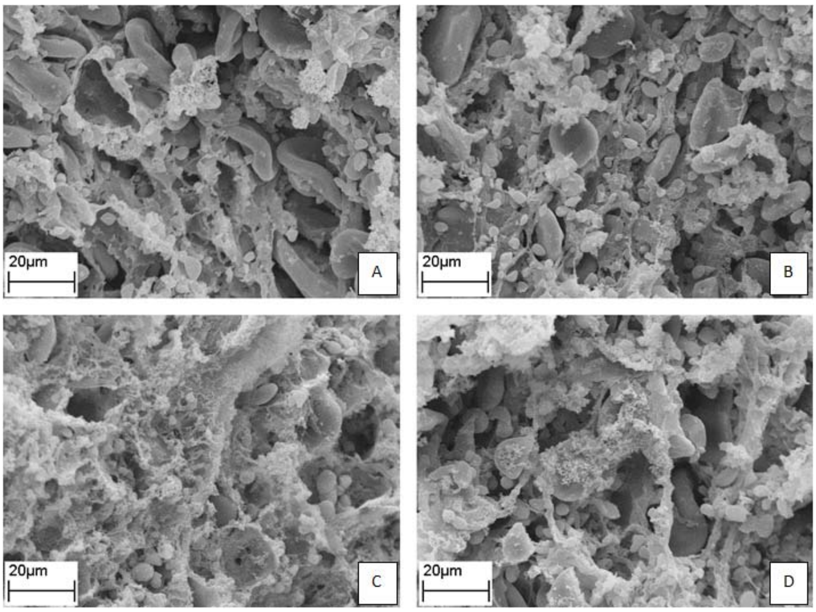

Figure 1. SEM micrographs of inner surface of MWC pasta (A) and TRC pasta (B),outer surface of MWC pasta (C) and TRC pasta (D), Unpublished data.

MW cooking gives to the pasta a better color retention, higher gel degree, a more compact gluten network and lower cooking loss; by considering that chemical-physical differences revealed by instrumental analyses are not sensory perceived and that MW cooking could reduce preparation time automating the cooking process, this innovative way to cook pasta could be regarded as a good alternative than TRC (Cocci et al., 2008).

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2. Aim of the thesis

The research have been focused on pasta overall quality evaluation. The aim of the thesis was to evaluate the effect of raw material, technological processes and cooking methods on pasta quality.

The work is split into three cases study. The object of first case study was to evaluate the effect of semolina from both mono-varietal and commercial mix durum wheat on qualitative characteristics of dry pasta; moreover, for each semolina was conducted a study on the effects of high and very high drying temperature on final product in order to assess if and how drying method could affect pasta. Six monovarietal semolina and two commercial mix were used to produce spaghetti than subjected to drying according to two different drying cycles: high temperature (75 ° C) and very high temperature (90 ° C) drying cycles thus obtaining a total of sixteen samples, two for each semolina sample

In the second case study, was evaluated the cooking quality of alternative cooked pasta with the purpose to understand which may be the best (reducing time and /or energy) alternatives to traditional cooking. Four different hollow shapes coming from the same production lot were used; pasta sample were than underwent to passive cooking and microwave cooking. Pasta quality was evaluated by means of sensory, physical and structural analysis by using traditional cooking as reference

Finally the third study aimed to asses the influence of chickpea flour and microwave drying operation on starch digestibility and glycemic index of composite legume-wheat pasta. A substitution of 20% chickpea flour was made with respect to the reference sample (100% semolina). Six pasta samples were prepared from 100% semolina, semolina (80%) and raw chickpea flour (20%), semolina (80%) and cooked chickpea flour; each sample was than subjected to traditional drying (40°C; RH 80%) and an optimized microwave drying.

3. I Study Case: Effect of raw material and drying temperature on pasta overall quality

Abstract

Pasta is a traditional wheat-based food, whose popularity, indisputable in Italy and progressive in Europe as well as in America and in the East, is essentially due to the nutritional and sensory qualities that have made it an attractive source of carbohydrates, enviable and difficult to replace in a healthy and balanced diet. The overall pasta quality is highly influenced by raw materials and production technologies. As far as the raw material, the protein content and the gluten quality of semolina are crucial factors in achieving good texture and cooking performance of the final product. Among the technological processes, the drying step is the most delicate and important. The aim of this study was to evaluate the effect of semolina quality and drying operation on the pasta characteristics.

Sixteeen samples of pasta (spaghetti size) obtained from six monovarietal durum wheat grain cultivars (Anco Marzio, Cappelli, Claudio, Core, Iride, Saragolla) and two commercial mixes (Santacroce, Tandoi), dried according to two different drying cycles (high temperature and very high temperature) were studied. Each sample was submitted to instrumental analysis and sensory evaluation. The results showed a significant effect of semolina and drying. Some parameters varied significantly also as function of interaction effect semolina x drying. Raw material drying treatment affected the characteristics of pasta in several ways. Compared to the other grains studied, the cultivar Cappelli was the oldest one, which gives both higher protein and higher ash content than modern cultivars. The samples Santacroce and Tandoi behaved in the same way probably due to the fact that they were two commercial mixes optimized according pasta industry needs.

3.1. Introduction

Pasta is a traditional Italian cereal-based food, popular worldwide, because of its convenience, versatility, sensory and nutritional value. Due to its unique flavor, color, composition and its rheological properties durum wheat semolina is the best raw material for pasta production. The required features of durum wheat include hardness, intense yellow colour and nutty taste (Sissons, 2008). After processing, durum wheat pasta has good cooking quality, is chewable and firm even when over-cooked. Wheat quality traits are becoming increasingly important in wheat breeding programmes because of higher standards imposed by millers, bakers and consumers. Changes in dietary habits have resulted in an increasing interest for wheat with specific quality attributes (Peña, 2007). Different factors influence the durum wheat quality but their role is not completely understood (D'Egidio et al., 1990).

Many researchers have shown that the main variation in pasta cooking quality is due in part to protein content in semolina and in part to the intrinsic characteristics of the proteins. The role of starch in the determination of durum wheat quality is not taken into account. Nevertheless, the surface characteristics of the starch granules may affect the type of protein-starch interaction and the viscoelastic behavior of pasta (Edwards 2002). There is general agreement that protein content and gluten strength are the main factors that influence pasta quality (Feillet et al., 1989; Novaro et al., 1993; Feillet et al., 1996). De Vita et al.(2007) found that modern durum wheat cultivars are characterized by good gluten properties with respect to the old cultivars. On the other hand, for farmers, productivity is the quality criterion of durum wheat and their vision of quality is closely linked to the need to obtain high yields in order to maximise profit. With the aim to identify the physiological basis of yield increase, comparisons have frequently been made between old and modern cultivars. Durum wheat modern cultivars present an increase of yield but a lower grain protein concentration in comparison with old cultivars (Calderini et al., 1995; Oritz et al., 1997) suggesting that durum wheat quality and yield are inversely related. Protein content is influenced by many factors; environmental conditions, nitrogen fertilisation, and breeding. Durum wheat decrease in protein is probably due to a dilution effect of proteins and other minor components due to the increased amount of carbohydrates, and not due directly to genetic effects (Hentschel et al., 2002). Protein concentration decrease negatively affects pasta-cooking and nutritional quality. Grain protein concentration is a critical trait that affects both pasta nutritional value and the technological parameters (Dick et al., 1988). One of the common strategies employed by millers in Italy to increase semolina technological value, is the blending with mono-varietal semolina of good gluten quality which enhances technological parameters and final pasta cooking quality. In addition, with the aim to improve pasta cooking quality, the pasta industry acts on pasta drying operations. Currently, most pasta manufacturers prefer high temperature (≥ 70°C) and very high temperature (≥ 90°C) drying technologies for their pasta production. Heating to 90°C, conformational changes of glutenins liberate new areas formerly inaccessible containing free SH-groups and, next, polymerized with oxidation of most SH-groups (Lagrain et al., 2006). This phenomenon suggests a protein aggregation through the formation of additional disulphide bonds and rises with the increase of drying temperatures; the high drying temperature cycle induces new macromolecular interactions, lowering the role of semolina quality in pasta cooking performance (Marti et al., 2013). However, according to different authors, generally higher drying temperatures improve pasta cooking performance (Resmini et al., 1988; Zweifel et al., 2003; Marti et al., 2013). The objective of this work was to evaluate the effect of semolina from both mono-varietal and commercial mix durum wheat on qualitative characteristics of dry pasta; moreover, the pasta derived from each different semolina underwent high and very high drying temperatures in order to assess, if and how, drying operations could affect pasta.

3.2. Materials and Methods

3.2.1. Pasta samples

Spaghetti were made with six monovarietal semolina (Anco Marzio, Cappelli, Claudio, Core, Iride and Saragolla) and two commercial mix (Santacroce and Tandoi). Spaghetti were produced from all semolina samples by using the same operating conditions: semolina was mixed with water through a rotary shaft mixer (Namad, Rome, Italy) at 25°C for 20 min to obtain a dough with 30% moisture content. The dough was extruded by a 60VR extruder (Namad, Rome, Italy). The extrusion pressure was about 3.5 bar. Spaghetti temperature at the end of extrusion operation were about 27–28°C. The extruder was equipped with a screw (30 cm in length, 5.5 cm in diameter) and a bronze die (diameter hole of 1.70 mm). The screw speed was 50 rpm. Subsequently, the pasta was dried in a dryer (SG600; Namad). Finally, fresh extruded pasta samples were dried according to two different drying cycles: high temperature (75 ° C) and very high temperature (90 ° C) drying cycles thus obtaining a total of sixteen samples, two for each semolina sample.

3.2.2. Chemical analysis

Dried spaghetti samples were ground with a Tecator Cyclotec 1093 (International PBI, Hoganas, Sweden) laboratory mill (1 mm screen, 60 mesh). Moisture and ash content (%) were measured according to AACC approved methods 44–19 and 08–03 (2007). Protein content (% N × 5.7) was analyzed following the micro-Kjieldahl method according to AACC approved method 46–13 (2007). The available carbohydrates were determined according to McCleary and Rossiter (2007) as described in the Available Carbohydrates Assay Kit (Megazyme). Total dietary fiber, water-soluble fiber and water-insoluble fiber contents were measured by means of the Total Dietary Fiber Kit (Megazyme, Bray, Ireland) based on the method of Lee et al., (1992). All determinations were expressed on a dry weight basis. All nutritional analyses of the flour and spaghetti samples were made in triplicate.

3.2.3. Cooking properties determination

Optimal cooking time (OCT) was evaluated by observing every 30 s during cooking the disappearance of the core of the spaghetti by squeezing it between two transparent glass slides according to the AACC approved method 66-50 (2007). Cooking loss was evaluated as the amount of solid substance lost in cooking water according to the AACC approved method 66-50 (2007). Swelling index and water absorption of the cooked pasta (grams of water per gram of dry pasta) were determined according to Padalino et al. (2013). Three measurements were performed for each analysis and the mean values were obtained.

3.2.4. Texture analysis

Each test was carried out on three cooked (at OCT) spaghetti strands (40mm length). Just after cooking, spaghetti were submitted to hardness and adhesiveness analysis, by means of a Zwick/Roell model Z010 Texture Analyzer (Zwick Roell Italia S.r.l., Genova, Italia) equipped with a stainless steel cylinder probe (2 cm diameter). The three samples were put on the lower plate and the upper plate was moved down on spaghetti surface. Hardness (mean maximum force, N) and adhesiveness (mean negative area, N mm) were measured. Were performed six measurements for each spaghetti sample. The tests were conducted using the following specifications: pre-load of 0.3 N; load cell of 1 kN; percentage deformation of 25%; cross-head speed constant of 0.25 mm s^{-1} (Padalino et al., 2013). Three measurements of the analysis were performed and the mean values were obtained.

3.2.5. Sensory evaluation

Descriptive analysis was used to determine sensory profiles of spaghetti samples. A panel of seven judges was trained in descriptive analysis of pasta. During the first three meeting sessions, a list of fourteen attributes and the evaluation techniques were developed (Table 1). Judges were supplied representative samples and were asked to choose the most appropriate attributes to describe each sample. An open discussion with the panel leader as a moderator was needed to stimulate the judges to generate attributes. The terms which defined important features of the product and with good discriminatory capability between samples were selected according to judges. After the selection of attributes to be used, a consensus about their usage was reached; for this purpose, attributes, their corresponding definitions, and evaluation techniques were precisely defined according to panel. Three training sessions were carried out with the judges tasting three pasta samples presented in random order. After the evaluation of panel discriminating ability and reproducibility, the sample evaluation was performed.

Pasta samples were cooked in unsalted boiling water until reaching to OCT and immediately drained for thirty seconds before to the taste. During each session were evaluated four samples identified with a three-digit numeric codes. Water was used for rinsing between samples. The sixteen samples were thus divided into four groups, each consisting of four samples by means of an incomplete block design.

Sensory evaluation was performed in the sensory laboratory of the University of Naples, which fulfills the requirements of the ISO standards (ISO 1985). Data were collected by using a computerized data system (Fizz Acquisition Biosystemes).

DESCRIPTORS	DEFINITION	EVALUATION TECNIQUE
BRIGHTNESS	The extent to which the light is reflected on the surface of spaghetti.	Visual, ranging from 0= absent to 10= very intense.
ROUGHNESS	Characteristic that describes the degree of irregularity of the surface of the strand.	Visual, ranging from 0= absent to 10= very intense.
YELLOW COLOR	The intensity of the yellow color on the surface of spaghetti.	Visual, ranging from 0= light yellow to 10= dark yellow.
BEIGE COLOR	The intensity of the beige color on the surface of spaghetti.	Visual, ranging from 0= light beige to 10= dark beige.
STICKINESS	Surface stickiness of the pasta which depends on the amount of starch released which makes it sticky.	Pressing lightly, you slide a piece of spaghetti between thumb and forefinger, just once, and you evaluate how much your hands are sticky, ranging from 0= not sticky to 10= very sticky.
ADHESIVENESS	The degree of attachment of the spaghetti between them which depends on the amount of starch released.	Take a piece of spaghetti with a fork from the pile and assess the ease in carrying out the operation, ranging from 0= least sticky to 10= very sticky.
EXTENSIBILITY	Mechanical characteristic that indicates the ability of a piece of spaghetti to be stretched without breaking.	Stretch your fingers with a sample length of 21 cm and assess to what stretches before breaking down; ranging from 0= not extendible to 10= very extendible.
BRITTLENESS	Mechanical characteristic which indicates the resistance to crushing of the cooked pasta with your fingers.	Take a piece of spaghetti between thumb and forefinger and evaluate the force required to compress till break, ranging from 0= least breakable to 10= very breakable.
COOKING PERFORMANCE	Sealing ability of the texture characteristic of the product at a distance of a certain time by cooking.	After evaluating all attributes, an elapsed period of time of about 7 min from coking, to assess the degree of clumping of spaghetti in the pot, ranging from 0= least herded to 10= very herded.
PASTA ODOR	Aroma associated with the cooked grain.	Approaching the flat to the nose, you evaluate the strenght of the odor by orthonasal, on a scale ranging from 0= absent to 10= very intense.
PASTA FLAVOUR	Olfactory-gustatory sensation associated with semolina pasta cooked.	Tasting a sample 21 cm long and evaluate the aroma of pasta that remains in the mouth after swallowing on a scale ranging from 0= absent to 10= very intense.
HARDNESS	Force required to cut the noodles with incisors.	Place a sample of spaghetti between the incisors and assess the force required to cut it; it goes from 0= little hard to 10= very hard.
CHEWINESS	Attribute relative to the time required to chew the sample and make it suitable for swallowing.	Taste a sample (lenght: 21 cm) and assess how many chews are needed to make it suitable for swallowing, on a scale ranging from 0= not chewy (many chews) to 10= very chewy (a few chews).
GRAINY MOUTHFEEL	Amount of residual pieces of spaghetti warned in the mouth after swallowing.	Taste a sample (lenght: 21 cm) and assess the amount of residual pieces that remain in the mouth after swallowing, on a scale ranging from 0= least grainy to 10= very grainy.

Table 1. Sensory descriptors, definitions and evaluation techniques.

3.2.6. Data analysis

The values of cooking loss, swelling index, available carbohydrate, ash, protein, soluble fiber, insoluble fiber and total fiber were expressed as a percentage. The hardness was expressed in Newton (N) and the adhesiveness in Newton per millimeters (Nmm). Sensory data were expressed as the averages of the ratings provided by the judges during the three replicates. Data collected were then subjected to analysis of variance (ANOVA) and multiple comparison averages test of Duncan ($p = 0.05$), by using the statistical software SPSS v 20.0 to determine if instrumental parameters and sensory characteristics were significantly affected by semolina and drying operation.

To identify the relationships between instrumental parameters and sensory characteristics, the matrix formed by samples and variables for which was highlighted a significant effect of semolina and drying was subjected to principal component analysis (PCA). The PCA was performed using the software SIMCA P.10 (Umetrics AB).

3.3. Results and Discussions

3.3.1. Physico-chemical parameters

Instrumental data related to chemical and physical parameters were subjected to two-way ANOVA analysis to assess the effects of raw material (semolina), drying operation (HT-VHT) and their interaction. The results are reported in Table 2.

Instrumental parameters	Semolina (df=7)	Drying (df=1)	Semolina x Drying (df=7)
% Cooking Loss	<< 0.0001	0.110	0.938
Swelling index	<< 0.0001	0.332	0.753
% Water absorption	<< 0.0001	0.665	0.908
Adhesiveness (Nmm)	<< 0.0001	0.855	0.996
Hardness (N)	<< 0.0001	0.247	0.911
% Ash	<< 0.0001	0.086	<< 0.0001
% Protein	<< 0.0001	0.022	<< 0.0001
% Available carbohydrate	<< 0.0001	<< 0.0001	0.0001
% Soluble fiber	<< 0.0001	0.016	<< 0.0001
% Insoluble fiber	<< 0.0001	<< 0.0001	<< 0.0001
% Total fiber	<< 0.0001	0.020	0.173

Table 2. - Two-way ANOVA. Significance value (p) of semolina, drying operation and semolina x drying interaction effects. *The effect is significant for $p \leq 0.05$*

The results showed a significant effect of semolina on all physico-chemical parameters determined on pasta samples. The parameters: % protein, % available carbohydrates, % insoluble fiber, % soluble fiber and % total fiber also underwent a significant effect of drying operation. The effect of interaction semolina x drying was significant for: % Ash, % protein, % available carbohydrate, % soluble fiber and % insoluble fiber. % total fiber showed a significant effect of semolina ($p << 0.0001$) and drying ($p = 0.020$), but did not show significant variations as a function of interaction effect ($p = 0.173$). Otherwise % ash showed a significant effect of semolina and interaction semolina x drying but did not show significant variations as a function of drying operation. Figure 1 shows the average values of parameters significantly influenced by semolina and the results of multiple comparison averages test of Duncan ($p \leq 0.05$).

Cooking loss varied from an average of 4,27% for pasta Cappelli to a value of 6,49 for Iride. Pasta Anco Marzio and Cappelli were not significantly different for this parameter; the same occurred for samples Santacroce, Core and Saragolla. These results could be due to different fiber content in samples studied. Higher cooking loss may arise due to the breaking of starch and proteins matrix, as well as to the irregular distribution of water inside pasta matrix caused by the fiber tendency to hydrate (Aravind et al., 2011). In relation to swelling index, three groups of samples were formed: pasta Claudio, Core, Iride, Santacroce and Saragolla were not significantly different, as well as samples Cappelli and Anco Marzio while pasta Tandoi resulted significantly different from all samples. Water absorption reflected the same trend observed for swelling index, excepted for sample Claudio that was not significantly different from any samples excluded Tandoi. The variations of these parameters were influenced mainly by raw material protein content; semolina characterized by high proteins content counteracted swelling starch through the formation of a denser gluten network (Cocci et al., 2008), raw material with lower protein content instead behaved in the opposite way.

Relatively to adhesiveness, higher average values were shown for samples Core (1.67) and Iride (1.63) which were not significantly different from each other. The lowest values were recorded by samples Cappelli (1.20), Anco Marzio (1.30) and Santacroce (1.32) which did not show significant differences from each other. Also in this case proteins play a key role, in fact, according to Del Nobile et al. (2005), adhesiveness is negatively correlated with protein content.

As regards the hardness, the samples showed high variability. Pasta Tandoi (14:11) and Cappelli (13:54) were significantly harder than the others; on the contrary, pasta Core (10.08) and Saragolla (10:47) behaved in the opposite way. These results may be caused by different insoluble fiber and protein content. In agreement with the results of Aravind et al. (2011) insoluble fiber caused a reduction in pasta hardness. A greater hardness may instead be due to a high protein content.

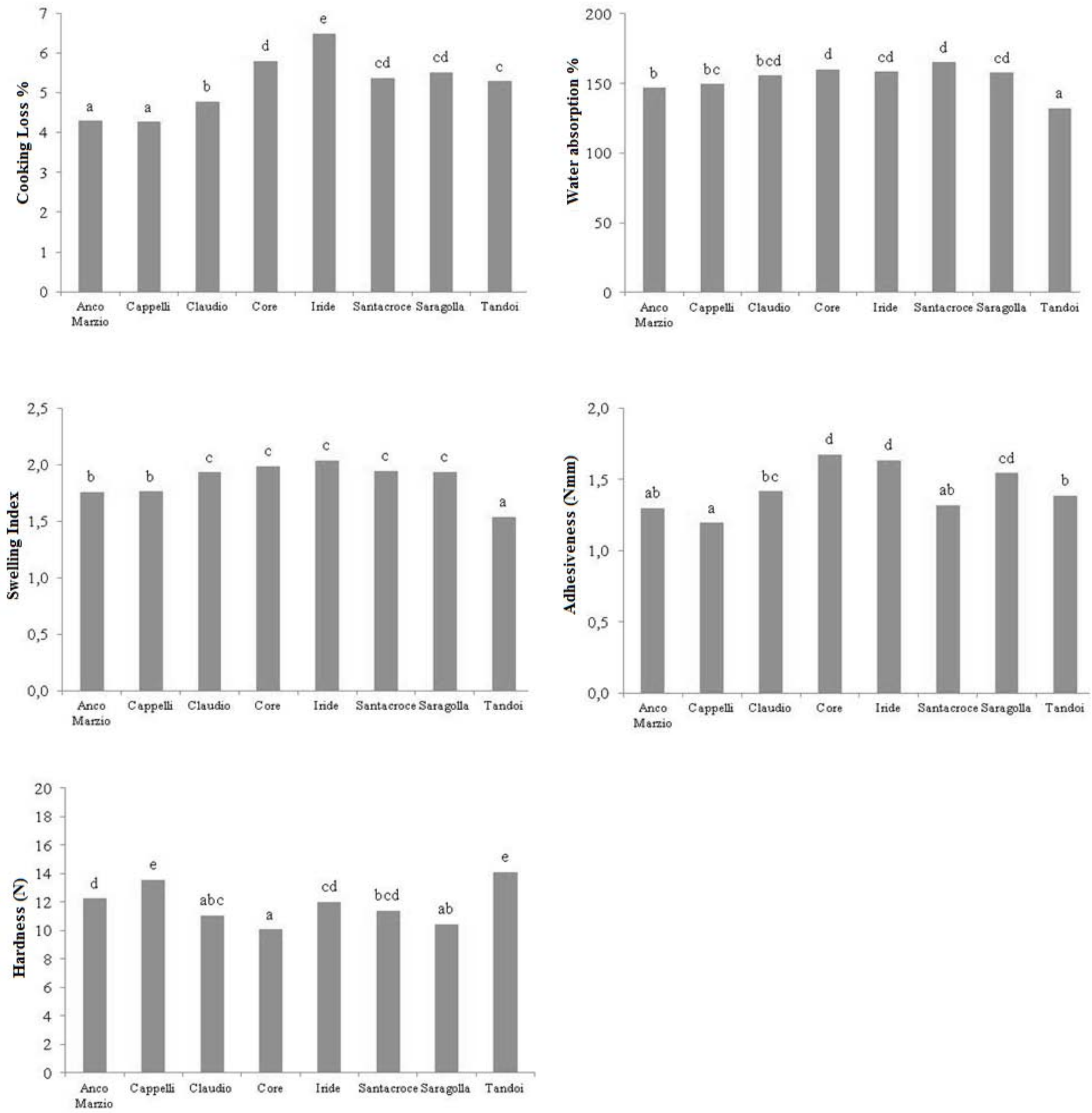

Figure 1. - Chemical and physical parameter average values influenced significantly by semolina. For each semolina was averaged the values of HT and VHT samples. For each parameter, semolina identified by different letters are significantly different (Duncan test, $p \leq 0.05$).

Total fiber % (Figure 2) showed a significant effect of semolina and drying operation. Pasta from monovarietals semolina showed a total fiber content higher than the commercial mix (Santacroce and Tandoi). Only spaghetti Iride and Santacroce showed a significant effect of drying operation, specifically VHT drying results in a reduction of total fibers.

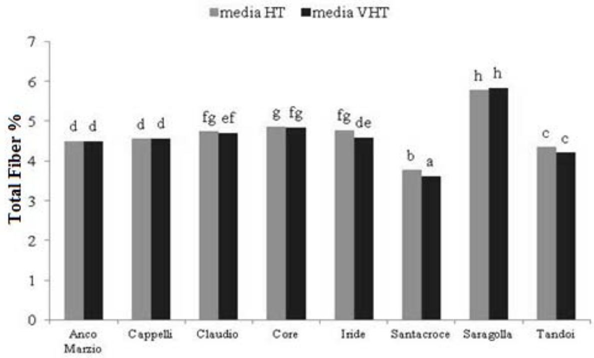

Figure 2. Total fiber average value. For each semolina were shown the average values of HT and VHT drying. Different letters correspond to significantly different values (Duncan test, p≤0.05).

Figure 3 shows chemical parameters average values for which a significant interaction effect semolina x drying was found and Duncan's test results (p≤0.05). Pasta Cappelli showed the highest protein content; this was due to the age of this cultivar. Cappelli is the oldest cultivar studied; according to other authors the oldest cultivars were characterized by higher protein and ash content than others (De Vita et al., 2007). Only pasta Santacroce, Iride and Claudio showed a significant effect of drying temperature; specifically pasta Santacroce and Claudio showed an increased amount of protein with increasing drying temperatures unlike pasta Iride which behaved in the opposite way.

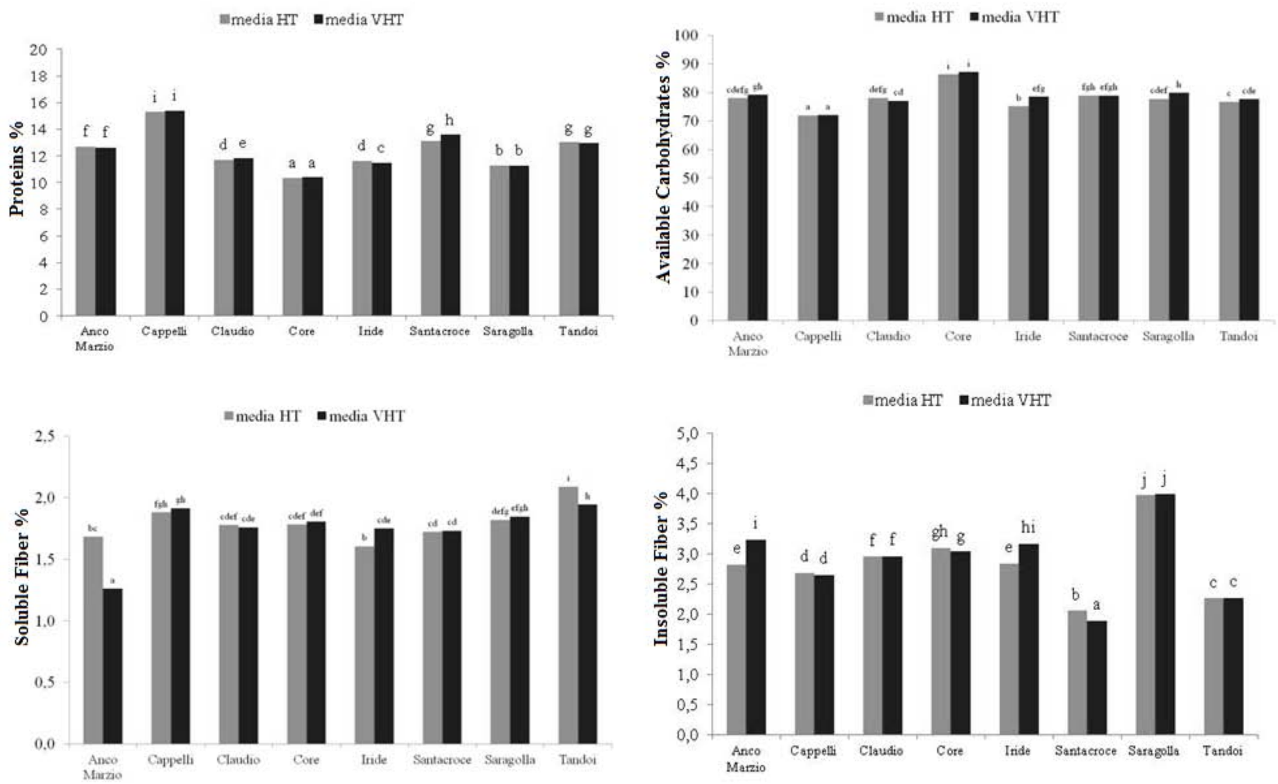

Figure 3. Average values of parameters affected significantly by interaction effect semolina x drying. For each semolina were shown the average values of HT and VHT drying. Different letters correspond to significantly different values (Duncan test, p≤0.05).

Relatively to % available carbohydrates, there were no major differences between samples. Samples Iride and Saragolla showed significant differences as regards drying temperature, specifically both showed an increase of available carbohydrates with increasing drying temperature. Even % soluble fiber content was subtly different. Significant differences as regards drying temperature were observed for samples Anco Marzio, Tandoi and Iris; very high temperature caused a decrease in soluble fiber for samples Anco Marzio and Tandoi while pasta Iride behaved in the opposite way.

The % soluble fiber increase may be caused by starch retrogradation process after gelatinization (Yue, Rayas-Duarte & Elias, 1999). Samples Santacroce and Saragolla were respectively the poorest and the richest samples in insoluble fiber. Pasta Anco Marzio, Iride and Santacroce showed significant differences as regards drying temperature. An increase in insoluble fiber was shown for samples Anco Marzio and Iride while Santacroce behaved in the opposite way.
The % ash content varied significantly regarding semolina and semolina x drying interaction effect while a significant variation regarding drying temperature was not shown.
Figure 4 shows % ash values of all samples studied. This parameter underwent significant variations as regards semolina, and the samples Cappelli and Santacroce showed, respectively the highest and lowest ash % content. Only for pasta Claudio and Tandoi a significant effect regarding drying temperature occurred; all samples behaved in the same way showing a decrease of ash with increasing temperatures.

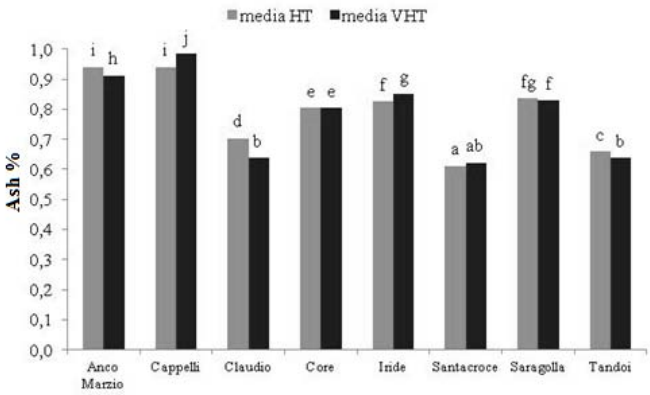

Figure 4. Average values of ash %. For each semolina were shown the average values of HT and VHT drying. Different letters correspond to significantly different values (Duncan test, p≤0.05).

3.3.2. Sensory properties

Sensory evaluation data were subjected to two-way ANOVA analysis to assess the effects of raw material (semolina), drying operation (HT-VHT) and semolina x drying interaction effects. The results are reported in Table 3.

Descriptors	**Semolina (df=7)**	**Drying (df=1)**	**Semolina x Drying (df=7)**
Pasta Odor	0.513	0.853	0.536
Stickiness	<< 0.0001	0.031	0.004
Adhesiveness	<< 0.0001	0.836	0.024
Extensibility	<< 0.0001	0.981	0.001
Brittleness	<< 0.001	0.859	0.390
Hardness	<< 0.0001	0.935	0.160
Chewiness	<< 0.0001	0.126	0.212
Grainy mouthfeel	<< 0.0001	0.353	0.419
Pasta flavour	0.146	0.687	0.264
Brightness	<< 0.0001	0.930	0.075
Roughness	<< 0.0001	0.591	0.714
Yellow color	<< 0.0001	0.067	0.077
Beige color	<< 0.0001	0.008	0.012
Cooking performance	0.001	0.756	0.023

Table 3. Two-way ANOVA. Significance value (p) of semolina, drying operation and semolina x drying interaction effects. *The effect is significant for p≤0.05*

The results showed a significant effect of semolina on all sensory attributes evaluated except for pasta odor and flavour. The parameters stickiness and beige color also underwent a significant effect of drying operation. The effect of interaction semolina x drying was significant for: adhesiveness, extensibility and cooking performance. Pasta odor and flavour did not show any significant effect as a result of independent variables. Figure 5 shows the average values of parameters significantly influenced by semolina and the results of multiple comparison average test of Duncan ($p \leq 0.05$). Chewiness showed the greatest variation respecting other attributes; pasta Cappelli was significantly different from all others with the lowest average (3.23) while pasta Tandoi recorded the highest average (6.14) showing no significant differences from samples Santacroce, Iride and Claudio. On the other hand brittleness showed the least variation of other attributes recording a minimum value of 3.6 for pasta Cappelli and a maximum of 5.63 for sample Core. Samples Anco Marzio, Claudio, Core, Iride, Santacroce, Saragolla showed no significant differences regarding brittleness.

In general as shown in Figure 5, multiple comparison average test of Duncan showed the formation of several sample groups which differed significantly from each other regarding each attribute; according to different authors raw material significantly influences pasta characteristics (De Vita et al., 2007; Padalino et al., 2014).

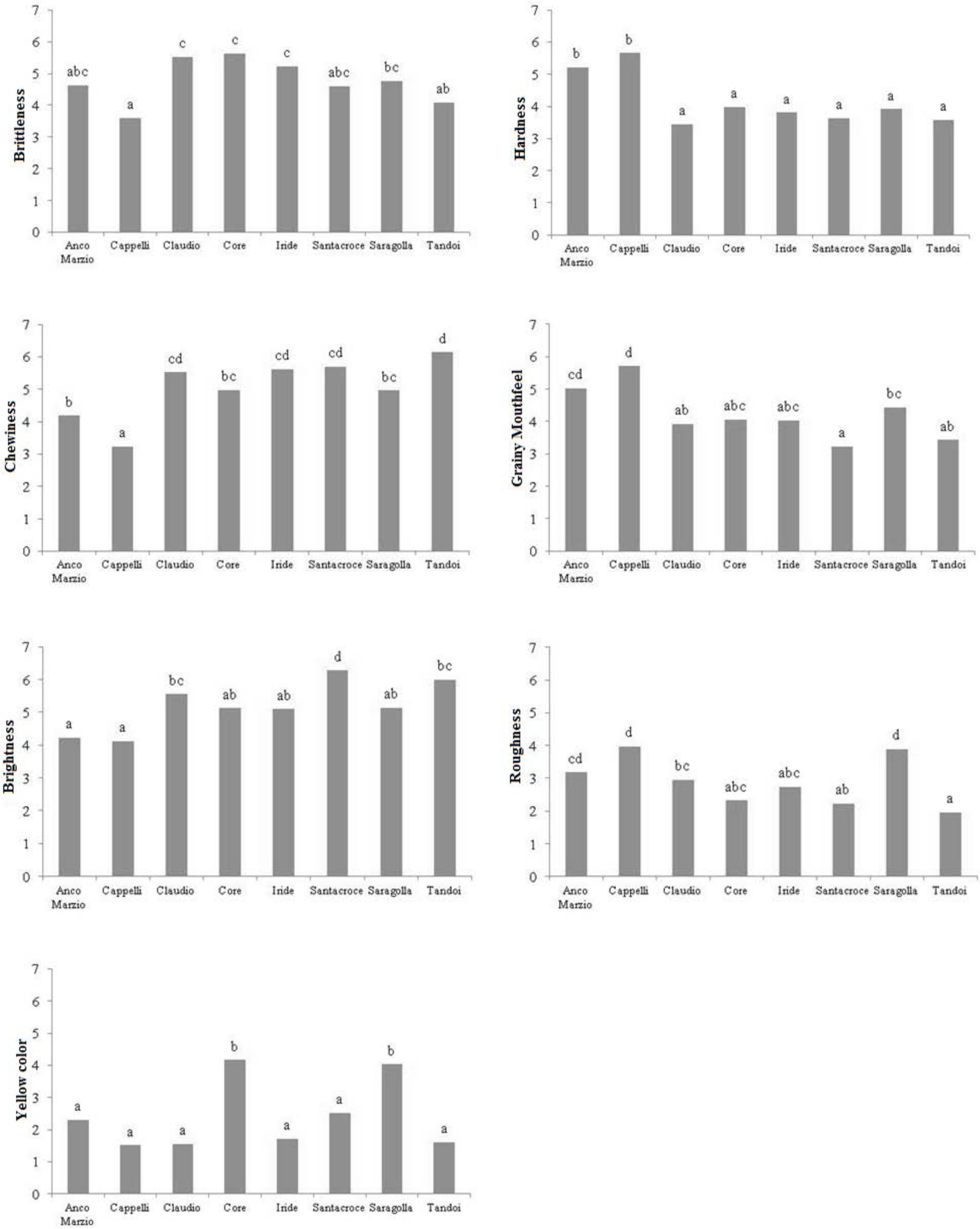

Figure 5.- The average values of attributes significantly influenced by semolina. For each semolina the values of HT and VHT samples was averaged. For each parameter, semolinas identified by different letters are significantly different (Duncan test, $p \leq 0.05$).

Figure 6 shows the attributes for which a significant interaction effect semolina x drying was found and Duncan's test results ($p \leq 0.05$). Stickiness varied from a maximum value of 6.72 to a minimum value of 2.79; only pasta Saragolla and Tandoi showed a significant drying operation effect with increasing temperature. Adhesiveness did not show significant variations as regards drying operation varying from a minimum value of 2.26 in pasta Core VHT to a maximum value of 5:53 for sample Saragolla VHT. Extensibility varied from a minimum value of 2.19 for pasta Core VHT to a maximum of 7.29 for pasta Santacroce VHT. Samples Cappelli, Claudio, Iride and Saragolla showed significant differences as a result of drying operation. Pasta Claudio and Saragolla showed increased extensibility with increasing drying temperature while samples Cappelli and Iride behaved in the opposite way.

Regarding beige color, in addition to a significant semolina effect, Cappelli, Iride and Saragolla also manifested significant differences regarding drying operation. Excluded pasta Iride, samples behaved in the same way; a decrease of beige color with increasing drying temperature was observed. Indeed, very high temperatures cause a development of maillard reaction compounds during pasta drying, inducing browning (Anese et al., 1999).

Finally, as regards cooking performance, minimum and maximum values were respectively 4.41 and 6.64. Pasta Iride was the only one that showed significant variation as a result of drying temperature; specifically higher temperature showed an increased cooking performance.

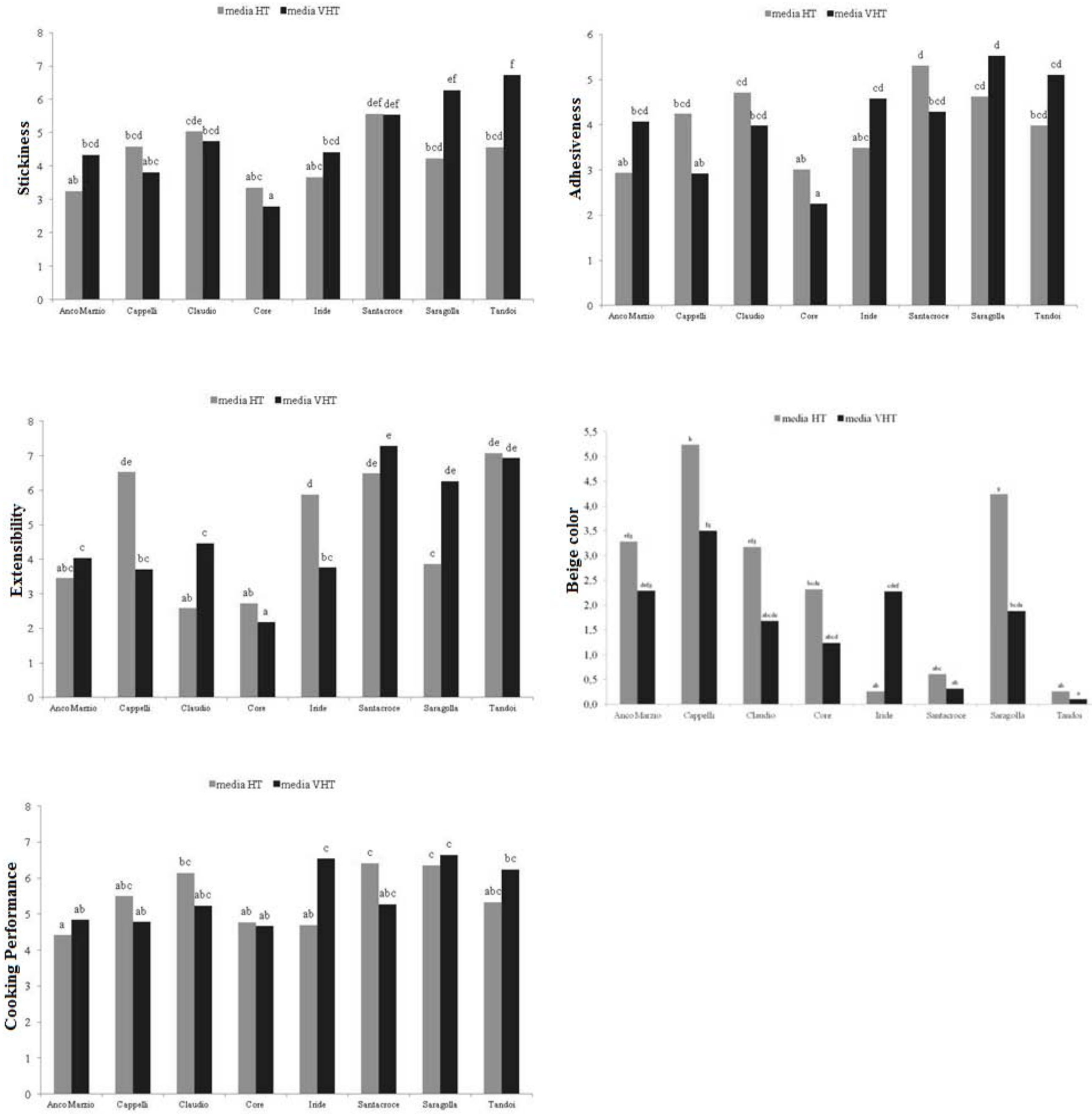

Figure 6. Average values of attributes affected significantly by semolina, drying and interaction effect semolina x drying. For each semolina the average values of HT and VHT drying were shown. Different letters correspond to significantly different values (Duncan test, $p \leq 0.05$).

3.3.3. Relationships between physico-chemical variables and sensory characteristics

Data matrix formed by pasta samples, instrumental parameters and sensory attributes that showed significant variation as a result of independent variables, were analyzed by the principal component analysis (PCA). The first three components extracted by PCA explained 75% of total variance.

Figures 7a and 7b represent samples (scores plot) and variables (loadings plot) on the plane formed by the first two principal components extracted (PC1-PC2).Looking at score plot (Figure 7a) it was possible to observe that all samples except Saragolla did not undergo great differences regarding drying temperature (HT and VHT) as these were in nearby positions on the plane. Specifically, samples from semolina Iride were the most similar to each other, and also very similar to pasta Saragolla VHT. Looking at loadings plot (Figure 7b) it was possible to obtain useful information about parameters relationships. Hardness and adhesiveness evaluated by texture analyzer were listed as hardness (TA) and adhesiveness (TA). Proteins % was positively related to hardness (TA) and negatively to % available carbohydrate and adhesiveness (TA). Pasta hardness decreases with a decrease of protein content (Dexter et al., 1983); a decrease in available carbohydrate (Padalino et al., 2014) and adhesiveness (TA) (Del Nobile et al., 2005) were observed with increasing protein content. Grainy mouthfeel, roughness and beige color were very interrelated and positively related to ash content. Contrary to expectated, hardness and adhesiveness assessed by sensory methods were not related with the same parameters measured instrumentally. Observing in a comparative way figures 4.8a and 4.8b it was possible to observe the behaviour of samples. Specifically, pasta Cappelli was the richest in protein and exhibited a very high hardness (TA). As previously said, semolina Cappelli is an old cultivar and is characterized by higher protein contents than recent cultivars. Samples Santacroce and Tandoi, were more adhesive, sticky, extensible, bright and chewable; they also showed high values for cooking performance and soluble % fiber. These samples behaved in the same way probably due to the fact that they were two commercial mixes optimized according to pasta industry needs. Pasta Core showed the greatest swelling index, water absorption and yellow color; it also expressed high % available carbohydrate, adhesiveness (TA) and brittleness. Anco Marzio samples were perceived as the hardest, grainiest and roughest, with an intense beige color. Pasta Saragolla HT was different from all the others and expressed the highest % total fiber and insoluble fiber.

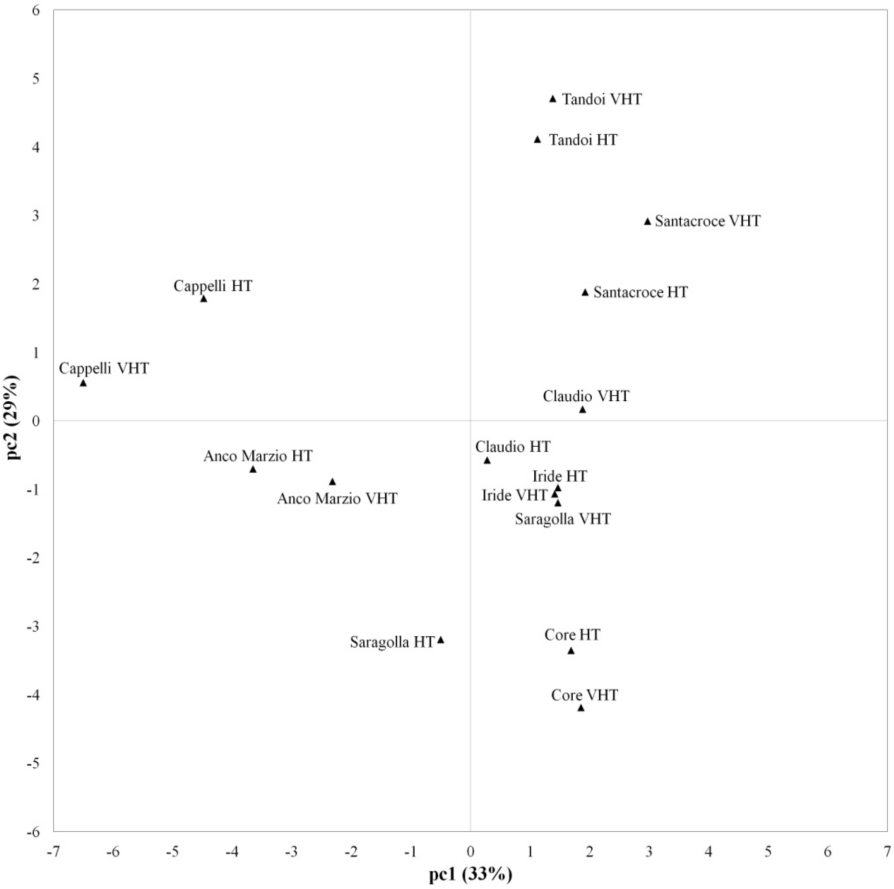

Figure 7a. Scores plot of two main components.

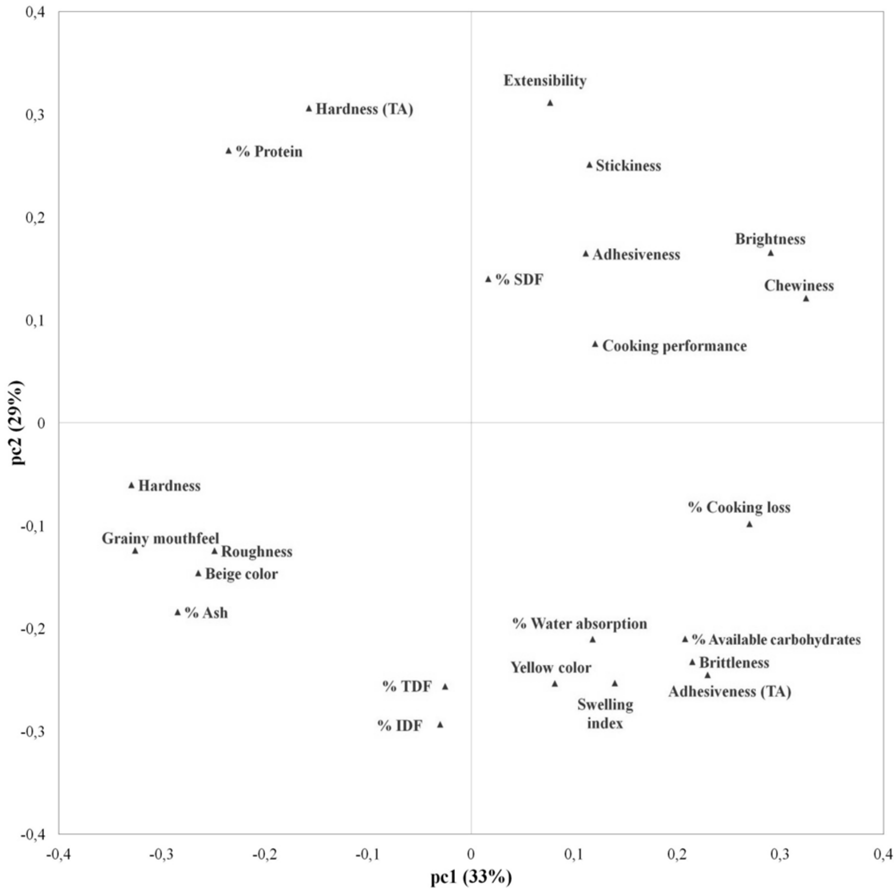

Figure 7b. Loadings plot of two main components

Figures 3.8a e 3.8b represent samples (scores plot) and variables (loadings plot) on the plane formed by the first and third principal component (PC1-PC3).
Observing the scores plot (Figure 3.8a) it was possible see that the third main component was able to discriminate samples regarding drying treatment. Only pasta Anco Marzio and Core were not affected by drying treatment. Observing the loadings plot (Figure 3.8b) useful information was found about the relationships between parameters. Roughness was positively related to % insoluble fiber and total fiber and negatively to % available carbohydrate and brittlenes, while the grainy mouthfeel was very related to ash content. Cooking performance was closely related to adhesiveness. Extensibility and % soluble fiber were related to each other and positively related to the yellow color. According to previous studies % protein and hardness resulted positively related (Dexter et al.,1983). It was interesting to observe that hardness and hardness (TA) were positively related when the plane formed by first and third main component was observed, while adhesiveness and adhesiveness (TA) were independent of each other also in this case.

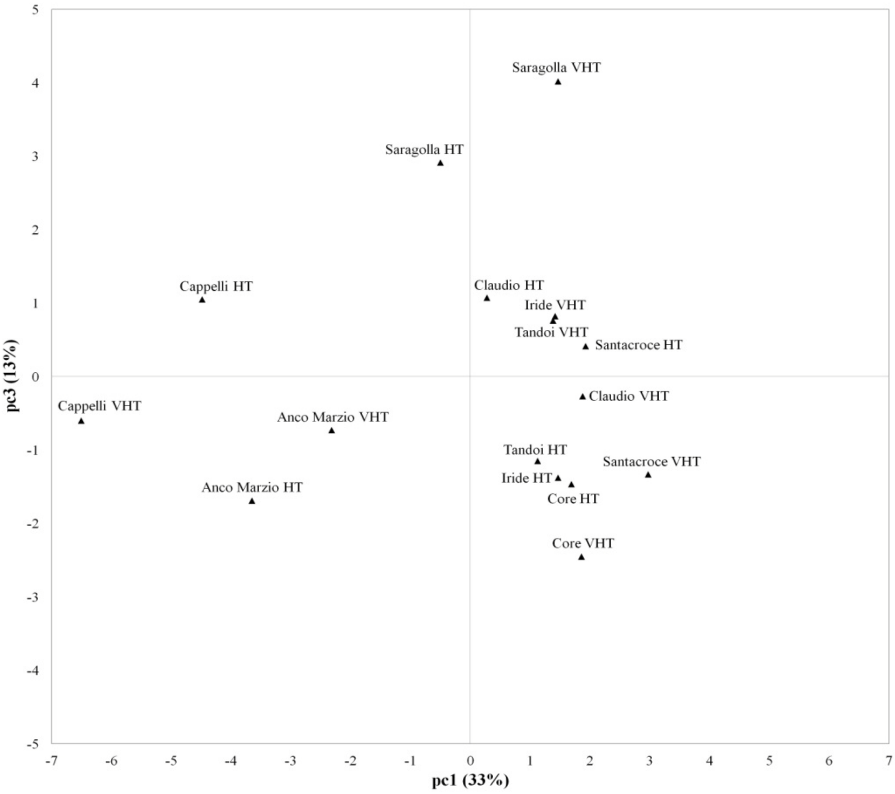

Figure 3.8a - Scores plot of first and third main components.

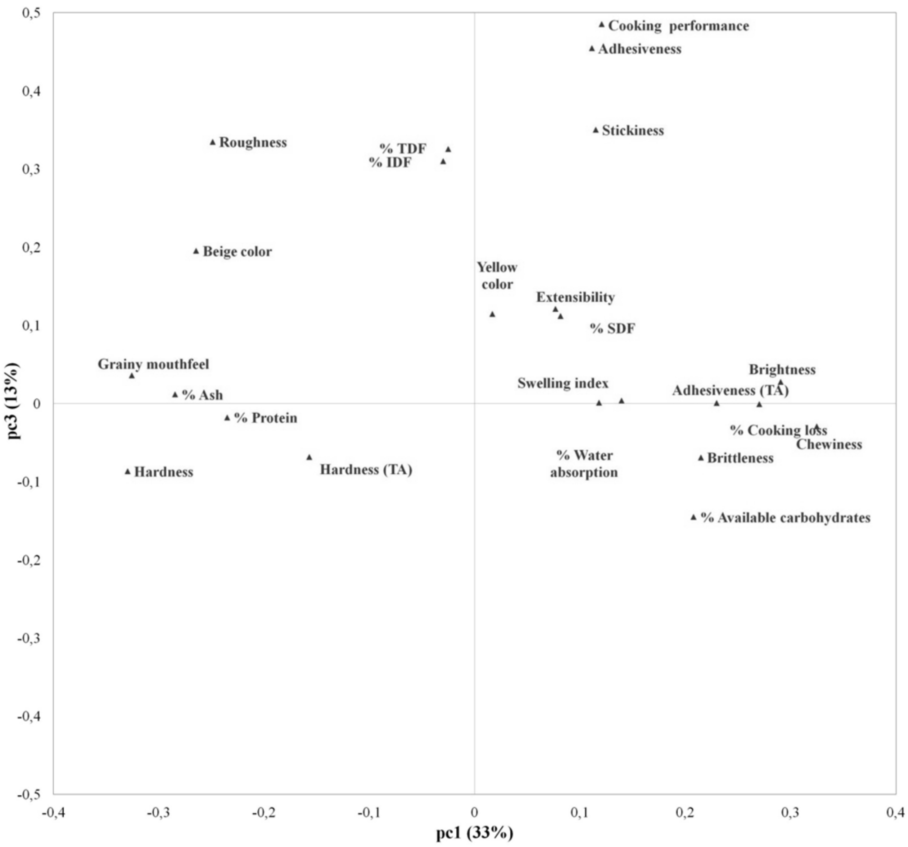

Figure 3.8b – Loadings plot of first and third main components.

3.4. Conclusions

Instrumental and sensory analysis results showed that raw material and drying treatment might affect pasta characteristics and both sensory evaluation and physico-chemical methods were very sensitive to change in product quality. Samples obtained from different semolina were significantly different from each other regarding all physico-chemical variables measured, while drying treatments showed significant differences for only five parameters estimated (% protein, % available carbohydrate, % insoluble fiber, % soluble fiber and % total fiber). According to physico-chemical data, sensory evaluation showed a large number of significant differences in pasta as regards semolina. Samples significantly differed for all sensory attributes evaluated, except for pasta aroma and flavour. It was demonstrated that raw material characteristics were critical factors in determining product quality and acceptability. Sensory data showed that samples were significantly different as regards drying only for stickiness and beige color. According to previous studies, VHT dried pasta showed a stronger gluten network which results in a lower release of amylose through the surface, and in a less sticky pasta (Petitot et al., 2009). Regarding beige color, high temperature drying caused non enzymatic browning; a development of maillard reaction compounds during pasta drying induced browning (Anese et al., 1999). Globally, PCA, showed that samples from commercial mixes were very similar to each other, while samples from semolina Cappelli (oldest cultivar considered) was very different from all the others. According to Del Nobile et al., (2005), protein content was positively related with hardness and negatively with stickiness measured with both sensory and instrumental methods.

3.5. References

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4. II Study Case: Effect of innovative cooking methods on pasta properties

Abstract

Pasta is a traditional Italian cereal-based food, popular worldwide, thanks its convenience, versatility, sensory and nutritional value. Cooking quality of durum wheat pasta is influenced by the transformation of protein and starch fraction during cooking. Protein coagulation and starch gelatinization phenomena, and, consequently the overall cooking quality of the final product are greatly affected by the native properties of raw material and by all the pasta production steps ending with the cooking step; pasta of good quality can be poor if the cooking operation is performed incorrectly. Cooked pasta should be firm, with no stickiness and clumpiness. To achieve the best results, pasta should be cooked until the white center of ungelatinized starch has just disappeared and must be immediately drained. The aim of this study was to evaluate the cooking quality of pasta cooked through innovative cooking methods; passive cooking (PC) and microwave cooking (MWC) quality of pasta were evaluated by means of sensory, physical and structural analysis by using traditional cooking (TRC) as reference. Four different hollow shapes coming from the same production lot were used. The differences between the shapes were only the length of the sample, and the cutting angle of the knife placed on the surface of the die.

The characteristics of pasta varied significantly as a function of the cooking technique used. Microwave and Passive cooked pasta resulted in cooking kinetics, physico-chemical and microstructural modifications different from traditional cooking. The sensory results suggested the possibility to use MWC as a faster alternative to traditional cooking without sacrificing pasta quality.

4.1. Introduction

Pasta is a traditional cereal based food whose origins date back to the first century, well known and accepted by consumers around the world for its ease of transportation, handling, cooking and storage properties (Tudoricá et al. 2002; Aravid et al., 2011).The structure of cooked pasta is commonly described as a compact matrix, with the starch granules trapped in the gluten network formed by wheat protein; precisely this structure gives to pasta the peculiar sensory and nutritional properties, and its formation relates to the characteristics of raw material and to all subsequent production steps (Scanlon et al. 2005; Kristensen et al., 2010). The sensory quality of pasta relates to several textural characteristics determined mainly by its behavior during cooking process. Ideally, cooked pasta should be of “al dente” quality. It is resilient, firm, with no surface stickiness and low cooking losses (Troccoli et al. 2000; Wood et al. 2001; Sissons et al.2005). Pasta cooking is such an important step in pasta processing; dried pasta of high quality may result in poor quality cooked pasta by a wrong cooking process (Menger 1979). Traditionally, pasta is cooked in an excess of water (pasta:water ratio 1:10) at boiling temperature for different time depending on the desired texture of the final product (Edwards et al.1993). Final pasta quality is mainly determined by the physical competition between coagulation of proteins in a continuous network and starch swelling with exudate losses during cooking process (Brennan and Tudorica, 2007). Starch and proteins transformations are in the same range of temperature and moisture conditions (proteins react at a little lower moisture level); both components are competing for water and the swelling of starch granules is antagonistic to the formation of protein network during cooking step. When protein network is not strong and elastic, the starch swells and gelatinizes before protein coagulation; amylose goes mainly in cooking water and amylopectin fragments move to the pasta surface reducing pasta cooking quality. On the contrary, when protein interactions prevail, starch granules, which hydrates slowly, are trapped within the protein network and the resulting cooked pasta will be firm with no stickiness and clumpiness (De Noni et al., 2010).

The protein and gluten content was reported as the main factor which determine pasta cooking quality (Feillet and Dexter 1996; Marti et al., 2013; Ruyman Nazco et al., 2014), due to their restrictive role in starch gelatinization, but the latter itself plays an important role in determining pasta cooking quality (Yue et al.1999; Güler et al. 2002) due to its interactions with other semolina components (Delcour et al. 2000).

With the aim to reduce the preparation time, costs and/or facilitate the cooking operation is growing interest in alternative cooking methods (Sebban & Sebban 2004; Fukuyama 2005; Cocci et al. 2008). The qualities of microwave cooked pasta products are affected by microwave cooking conditions including cooking time and the amount of microwave energy absorbed; however by modulating the cooking time it is possible to obtain microwave cooked pasta with values of weight increase and firmness, equal to traditional cooked pasta. By using a sensory panel of trained judges no differences were observed between traditionally cooked pasta and microwave cooked pasta, except for yellow color intensity (Cocci et al., 2008). In addition to the interest for microwave cooking (MWC), recently in Italy foodservice is experiencing a new cooking technique called passive cooking (PC). This alternative cooking method is performed similarly to traditional cooking (TRD), bringing a pot of water to boil and adding pasta, then after a preselected cooking time, turning off the burner and leaving cook pasta in hot water until reaching the optimal cooking time (OCT). No results were found in literature about this innovative cooking method.

We aimed to investigate cooking quality of microwave ad passive cooked pasta with the purpose to understand which may be the best (reducing time and /or energy) alternatives to traditional cooking (TRC). In this study the use of passive cooking process was carried turning off fire since zero cooking time, with the aim to better bring out the differences between passive and traditional cooked pasta.

4.2. Materials and methods

4.2.1. Pasta samples

Pasta samples used in this study were produced and provided by Pastificio Artigianale Leonessa (Cercola, Na, Italy). Four different hollow shapes coming from the same production lot were used. The differences between the shapes were only the length of the sample, and the cutting angle of the knife placed on the surface of the die. The four shapes used were: mezzanelli, ditalini, penne a candela and penne. The physical and chemical tests were conducted on mezzanelli (all shapes had the same features as the same production lot) while in the case of sensory analysis were used all the shape in order to have a satisfactory number of samples.

4.2.2. Cooking procedures

The optimum 1:10 pasta to water ratio was chosen according to Menger (1979).

4.2.2.1. Conventional

Fifty grams of pasta were cooked in a stainless steel pot using 500 ml of boiling tap water without adding salt. The pasta was cooked until the optimum cooking time and immediately drained for 30s just after cooking.

4.2.2.2. Microwave

Fifty grams of pasta were immersed in 500 ml of tap water at room temperature without salt. Pasta was cooked at 900 W in microwave oven (Sanyo,EM-s1000 China) until the optimum cooking time and immediately drained for 30 s just after cooking.

4.2.2.3. Passive

Fifty grams of pasta were immersed in a stainless steel pot using 500 ml of boiling tap water. After the immersion of pasta the burner was turned off and pasta was left cook until the OCT.

4.2.3. Determination of pasta cooking properties

4.2.3.1. Water absorption

During cooking, at regular time intervals up to the OCT, samples were withdraw from the pot, drained for 30 s and weighed. Water absorption was calculated as the percentage of weight increase (WI) of the weight before cooking.

4.2.3.2. Optimum Cooking Time

The optimumcooking time (OCT)was determined by compressing pasta between two glass slides in 30-s intervals. It was defined as the time at which the white center of ungelatinized starch had just disappeared, according to the approved method 66-50 (AACC 2000).

4.2.3.3. Cooking Loss

Cooking water collected from each pot was evaporated until constant weight in an air oven at 105°C. According to approved methods 16-50 cooking loss (AACC 1995), the residue was weighted and reported as percentage of the original pasta sample.

4.2.3.4. Thickness increase

Thickness increase was determined using a computer-assisted image analysis. High-resolution digital image of cooked pasta thickness were recorded using a Olympus SZ-PY microscope fitted with a 40x objective and an Olympus C-700Wide Zoom camera. Image were processed by Image tool software (Image Pro Plus 6.1 for Windows).

4.2.4. Microstructure

Small portions of each pasta samples were cut, fixed in 5% glutaraldehyde and sequentially embedded in alchool solutions of increasing concentration to ensure full dehydration. Samples were dried at the critical point and coated with gold particles. Microstructure was observed by means of Scanning Electron Microscopy (LEO EVO 40 SEM, Zeiss, Germany) with a 20 kV acceleration voltage and a magnification of × 1.500. The inner surface of mezzanelli cooked with the three different cooking methods was observed.

4.2.5. Texture analysis

Pasta samples were cut using an Instron Universal Testing Machine (Instron Ltd., Model 4467, High Wycombe, UK) equipped with a clamp and a blade. All the tests were performed at room temperature (25°C). The crosshead speed were set to 5mm/min and to 50mm/min with a strain level of 90% by using a load cell of 100N.The maximum stress required to cut the samples was evaluated.

4.2.6. Sensory evaluation

Sensory evaluation of pasta samples was performed by a panel consisted of thirteen judges, in the Sensory Laboratory of the Food Science and Agricultural Department, University of Naples - Federico II.
A modification of Flash Profile (FP) method (Dairou and Sieffermann 2002) was used to increase its rapidness, the interpretability of the result and products discrimination (Di Monaco *et al.* 2015).
The modified FP included two ideas on improvement of the classical FP approach. Firstly, a Napping followed by an Ultra-Flash Profile step was integrated to classical FP practice as a way to help assessors to focus on the differences and similarities among products as well as to focus on attributes that discriminated the samples. This Napping task was done during the attribute generation process. The second modification was that assessors were restricted to use maximum 10 relevant attributes during FP ranking, with the expectation that this would help the assessors focus on the core sensory differences between the samples and decrease the noise level in the data collected (Liu *et al*., submitted).
Four different pasta shapes were used from the same production lot in order to have a reasonable number of samples with the same OCT for each cooking methods. Two replications of the ranking procedure were performed in two different and sequential days.

4.2.7. Glycemic index

The evaluation of glycemic index was performed by using the procedure proposed by Kim and White (2012).

4.2.8. Data analysis

Both cooking procedures and sample analysis were conducted in triplicate. Experimental data were submitted to one-way analysis of variance (ANOVA) and multiple comparison averages test of Duncan (α= 0,05) (IBM SPSS Statistics v 20.0). Data from sensory evaluation were analyzed by Generalized Procrustes Analysis (GPA) and Multiple Factor Analysis (MFA) (XLstat Vers. 2014.5.03).

4.3. Results and Discussion

4.3.1. Water absorption

Water absorption versus cooking time,corresponding to the three cooking procedures, was reported in Figure 1 To better understand experimental results in Figure 2 was shown the temperature of the water during cooking phase. Under the conditions used for this study, during PC and TRC the water in the pot began to boil after 4 min of heating on the gas stove, for this reason in the case of PC and TRC pasta preparation time does not correspond to optimum cooking time; otherwise for MWC, OCT and pasta preparation time coincided.

Initially, cooking time less than 5 min, the kinetics of absorption of water is very similar for the three cooking methods. Then, with PC a decrease of water absorption rate was observed compared to the TRC. During pasta cooking the gelatinization front, an interface between a cooked and an uncooked layer, is moving from the outside surface into the center of the pasta. So, water absorption depends on water diffusivity trough the cooked layer and on the moving front velocity. Considering the water temperature (Fig. 2) it can be assumed that during PC both the water diffusivity and the moving front velocity decreased , lowering the water absorption kinetics and prolonging the OCT.

When a MWC was conducted, after about 6 min, water absorption rate exponentially increased up to the OCT. This specific behavior started when cooking water reached 100°C (Fig. 2). Unlike the conventional cooking method, microwave cooking generates heat inside the pasta; Cho et al.(2010) observed that the temperature of the cooking water and noodles increased simultaneously during MWC and that the edge of samples showed higher temperature than cooking water while during traditional cooking the samples had a lower temperature than water during cooking time. Microwaves reach the inner pasta layer affecting temperature profile inside the food material (Cocci et al. 2008). With the increase of temperature over the gelatinization temperature, water induced a glass-rubbery transition in pasta matrix and eventually the melting of starch crystals by lowering their melting temperature (Lelievre 1973, 1976). As a consequence, more water could penetrated into the matrix promoting the starch swelling. (Edwards et al.1993; Del Nobile et al. 2003).

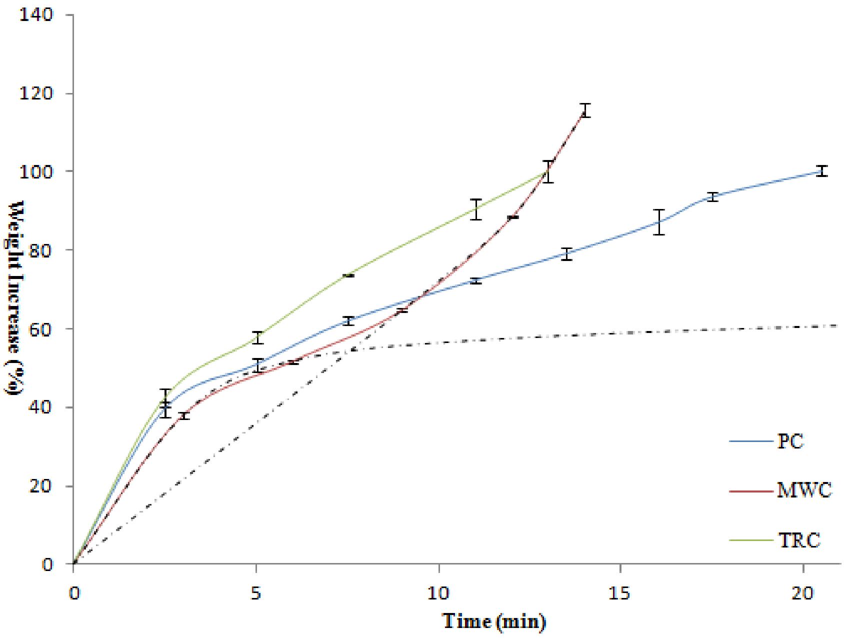

Figure 2. Pasta weight increase (%) of TRC, MWC,PC versus time (s). The dotted lines represent the trends of WI during MWC. Data are reported as means ± s.d.

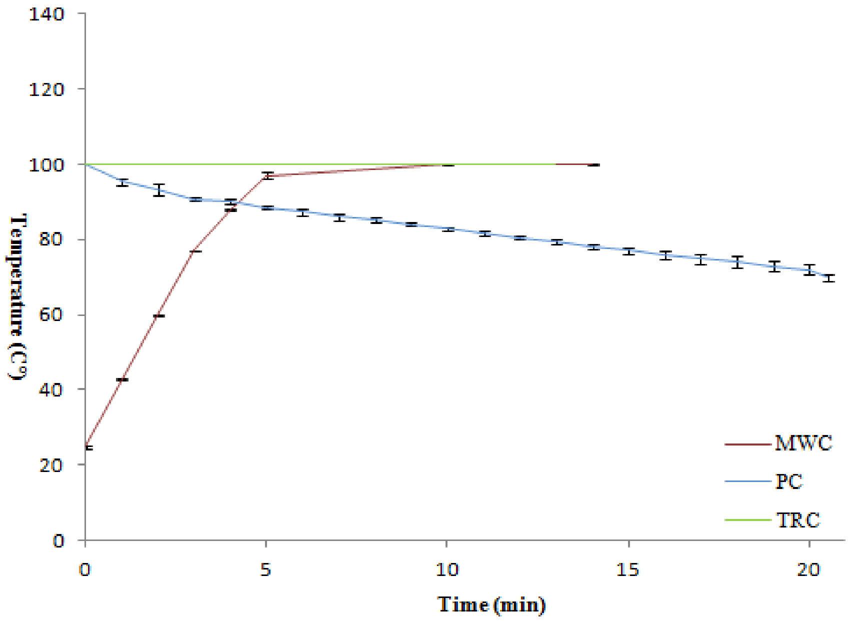

Fig. 3. Water temperature during microwave cooking (MWC) and passive cooking. Data are reported as means ± s.d.

4.3.2. Physico-chemical parameters

Table 1 summarizes the results of cooking properties corresponding to the used methods: optimum cooking time, total weight increase, cooking loss and thickness increase. The OCT varied from 13 min to 20.5 min depending on the cooking method. Considering that the time to boil the water was equal to 4 min, TRC presented a total time of preparation of 17 min, therefore, the faster cooking method was MWC. Indeed, although initial water temperature was 20°C, for MWC water absorption kinetics was faster reducing OCT. The difference of optimum cooking time between PC and TRC was justified by the water temperature reduction during the passive cooking. Although the temperature was always above the temperature of starch gelatinization there was a delay of 7:30 min to reach at OCT respect traditional cooking. This shown that the higher was the temperature more rapid was the absorption of water towards the center and less time was necessary to achieve the OCT. Probably as showed by Cho et al. (2010) the higher temperature who underwent the samples during microwave cooking could explain the unusual WI showed by MWC.

Cooking	Optimum Cooking Time (min)	Total Weight Increase (%)	Cooking loss (%)	Thickness increase (%)
Traditional	13	100,27°	3,45b	29°
Microwave	14	115 ,00b	4,88c	39b
Passive	20,5	100,09°	2,59a	54c

Table 1. Quality parameters of MWC, TRC, and PC cooked samples. Data with different letter within a column are statistically different at a p <0,05 level.

The highest total weight increase was recorded for the pasta microwave cooked, while between TRC and PC no difference was found (Tab.1). On the other hand, respect to the cooking loss all samples are significantly different. The lower cooking loss was observed in PC, followed by the TRC and finally by MWC with the highest value. This results could be attributed to the fact that the samples was subjected to different stress during cooking. During passive cooking the average temperature of water was lower than TRC and MWC, also samples was not subject to mechanical stress caused by boiling water flow; this could justify the lower coking loss. Concerning MWC probably the combined effect of pasta higher temperature, boiling water and microwave caused greater stress to the structure of the sample causing an increase in cooking loss.
Even concerning thickness increase there was significant different among the samples. The smaller increase in thickness was recorded by TRC (29%) followed by MWC (39%) and finally by PC (54%). These results were not only related to

the total water absorbed, higher for MWC and lower for PC, but also to the protein and starch transition that at lower temperatures will probably give rise to a different microstructure.
No significant difference was found concerning glycemic index in samples cooked through the three different cooking methods. The glycemic index values were respectively 65±3, 68±2,6 and 65±4 respectively for the MWC, TRC and PC
Table 2 reports the results of the cutting test, performed at 5 and 50 mm/min, of TRC, MWC and PC samples. A significant effect of cooking methods on maximum cutting stress was observed. At both crosshead speed TRC samples showed a higher cut resistance, followed by MWC samples and then by. PC samples.. As expected, increasing the crosshead speed the , maximum cut stress increases too.

Maximum stress (kgf)	TRC	MWC	PC
50mm/min	0,213a	0,156b	0,135c
5mm/min	0,139a	0,124b	0,077c

Table 2. Maximum cutting stress of TRC, MWC and PC pasta. Data with different letter within the same lines are statistically different at a $p < 0,05$ level.

The effect of cooking methods on cutting stress could be attributed to different structural changes that occur in both at the macro and microstructural level; there seemed to be an inverse relationship between the increase in thickness and the maximum cut stress. Probably the reason for this report was due to the fact that the different thickness increase, resulted in a decrease in the density of the samples; the greater was the thickness increase, the less resulted maximum shear stress.

4.3.3. Microstructure

Pasta cooked structure was the result of all the changes occurred during the making process, mainly affected by the protein and starch fractions (Petitot et al. 2009), and the cooking phase. The main phenomena involved during cooking are starch gelatinization and protein coagulation.
Generally along the thickness of the cooked pasta can be identified an external region, an intermediate region and a central region, concentric each other (Heneen et al.2003). In the outer region, starch granules are usually highly deformed, swollen and observing under SEM it is difficult to recognize them from proteins (Fardet et al.1998; Heneen et al.2003). Typically the intermediate and central regions are clearly distinguished from the external regions; intermediate region is characterized by partly swollen starch granules embedded in a dense protein network (Fardet et al.1998; Heneen et al.2003). while the centre of pasta show a low starch granules swelling with a lower degree of gelatinization, due to limited water absorption(Cunin et al. 1995).
In this study, cooked pasta was observed at the microscope distinguishing an inner region and an outer one. In Figure 3 were shown the micrographs of MWC, TRC and PC samples, from top to bottom respectively; the right side of the graph reported the outer region while the left side reported the inner region of the samples.
The inner part of MWC samples shows a more pronounced morphological modification of starch granules, that presented a shape of a flatted disk, also observed by Cocci et al. (2008), probably according with these authors this phenomenon was due to a greater degree of gelatinization of starch caused by the effect of the dielectric heating on the inner food polar molecules during microwave cooking (Cocci et al. 2008). In the outer region it is not possible to distinguish between starch granules and protein network, the structure is compact enough. Microwave application could induce an higher protein denaturation resulting in a more compact gluten network (Altan et al. 2004).Outer region TRC pasta appears with the typical honey comb-like network, observed also by other authors (Cocci et al. 2008). PC samples micrograph were the most similar each other. This showed that pasta could better preserve its original structure when was performed this type of cooking. Despite the cooking, in the external region of the sample were well visible the swollen starch granules, larger than those observed in all other micrographs. In both MWC and TRC external samples region were not well visible starch granules.

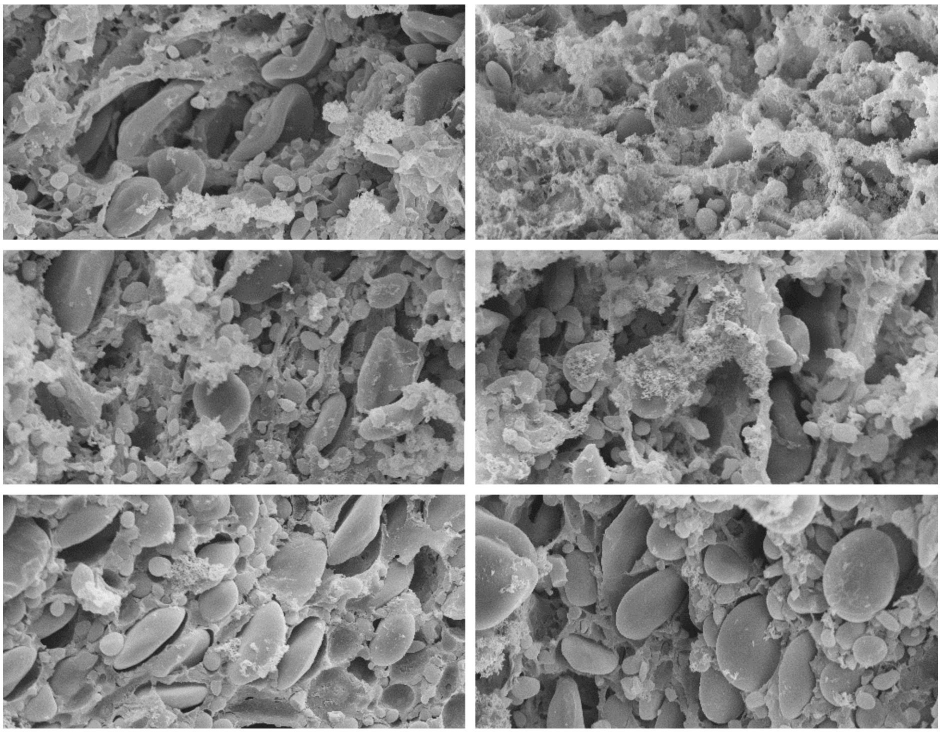

Figure 3. SEM micrographs of outer (right side) and inner (left side) surface of MWC, TRC and Pc pasta (from top to bottom respectively).

4.3.4. Sensory evaluation

In Napping and Flash Profile judges were expected to create their own attributes differently from conventional methods. The interpretation of sensory terms is not always easy due to the large number of the terms and the lack of the definition and evaluation procedure (Albert et al. 2011). For this reason, in this study assessors were first instructed to give a definition of their own attributes and secondly, they were limited to use not more than 10 attributes in the ranking procedure .

In FP each judge generated 5-7 attributes while during Napping used relatively more attributes 5-10. In this way the initial number of attributes generated by all the judges were reduced from 55 to 45. Similarly, the number of common attributes used by the judges was reduced from 20 to 13

In this study, two alternatives of FP and Napping data analyses were used: MFA and GPA. . The reproducibility of the judges was assessed by comparing the two replications of each judge. An increase in the variance explained was observed for both the GPA and MFA when five judges were eliminated, since they showed a low reproducibility with themselves. Since we had again a sufficiently high number of judges, it was decided to analyze the data without those judges in order to improve efficiency of the statistical analysis and thus the interpretation of data.

It was observed that GPA gave 83% of the explained variance whereas MFA gave 76% of the explained variance of the data set; thus, due to its high percentage of explained variance, GPA was selected as a treatment methodology of data analysis. Also, through GPA a consensus test was performed to check if the consensus configuration reflected a true consensus. This permutation test (Fig.4) allowed determining whether the observed Rc value (Rc corresponds to the proportion of the original variance explained by the consensus configuration) is significantly higher than 95% of the results that are obtained when permuting the data (XLSTAT, 2014). If the quartile is beyond the confidence interval, it can be concluded that GPA significantly reduced the variance. As it can be seen from the Figure 4, quartile value lies beyond Rc values appear as 0.5, showing that GPA reduced the variance and was suitable for data treatment.

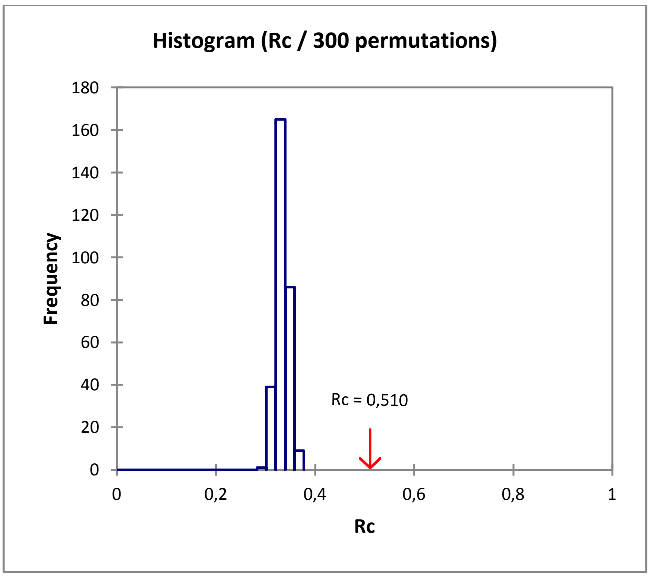

Figure 4. Permutation test of GPA.

Figure 5 showed the permutation test for each first three factors with the corresponding F value (ratio of the variance between the objects and between the configurations). To evaluate if a dimension contributed significantly to the quality of GPA, the quartile needed to be beyond the confidence interval. Observing the results it was possible to conclude that factor 1 and factor 2 could be considered as significant for GPA quality.

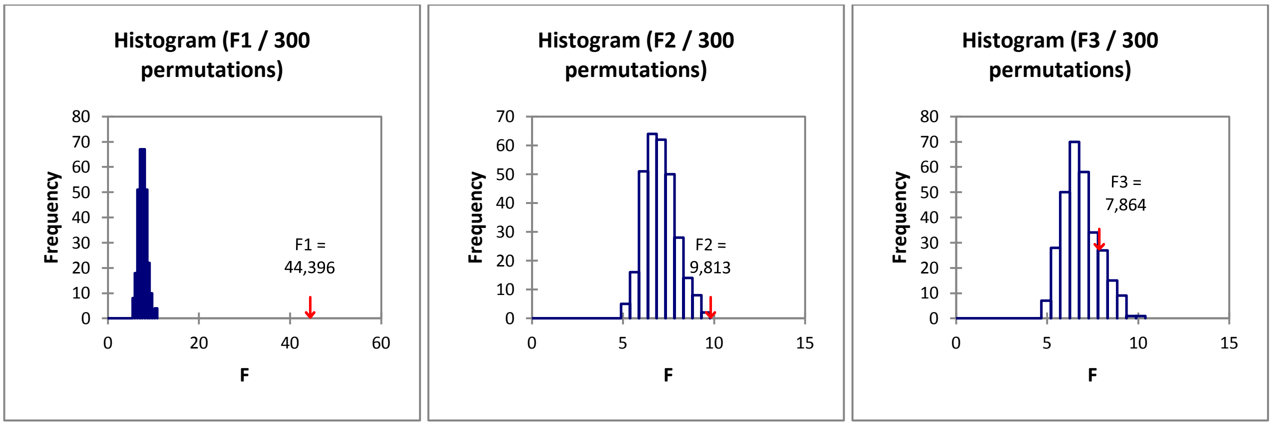

Figure 5 Permutation test for each first three factor.

In the figure below (Fig. 6), GPA consensus map of factor 1 and 2 was displayed. Samples were coded in an order to their shape (mezzanelli [MZ], ditalini [DT], penne a candela [PC] and pennette [PT]) and the cooking methods (microwave [W], passive [P], traditional [T]). In order to better visualize the clusters, samples treated with same cooking methods were linked by different styles of lines. It is possible to observe that samples with different cooking methods appeared in different parts along the x axis. PC samples were placed on the right side while MWC and TRC samples were in the left side. Thus it is possible to assume that PC samples were very different from TRC and MWC samples; instead the latter ones were quite similar to each other since they were located in closed areas on the plan. .
Although it was recommended to the judges do not use the shape of the samples in order to discriminate among them, the samples were placed along the y axis from the shortest to the longest ones.

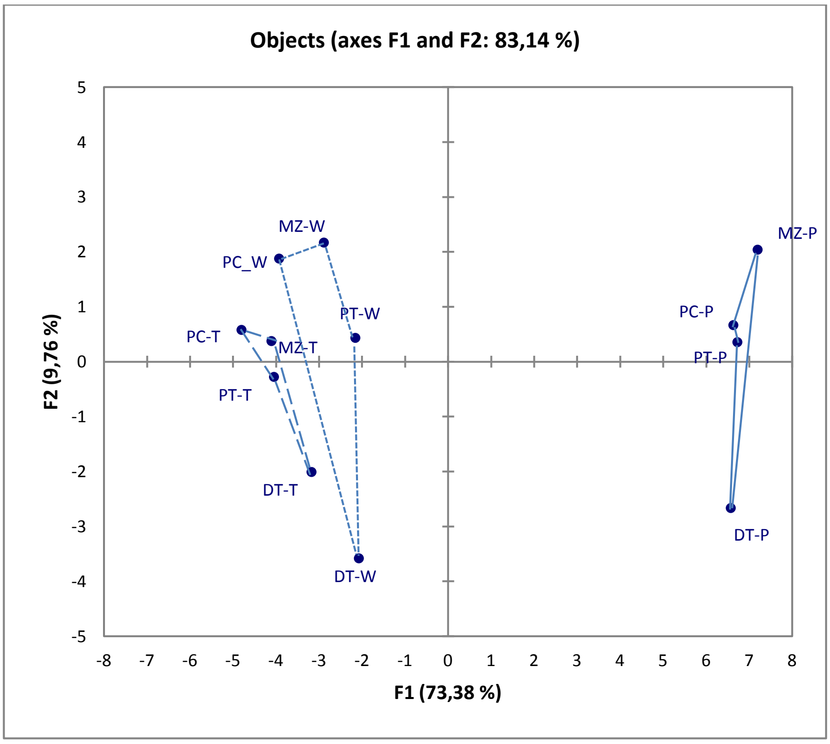

Figure 6. GPA samples consensus configuration.

The GPA configuration of individual attributes (Fig.7) showed that some attributes have a similar meaning for the different judges. Visible white core, stickiness and adhesiveness were concentrated in the first and fourth quadrant representing that PC samples were more characterized by those attributes. In the third and fourth quadrant, there is a high concentration of the attribute chewiness (4 of 5 total) and this probably explains why the shapes were oriented along the y axis; as more the samples were short the greater were their chewiness. Adhesiveness, visible white core, stickiness and hardness were the most used attributes by judges to discriminate the samples.

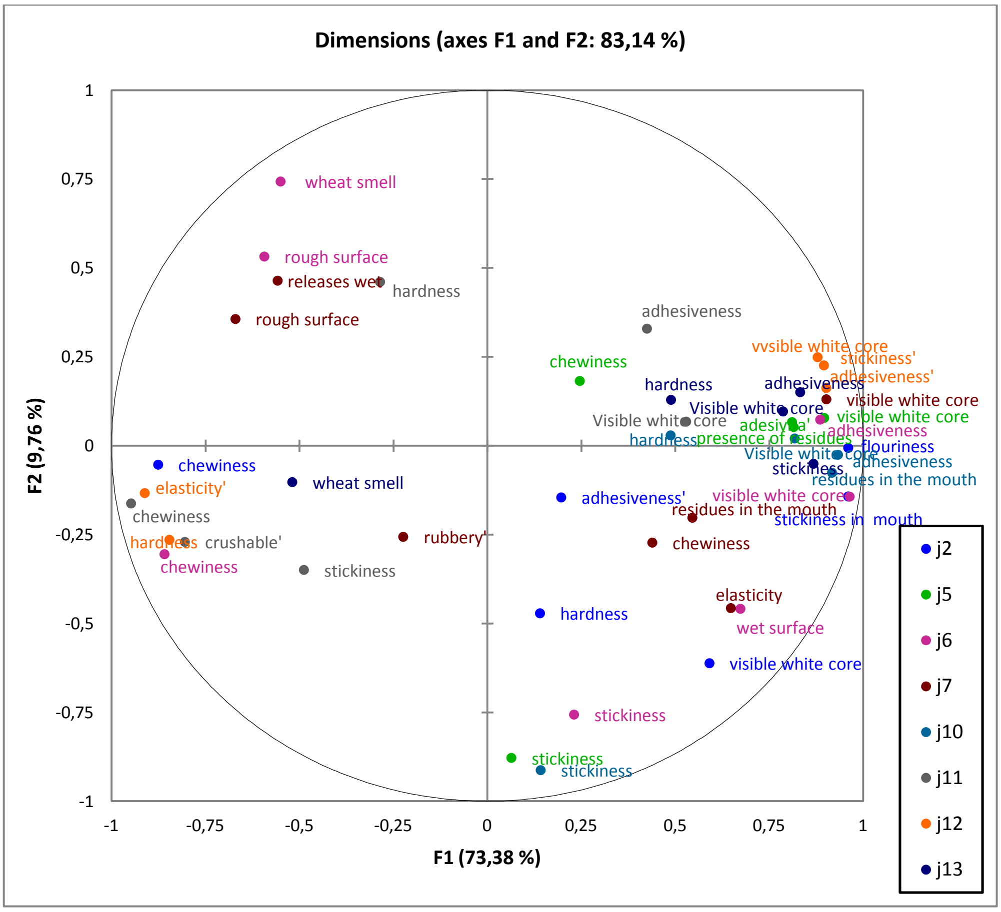

Figure 7. GPA configuration of individual attributes on the map.

4.4. Conclusion

Microwave and Passive cooking resulted in water absorption kinetics, physico-chemical and microstructural modifications different from traditional cooking. In particular, MWC resulted in a more compact gluten network in pasta outer layer, a higher total weight increase and cooking loss. No significant differences, between TRC and MWC, were founded for sensory attributes.. Considering that MWC can reduce preparation time, it could be regarded as a convenient cooking alternative to TRC one.

From the results obtained by PC is highlighted that this cooking method increases the preparation time and reduces the pasta cooked quality, from sensory point of view. Further studies should be conducted with respect to the use of the PC; increasing the cooking time in boiling water before to turn off the heat could allow to reduce the preparation time and to improve pasta quality . It would be interesting investigate different cooking times in boiling water with the aim to verify which pairs of times, boiling-water/cooling-water can eliminate the significant differences from the TRC in order find a save energy alternative.

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5. III Study Case: Effect of microwave drying operation and chickpea addition on pasta glycemic index.

Abstract

The low glycemic index of pasta can be related to its specific structure, and change in pasta structure can result to a change in its starch digestibility. Industrial production can modify pasta’s structure, influencing starch digestibility and protein hydrolysis. Drying temperature has been demonstrated that influences pasta *in vitro* pasta digestibility; low glycemic index diets improve glucose tolerance in human. However, there is a need of a more diversified range of low glycemic index foods. The object of this work was to investigate the effect of incorporation of chickpea flours as nutritional additives in pasta and evaluate the effect of chickpea flours and microwave drying on pasta starch fractions and glycemic index. A substitution of 20% chickpea flour was made with respect to the reference sample (100% semolina). Six pasta samples were prepared from 100% semolina, semolina (80%) and raw chickpea flour (20%), semolina (80%) and cooked chickpea flour; each sample was than subjected to traditional drying (40°C; 80% RH) and an optimized microwave drying. Results showed a significant effect of formulation on total starch (TS), resistant starch (RS) and glycemic index (GI) while the drying method showed no significant effect. The value of TS reported in reference samples was significantly higher to that observed in both, pasta with raw and cooked chickpea flour which did not differ significantly from each other. Glycemic index was lower in pasta added with chickpea flour than in semolina control pasta, reflecting the slow and low digestion of the starch in the leguminous ingredient. Highest percentage of resistant starch was observed in pasta with cooked chickpea flour probably due to the tendency of legume starch to recrystallize upon cooling, forming retrograded indigestible starches fractions.

5.1. Introduction

Pasta is a wheat-based food consumed in large quantities worldwide for its flavour, low cost and nutritional value. Durum wheat semolina (*Triticum turgidum* ssp. *durum*) is the preferred raw material for the production of good-quality pasta. In more recent years, pasta has become recognised as a healthy food, with low fat, no cholesterol and a low glycemic index (Cleary & Brennan, 2006). To improve nutritional quality and /or make special pastas some ingredient can be added to semolina (Padalino et al., 2014). Indeed, pasta is also used to carry nutraceutical substances (Chillo et al., 2008). In United States of America, pasta is enriched with vitamins and mineral. Other examples of materials added to pasta are wheat bran and other kind of fiber used for the purpose of increase dietary fiber content. A variety of non wheat and no cereal products have been used to low glycemic index (GI) or to improve cooking or textural quality of pasta. Both low-carbohydrate and slowly-digested carbohydrate food products are considered nutraceuticals (Osorio-Díaz et al., 2008) Several studies have indicated the possibility of adding legume flour to semolina in pasta preparation, even if the results are controversial relating to the effects of such additions on the sensory properties of pasta (Wood, 2009; Gallegos-Infante et al., 2010). Legumes are themselves low in fat rich in protein, with complex carbohydrates and minerals (Geil & Anderson, 1994). As such, legumes can be a simple system to obtain several goals: to improve the nutritional value of durum wheat pasta, to enhance the cultivation of typical crops of the Mediterranean area, and to increase the market supply of new food for consumers. The number of low-GI foods is very limited, and so a much wider range of low GI products will be required to make a well-balanced low GI diet practicable (Björck et al., 2000). Moreover, legume consumption is inversely associated with the risk of coronary heart disease (Bazzano et al., 2001), type II diabetes mellitus (Villegas et al., 2008) and obesity (Rizkalla et al., 2002). Due to the presence of a high portion of non-digestible carbohydrates, legume seeds generally promote a slow post-prandial blood glucose increase (Garcia-Alonsoet al., 1998; Bjorck et al., 2000). Among the legumes, chickpea does not have a prominent 'beany'flavour; for this reason it is a preferred ingredient for the improvement of pasta nutritional value. Goni and Valentın-Gamazo (2003) showed that pasta with 25% chickpea flour has a lower glycemic index respect to durum wheat pasta; several studies have also shown that the thermal processing of legumes (soaking, cooking and dehydration) can produce changes in their carbohydrate composition affecting starch fractions and pasta digestibility (Hoover & Ratnayake, 2002; Martin-Cabrejas et al., 2006; Aguilera et al., 2009). However, industrial production can modify pasta's structure, influencing starch digestibility and protein hydrolysis (De Zorzi et al., 2007; Petitot et al., 2009). The protein network is strictly related to the drying operation and influences the action of the proteolytic enzymes with the formation of highly-aggregated proteins linked by covalent bonds (De Zorzi et al., 2007; Petitot et al., 2009). When pasta drying temperatures exceed 90 °C, all SH-groups of glutenin can induce a covalent linkage with gliadin through a heat-induced SH-SS exchange mechanism catalyzed by SH-groups (Lagrain et al., 2006). A more compact structure of the pasta with starch granules trapped in a strong protein network can reduce or delay access by amylolytic enzymes, thereby delaying starch digestion (Fardet et al., 1999). On the other hand conventional air drying (especially high temperatures) can cause serious damage to flavor, color and nutrients and can reduce rehydration capacity of dried pasta. The desire to eliminate these problems, to prevent significant quality loss and to achieve fast thermal processing, today result in the increasing use of microwaves for food dried (Altan et al., 2005). Microwave drying has gained popularity in recent years as alternative drying method for a wide variety of food products such as vegetables (Sharma & Parasad, 2001),fruits (Maskan, 2000; Maskan, 2001), snack foods, and pasta (Berteli & Marsaioli Jr., 2005; Goksuet al., 2005). Physical and texture properties of pasta dried with combined hot air/microwave resulted equal or better than that conventionally dried (Altan & Maskan, 2004). Generally, an increase in pasta firmness and a reduced cooking loss is observed with microwave application. The aim of this study was evaluate the influence of chickpea flour and microwave drying operation on starch digestibility and glycemic index of composite legume-wheat pasta. An optimization of pasta microwave drying was necessary. A substitution of 20% of chickpea flour was performed in two pasta samples by using pasta from 100% durum wheat semolina as a reference. Raw chickpea flour and cooked chickpea flour were used for replace semolina with the objective to evaluate also the effect of the different formulations on pasta starch digestibility and glycemic index.

5.2. Materials and methods

5.2.1. Chemical composition of chickpea and durum wheat semolina

Semolina was gratefully donated by Italpasta (Puebla, Mexico) while chickpea was purchased in a local supermarked. Chemical proximal characteristics as indicated in the data sheets were:

- Semolina: water, 10.5 g/100g; protein, 11.5 g/100g; carbohydrates, 73.1 g/100g, ashes, 0.83 g/100g; lipids, 0.47 g/100g, fiber: 3.6 g/100g.
- Chickpea: water, 10.4 g/100g; protein 19 g/100g; carbohydrates 47 g/100g; ashes, 2 g/100g; lipids, 6 g/100g; fiber, 15.5 g/100g.

5.2.2. Samples preparation

Three different pasta doughs were produced A, B and C. The control dough (A) was prepared from durum wheat semolina and water; B and C were produced with the substitution of chickpea flours (20%). Dough B and C were prepared with raw chickpea flour and cooked chickpea flour respectively. Raw chickpea flour was obtained by milling chickpeas in a domestic food processor (Moulinex, AR6838, México, DF) and sieving (0,180 mm mesh). For the production of cooked chickpea flour, chickpeas were cleaned and cooked, with a water ratio of 1:4 for 120 min. For each formulation, semolina, chickpea flours and different amount of water were mixed using a domestic blender (Kitchen Aid, Mod K5SSWH) for 15 min, to obtain homogeneous dough. The dough was than laminated (thickness 1.7 mm) and cut in a pasta machine (Multipast 98-087, Italy) in tagliatelle shape. Different preliminary water-raw material ratios was tested to obtain the base formulation of the 3 different doughs and thus were selected as a function of the characteristics performed in kneading, lamination and workability. Two drying operation were performed: traditional drying and microwave drying. Traditional drying operation was carried out in a pilot plant drying (Yautepec, Mexico) using process parameters previously optimized (40°C; 80% RH). The drying cycle was conducted on 100 g of fresh pasta until the samples reached at moisture level of 11 (g/100g). Microwave drying was performed by a SHARP R-530ES Household Microwave. To meet the best conditions for microwave drying was necessary the process optimization by using the response surface methodology; for this experimental central composite design (CCD) through Design-Expert software (version 7.1.5, State - Ease Corporation, Minneapolis) was performed.

5.2.3. Experimental design

The CCD is used to study the effects of independent variables on their responses and subsequently in the optimization studies. This method is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with minimum number of experiments as well as to analyze the interaction between the parameters. In order to determine the existence of a relationship between the factors and response variables, the collected data were analyzed in a statistical manner, using regression. A regression design is normally employed to model a response as a mathematical function (either known or empirical) of a few continuous factors and good model parameter estimates are desired (Saravanan et al., 2013).
Were selected as independent variables microwave power and treatment time, for which the selection was based on preliminary experimental tests. The ranges of the independent variables are shown in Table 1. The response variables evaluated were: temperature, relative humidity and brightness at the end of microwave drying process.

Variables		Level		
		-1	0	1
Microwave power (Watts)	X_1	0	120	240
Time (Min)	X_2	20	30	40

Table 1. Independent variables and experimental design levels for pasta dried by microwave.

According to the CCD, the total number of experimental combinations is $2^k + 2k + n0$, where k is the number of independent variables and n0 the number of repetitions of the experiments at the centre point. The experimental design was performed with two independent variables at three levels and five replications of the central point getting 13 runs (Montgomery, 2006).
Two of the thirteen races were not taken into account for the response surface study because we could not obtain the necessary conditions for its realization. The arrangement of CCD as shown in Table 2 was in such a way that allows the development of the appropriate empirical equations (second order polynomial multiple regression equations) (Mason et al., 2003): y = β0 + β1x1 + β2x2 + β11x21+β22x22+ β12x1x2 .

Run	Power (watts)	Time (min)
1	240	40
2	120	30
3	120	16
4	0	40
5	240	20
6	0	20
7	120	30
8	120	30
9	120	30
10	120	45
11	120	30

Table 2. Arrangement of the CCD for the three two variables used in the present study

5.2.4. Total starch

The procedure followed for the determination of Total Starch (TS) has been reported previously (Goñi et al., 1997). Briefly, s Arrangement of the CCD for the three two variables used in the present study amples (50 mg) were dispersed in 2 M KOH to hydrolyze the starch and samples were incubated (60 °C, 45 min, pH: 4.75) with amyloglucosidase (102 857, Roche Diagnostics, S.L. Barcelona, Spain). Starch was measured as glucose with Peridochrom Glucose GOD-PAP (676 543, Roche Diagnostics, S.L. Barcelona, Spain). The glucose content was determined and the starch was calculated as glucose (mg) x0.9.

5.2.5. Resistant starch and available starch

Resistant starch (RS) was measured following the procedure of Goñi et al. (1997). Briefly, protein and digestible starch were removed after treating with pepsin (Merck7190, Darmstadt, Germany; 40 °C, 1 h, pH 1.5), and a-amylase (Sigma A-3176, Madrid, Spain; 37 °C, 16 h, pH 6.9), respectively. After centrifugation, residues were dispersed with 2 M KOH to dissolve RS, incubated with amyloglucosidase and glucose was quantified spectrophotometrically using the GOD-PAP reagent (676543, Roche Diagnostics, Barcelona, Spain). RS was calculated as glucose x 0.9.
Available starch was calculated as the difference between total starch and resistant starch.

5.2.6. Glycemic index

The in vitro rate of hydrolysis was measured using hog pancreatic α-amylase according to Holm et al., (1985) with minor modifications. A 50 mL of phosphate buffer (pH 6.9) were added to a portion of each sample containing 500 mg of available starch. Samples were incubated at 37 °C in a shaking water bath. In the first 5 min, before the addition of enzyme, aliquots of 0.2 mL of each sample were taken to mark as time zero. After an interval of 1 min, 1 mL of a solution containing 40 mg of porcine pancreatic α-amylase (A-3176, Sigma Chemical Co.) in 1 mL of phosphate buffer was added to each sample. Samples (0.2 mL) were withdrawn after 15 min and every 15 min for 90 min. These samples were added to tubes than containing 0.8 mL distilled water and 1 mL of 3, 5 dinitrosalicylic acid (DNS). Samples were incubated at 100 °C in water bath for 10 min. Then 15 mL of distilled water was added to each tube and mixed well. The reducing sugars released were measured at 530 nm in parallel with a standard curve of maltose. The rate of hydrolysis was expressed as the percentage of starch hydrolyzed with respect to dry matter at different times.
The predicted glycemic index (pGI) was calculated from percentage of starch hydrolyzed at 90 min (H90) values using the formula proposed by Goñi et al., (1997): $pGI = 39.21 + 0.803 (H90)$ ($r = 0.909$, $p \leq 0.05$).

5.2.7. Moisture determination

To determine samples final moisture was employed a thermobalance (Ohaus MB45) programmed to a temperature of 90°C with an amount of initial sample of 5g. It was performed in triplicate.

5.2.8. Optimum Cooking Time

The optimal cooking time was determined by compressing pasta between two glass slides in 30-s intervals. The optimum cooking time (OCT) point was reached when the white center of ungelatinized starch had just disappeared according to the approved method 16-50 cooking time (AACC 1995).

5.2.9. Temperature determination

Temperature was a response variable considered in the optimization of microwave drying. Temperature of pasta sample was recorded immediately at the end of microwave drying treatment, with a digital infrared thermometer (SI Raynger Noncontact thermometer). 3 readings were taken to obtain an average of the temperature reached at the end of the dehydration process.

5.2.10. Color measurements

Color measurements were a response variables considered in the optimization of microwave drying. Color measurements of microwave dried sample were taken in triplicate using a colorimeter (DR-10, Konica Minolta). The variable evaluated was L = brightness.

5.2.11. Data analysis

Samples analyses were conducted in triplicate. Experimental data were subjected to analysis of variance (ANOVA) and multiple comparison averages test of Duncan ($p < 0.05$) to evaluate the effect of drying treatment and formulation on glycemic index of pasta.

5.3. Results and discussion

5.3.1. Optimal doughs formulation

For the selection of sample A suitable formulation, different experiments were conducted with a constant base of semolina (200g) and a variable amount of water. In Table 3, were represented the results of these experiments according to an estimate scale where a higher number of crossings correspond to a higher product quality each process.

Mix	Semolina (g)	Water (g)	Kneading	Lamination	Workability
1	200	79	++	++	++
2	200	82	+++++	+++++	+++++
3	200	84	++++	++++	++++
4	200	86	++++	++	++

Table 3. Quality assessment of different pasta formulations.

The mix number 2 resulted in the highest quality and best features during kneading, lamination and molding; dough with better workability and consistency was obtained (Fig. 1).

Figure 1. Laminated dough from mix 2.

As shown in Figure 2, mix 1 presented problems in dough kneading and rolling due to insufficient hydration of semolina.

Figure 2. Laminated dough from mix 1

On the other hand the dough from mix 3 generally provided an acceptable product quality of each phase, but it pasted in the rollers during lamination. The dough from mix 4 instead stretched excessively, was too chewy and sticky.
In the same way were obtained the best formulations for sample B and C. The results are shown in table 4.

Mix	Semolina (g)	Water (g)	Chickpeas floor g	Cooked Chickpeas floor g
A	200	82	-	-
B	160	79	40	-
C	160	84	-	40

Table 4. Best formulation for pasta doughs.

5.3.2. Conventional drying

Pasta from dough A reached at a moisture content of 11±0,2 g/100g in 3 hours; sample B reached to the same moisture content in 200 min, while sample C needed 222 min. Pasta from sample B needed more time to react to final moisture level compared to the reference (A) despite dough B initial moisture was lower. Similarly the samples C needed 23.33% drying time more than reference sample in spite had only 1% more water. This could be probably to the formation of different structure when chickpea flour was added, causing a slower migration of water within the product and extending drying times.

5.3.3. Microwave drying

By statistical analysis were obtained the equation describing the effect of independent variables on response variables, likewise their response surface graphs were generated. Each surface plot was generated as a function of two independent variables. The independent variables were located in the X and Y axes, while the response variable was located on the Z axis.

5.3.3.1. Moisture response surface analysis

Experimental results of pasta moisture output varied in a range from 7.66 g/100g to 33 g/100g whereas the central points of design had an average value of 12.6 g/100g. To evaluate the responses obtained was selected the model that better fitted the experimental results and their correlation coefficient. With a coefficient of determination (R^2) of 0.998 a quadratic model was selected for data fitting. The mathematical model describing the effects of Power (watt) and Time (min) on pasta output moisture was shown in equation 1.

Equation 1

$M = 12.604 - 9.475P – 3.76t + 0.895Pt + 6.193P^2 - 1.708t2$

Where M is pasta output moisture (g/100g), P is the microwaves power (Watts) and t is drying time (minutes).
In Figure 3 the output relative humidity surface analysis is shown as a function of power and treatment time.

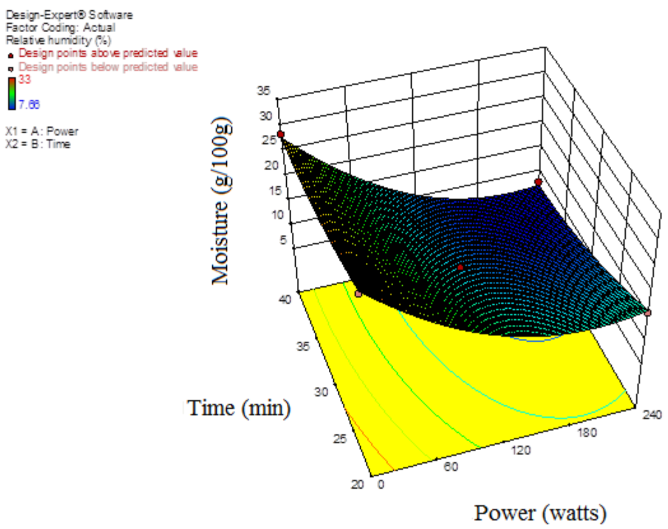

Figure 3. Output moisture response surface analysis as a function of power and time.

The treatment time and microwaves power had a big and negative effect on final moisture. In particular the lowest moisture was obtained at the highest treatment time and microwaves power. As expected, in order to obtain samples more dried, longest processing times and highest microwaves power were required. By using microwave is possible to achieve an higher moisture reduction in drying process, thanks to an higher yield (%) and a more uniform transmission of energy inside the food with respect to a convective drying (Miranda et al., 2002). The food water molecules undergo to an ionic polarization caused by microwaves. The resulting motion and friction produce heat that is transferred to the surrounding molecules. The free water begins to evaporate from the inside, causing a vapour pressure gradient that accelerates the dehydration (Bouraoui et al., 1993).

5.3.3.2. Temperature response surface analysis

Experimental results of pasta output temperature varied in a range from 19.13 to 67.3 ° C whereas the central points of design had an average value of 53.2°C. To evaluate the responses obtained was selected the model that better fitted the experimental results and their correlation coefficient. With a coefficient of determination (R^2) of 0.9698 a quadratic model was selected for data fitting. The mathematical model describing the effects of Power (Watt) and Time (min) on pasta output temperature was shown in equation 2.

Equation 2.

$$T = 53.182 + 20.3675P + 5.58874t + 3.5825Pt - 12.8335P^2 - 0.716t2$$

Where T is pasta output temperature (°C); P is the microwave power (Watts); and t is the drying time (minutes).
In Figure 4 the output temperature response surface analysis is shown as a function of power and time of treatment.

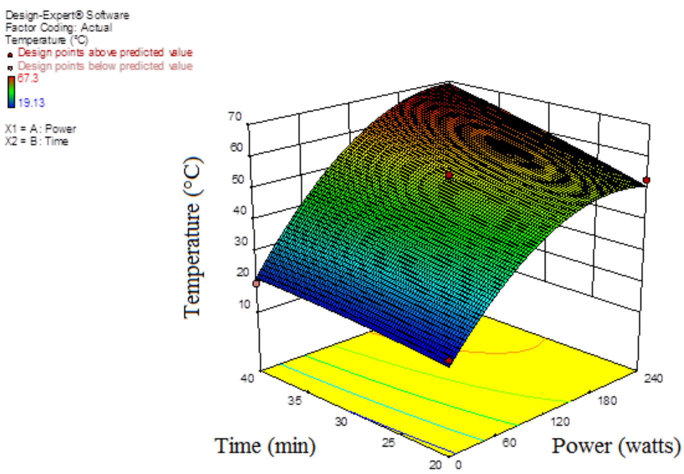

Figure 4. Temperature response surface analysis as a function of power and time of treatment.

Treatment time and microwaves power had a big and positive effect on final temperature. In particular the lowest moisture was obtained at the highest treatment time and microwaves power. As expected, in order to obtain lowest final temperature, lowest processing times and lowest microwaves power were required.

5.3.3.3. Brightness response surface analysis

Experimental results of pasta brightness “L” varied in a range from 69.3 to 73.05 whereas the central points of the design had an average value of 72. To evaluate the responses obtained was selected the model that better fitted the experimental results and their correlation coefficient. With a coefficient of determination (R^2) of 0.978 a quadratic model was selected for data fitting. The mathematical model describing the effects of Power (Watt) and Time (min) on pasta brightness was shown in equation 3.

Equation 3.

$L = 72.1355 + 1.7P - 0.4158t$

Where L is brightness, P is the microwave power (Watts) and t is drying time (minutes).
In Figure 5 pasta brightness is shown as a function of power and time of treatment.

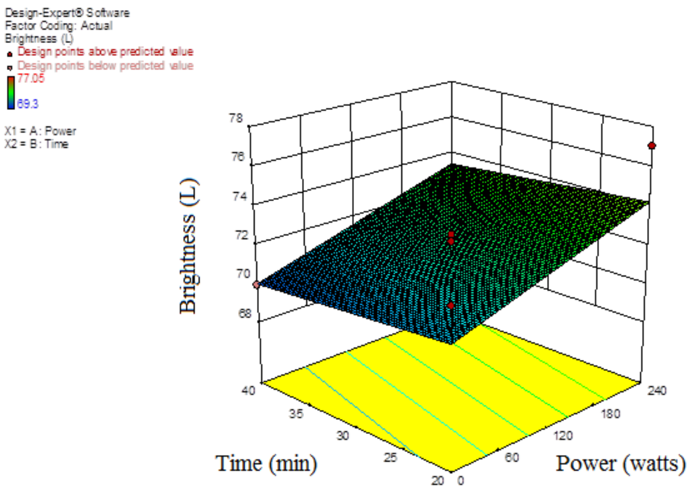

Figure 5. Brightness response surface analysis as a function of power and time of treatment.

The analysis shows that microwaves power had a big and positive effect on final brightness while the time of treatment not seems to have effect. As previously observed, microwaves power had a positive effect on pasta temperature that play an important role on final brightness. It was reported that spaghetti dried at high temperature showed a tendency to ‘browning’, reducing brightness; however, when the temperature was kept at or below 60 °C, the brownness was not greatly affected by time or humidity (Feillet et al., 2000).

5.3.4. Microwave drying optimization

Obtained the graphs and equations that express the relationship between the dependent variables with independent, a numerical optimization was performed with the support of Design-Expert software, which, from a set of criteria selected based on the observations of the researcher and statistical analysis, determined the most appropriate values of process variables to obtain the desired product combinations. It fell to the researcher to select the conditions that met the highest percentage of desirability and they were reproducible under their experimental constraints. The numerical optimization of drying process was performed using a restricted value ranges for independent and dependent variables as shown in Table 5.

Variable	Lower limit	Maximum limit
Power (Watts)	0	240
Time (Min)	20	40
Temperature output (°C)	45	65
Moisture (g/100g)	10	12.5
L	69.3	73.05

Table 5. Independent and dependent variables restrictions for numerical optimization of the drying process

From the statistical analysis models of response variables and limits corresponding restriction, were obtained 29 possible points of optimization as shown in Tab 6.

Number	Power	Time	Desirability
1	120.000	36.000	1.000
2	120.000	37.643	1.000
3	120.000	35.795	0.998
4	120.000	36.701	0.997
5	120.000	36.284	0.997
6	120.000	37.180	0.997
7	120.000	36.795	0.996
8	120.000	36.507	0.996
9	120.000	36.615	0.996
10	120.000	37.399	0.996
11	120.000	37.964	0.995
12	120.000	38.422	0.994
13	120.000	36.940	0.993
14	120.000	37.547	0.993
15	120.000	39.153	0.992
16	120.000	35.902	0.991
17	120.000	36.196	0.987
18	120.000	36.084	0.986
19	120.000	38.627	0.983
20	120.000	38.315	0.980
21	120.000	36.406	0.975
22	120.000	38.498	0.974
23	120.000	38.951	0.967
24	120.000	39.623	0.965
25	120.001	36.868	0.964
26	124.334	34.117	0.964
27	125.402	33.779	0.955
28	129.705	32.609	0.919
29	135.991	31.268	0.867

Table 6. Possible point of optimization suggested by software.

Between all possible solutions was chosen and validate the first point of optimization suggested as had the higher desirability and a low drying time. To validate the findings of the analysis were carried out three experimental tests to check the chosen solution. The results of the tests and then the average value of these were within the range of expected values with a confidence interval of 95% as shown in the Table 7; it was possible to conclude that was confirmed the predictive ability of the model; finally microwave drying was optimized with a time of 36 minutes and a power of 120 watts.

	Predicted			CI for Mean			
Response	**Mean**	**Median**	**StdDev**	**SE Mean**	**95% CI low**	**95% CI high**	**Observed**
Ur %	10.9643	10.9643	0.746	0.330028	10.1159	11.8126	10.91
L	71.8859	71.8859	1.783	0.657622	70.3694	73.4024	72.12
T °C	56.2775	56.2775	2.513	1.11186	53.4194	59.1356	56.3

Table 7. Predicted and observed results of the optimization point number 1

5.3.5. Optimum coking time

The optimum cooking times, determined by observation of disappearance of the white uncooked core in pasta samples, were 8 min for all samples dried by hot air and 9 min for those dried by microwaves. No differences in OCT were found between the different pasta formulations. According to the findings of De Pilli et al. (2009), pasta dried by microwave required a longer time to reach to OCT. The increase of cooking time of pasta dried by microwaves could be attributed to the delay of starch swelling and, subsequently, a longer time for gelatinization was required (De Pilli et al., 2009).

5.3.6. Total starch, resistant starch and predicted glycemic index.

Two-way ANOVA showed significant effects of formulation on total starch (p=0,022) , resistant starch (p=0.048) and GI (p=0.03); drying methods and interaction did not have any significant effect (p >0.05). Table 8 shows results of Duncan test of starch fractions and GI data as influenced by formulation. As can be seen from table 8 the highest percentage of TS was observed in sample produced exclusively from durum wheat semolina (A) in both drying conditions. The value of TS reported in sample A was significantly higher to that observed in samples B and C which did not differ significantly each other. This is due to the fact that adding chickpea flour to other samples increases the percentage of fiber and proteins in dough reducing carbohydrates percentage. Furthermore, the addition of flour chickpea resulted in a significant increase in (RS). An increased RS content should not be disregarded, considering the beneficial effects associated with the consumption of RS (Hallert et al., 2003). The highest percentage of resistant starch was observed in sample C; this could be due the presence of cooked chickpea floor. Cooked legume starches have a marked tendency to recrystallize upon cooling, forming retrograded indigestible fractions (Tovar et al., 1990; Peñalver et al., 2007) that is associated to dietary fiber residues (Saura-Calixto et al., 1993; Tovar, 2001).
Samples B and C GIs were found significantly lower than A. Predicted GIs of tagliatelle added with chickpea flour confirm that this type of pasta process production preserves the beneficial "slow digestion" features of legume starch (Würsch et al., 1986; Tovar et al., 1992; Velasco et al., 1997; Tovar et al., 2003). In addition to the intrinsic properties of legume starches, their cognate viscous dietary fibers have been suggested to slow down diffusion of amylolytic products to the absorptive mucosa (Würsch et al., 1986; Jenkins et al., 1987; Tovar, 1994; Björck et al., 1994), a possibility that might therefore decrease the diffusion rate of composite pasta starch digests. The combined action of these factors results in moderate glycemic responses, as suggested also for other products (Tovar et al., 2003; Sáyago-Ayerdi et al., 2005).

	Drying	A	B	C
Total starch	TRD	74,256b	71,216a	71,176a
	MW	74,096b	70,816a	71,386a
Resistant starch	TRD	2,684a	3,564b	4,104c
	MW	2,654a	3,444b	4,184c
Glycemic index	TRD	69,213b	59,705a	60,67a
	MW	69,424b	59,52a	60,662a

Table 8. Starch fractions and Glycemic Index response of pasta sample. Data with different letter within the same line are statistically different at a p <0.05 level.

5.4. Conclusions

It wasn’t finding any correlation between the drying method used and the values of starch fractions and glycemic index. Microwave drying has shown to be very efficient, regards to a shorter drying time and also because it is possible to have a final product without fissures. The addition of chickpea flour has shown positive effects by reducing glycemic index and increasing resistant starch. These results are in agreement with previous studies suggesting that pasta added with chickpea flour may be an alternative for people with special caloric or metabolic requirements.

Moreover, the addition of cooked chickpea floor significantly increased the content of RS suggesting a better alternative considering the beneficial effects associated with the consumption of RS.

It is recommended a more precise analysis of microwave drying methods considering costs and benefits respect to traditional drying method. Furthermore an assessment of pasta through sensory analysis could be conducted in order to verify the acceptability of the pasta enriched with chickpea flour compared to standard products.

5.5. References

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7. Appendix

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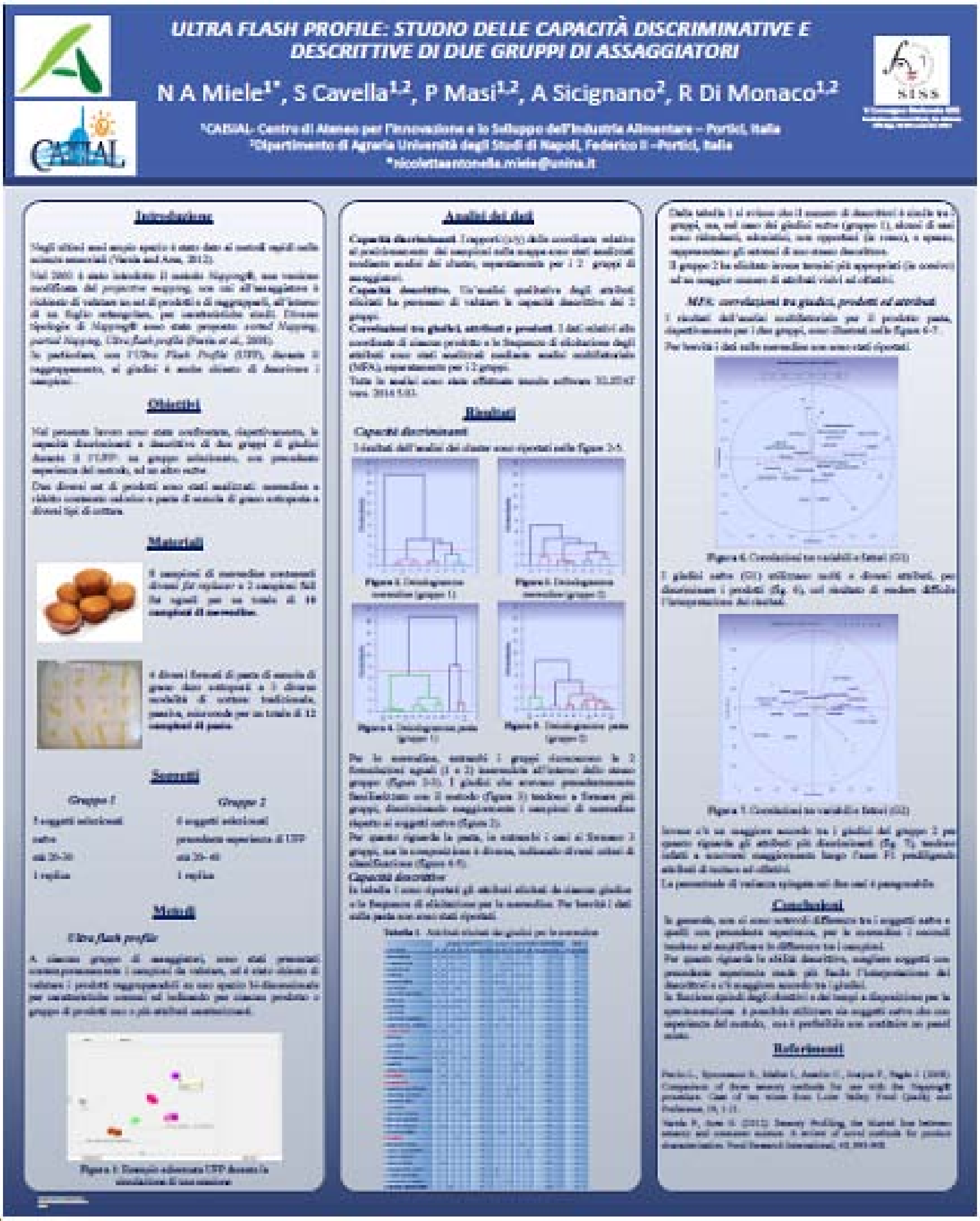
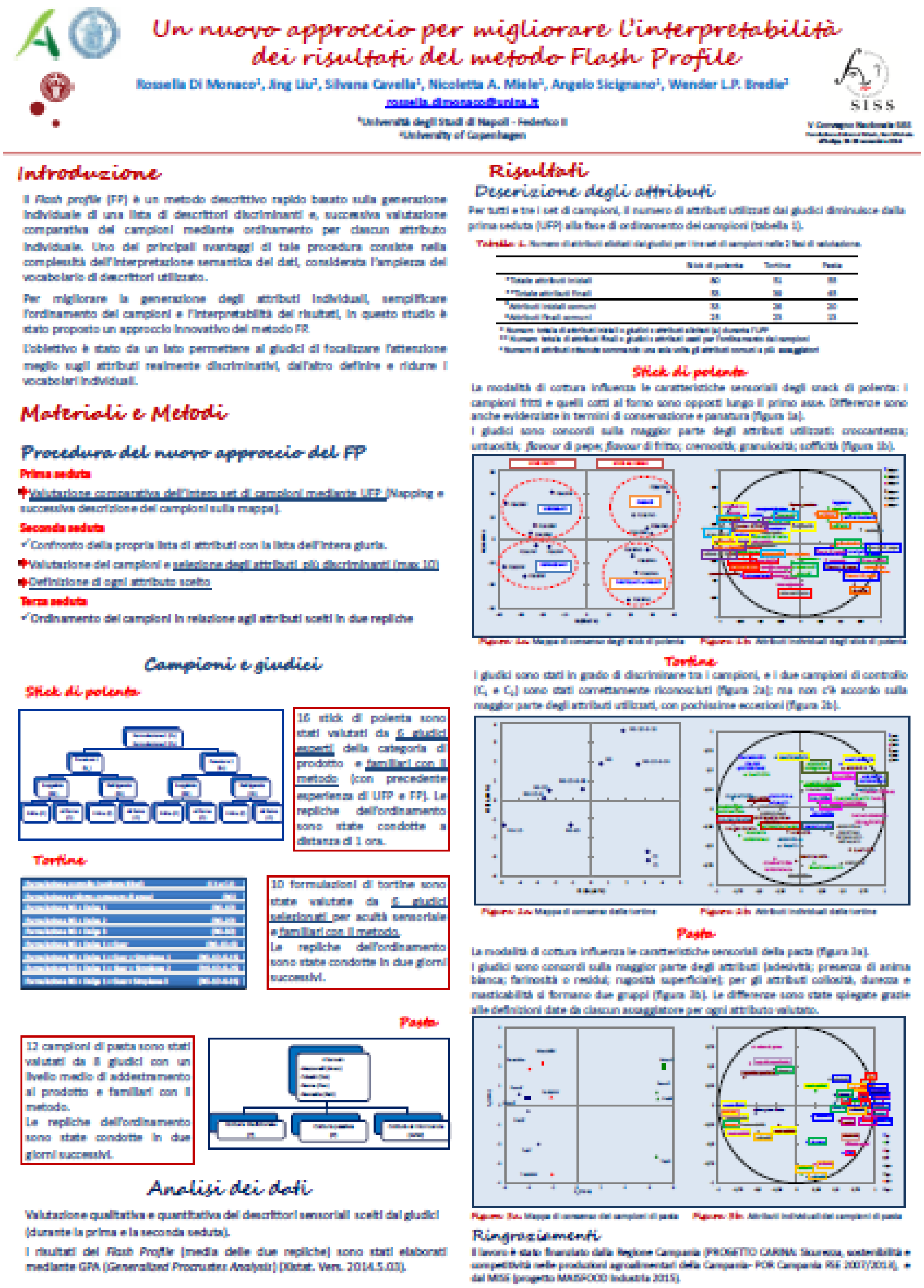


Di Monaco R., Liu J., Cavella S., Miele N. A., **Sicignano A**. & Wender L. P. Bredie. Un nuovo approccio per migliorare l'interpretabilità dei risultati del metodo Flash Profile. In: V Convegno Nazionale della Società Italiana di Scienze Sensoriali. In Press.



Sicignano A., Di Monaco R., Masi P. & Cavella S. From raw material to dish: pasta quality step by step. J. Sci Food Agric.In Press.

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