# Pasta from yellow lentils: how process affects starch features and pasta quality

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**Abstract:**

Thanks to their health-promoting features and high sustainability, pulses are an interesting alternative to both wheat-based and gluten-free products. In this study, the effects of two different pasta-making processes (conventional extrusion and extrusion-cooking) were investigated on 100% yellow lentil flour. Regardless of the type of extrusion, pasta showed good cooking quality, even in overcooking. Therefore, contrary to what is known for gluten-free cereals, the conventional pasta-making process is effective in producing pasta from native yellow lentils with no need for a pre-gelatinization step. However, pasta obtained using the extrusion-cooking process was characterized by better textural properties. In this sample, starch presented a higher degree of gelatinization and thus lower enthalpy. At the same time, extrusion-cooking promoted a more compact structure that required higher temperature for melting and showing pasting properties. In conclusion, by selecting suitable extrusion conditions it is possible to improve the cooking behavior of 100% pulse pasta.

**Keywords:** pulse; gluten-free; extrusion; pasta-making; starch; cooking quality

**Abbreviations:** HI, hydrolysis index; Pa_CV, pasta from conventional extrusion; Pa_EC, pasta from extrusion-cooking; Pe, pellets (intermediate products of extrusion-cooking); RS, resistant starch; YL, yellow lentil flour

## 1. Introduction

Pulses are viable food ingredients for multiple end-use applications thanks to their high nutritional value, sustainability, and cost-effectiveness. Indeed, they are an excellent source of protein (about 30% of lysine-rich proteins), resistant starch, dietary fiber, vitamins, minerals and bioactive compounds, such as phenols and γ-aminobutyric acid (Tiwari & Singh, 2012). Overall, pulses could help to prevent or manage chronic health issues such as diabetes, cardiovascular disease and obesity, thus contributing to human health and wellness (Basset et al., 2001). Besides the nutritional benefits, pulses are characterized by positive agronomic traits. They are excellent rotational crops by contributing nitrogen to the soil rather than extracting nitrogen from it; they are more drought and temperature tolerant than cereals. In addition, being resistant to several diseases and growing well in areas where weed pressure is low, pulses require low amounts of pesticide and herbicide (Best, 2013). However, pulses are still infrequently consumed, mainly in Western countries, due to several factors, including their long preparation times, presence of anti-nutritional compounds and indigestible oligosaccharides of the raffinose family sugars (i.e., raffinose, stachyose and verbascose) that might cause flatulence. In order to enhance their consumption, recently, various pulse-based products (i.e. bread, snacks, and pasta) have been developed (Bresciani & Marti, 2019). Among them, pasta has become a popular meal worldwide due to its long shelf-life, simplicity of preparation, low cost, as well as sensory and nutritional features, especially in relation to the medium-low glycemic index (Scazzina et al., 2016). In past decades, pulse-enriched pastawas proposed to enhance fiber and protein content, as well as to improve the amino acid balance of wheat (Petitot & Micard, 2010; Petitot et al., 2010).

Nowadays, the continued interest in gluten-free (GF) foods - as well as the need of enhancing their nutritional profile (Pellegrini et al., 2015) - has shifted attention to 100% pulse pasta formulation. Pulse pasta - especially from chickpeas or lentils - are gaining popularity. However, despite the interest in using pulses as the only ingredient to produce GF pasta that is high in protein, dietary fiber and resistant starch (Laleg et al., 2016), no studies are available on the related pasta-making process, especially in relation to the extrusion step. For this reason, this work focused on understanding the role of extrusion conditions (conventional extrusion *vs* extrusion-cooking) on starch properties and cooking behavior of pasta from 100% yellow lentils.

## 2. Materials and Methods

### 2.1 Pasta-making process

Flour from decorticated yellow lentils (YL; starch: 50% d.b.; proteins:23% d.b.; fiber: 5.5% d.b.) was processed into pasta by means of two approaches: conventional extrusion and extrusion-cooking (Figure 1). In the first approach, YL was mixed with water (30% final moisture content) and extruded in macaroni shape (with the length of 40 mm, inner diameter of 7 mm and wall thickness of 1.2 mm) using a continuous press for semolina pasta production (Braibanti, Milan, Italy). A jacket with cold water kept dough temperature at about 50 °C at an extrusion pressure of $10^7$ Pa. In the second process, YL and water (30% final moisture content) were treated with steam in an extruder-cooker (Braibanti, Milan, Italy) at 110 °C for 15 min then extruded (screw temperature: 130 °C) into small pellets (Pe; i.e., cylinder shape with diameter of 3 mm). A portion of Pe was dried at 45 °C for further analyses (see section 2.4, 2.5, 2.6, and 2.7); the rest was shaped into pasta (i.e., macaroni) by the conventional extrusion described above. All pasta samples were dried in an experimental drying cell (Fava S.p.A., Cento, Italy) using a low-temperature drying cycle (60 °C for 17 h). All samples were stored at room temperature until analyzed. For starch content and its susceptibility to α-amylase, starch gelatinization, thermal and pasting properties, pasta samples and pellets were ground (particle size less than 250 mm) using a laboratory mill (IKA Universalmühle M20; IKA Laborteknic, Staufen, Germany), with a water cooling system to avoid overheating.

### 2.2 Images of pasta and color measurement

Pasta images were acquired at 300 dots per inch with a digital scanner (Epson Perfection 550 Photo, Seiko Epson Corp., Suwa, Japan). The color of uncooked pasta was measured using a reflectance color meter (CR 210, Minolta Co., Osaka, Japan) to measure the lightness and saturation of the color intensity. Results were expressed in the CIE L* a* b* color space. Color difference (ΔE) was calculated as:

$$\Delta E=\sqrt{(L2-L1)^2+(a2-a1)^2+(b2-b1)^2}$$

## 2.3 Cooking quality

The cooking quality of pasta was assessed at both optimal cooking time and in overcooking. The former was evaluated by ten people tasting the product at different cooking times; the latter was considered as +25% compared with the optimal cooking time.

Pasta (25 g) was cooked in 250 ml of boiling distilled water (pasta:water ratio = 1:10). Pasta weight increase due to cooking was expressed as the ratio percentage between the weight increase and the weight of uncooked pasta. Cooking loss was evaluated by determining the amount of solids lost in cooking water according to the standard method AACC 66-50.01 (Cereals & Grains, 2011). After cooking, the level of water was brought to the initial volume. Solid loss was determined on 40 ml of cooking water, dried overnight to a constant weight at 105 °C. Results are expressed as grams of matter loss/100 g pasta dry basis. Texture properties of cooked pasta were determined by a compression-extrusion test using a texture analyzer (Z005, Zwick Roell, Ulm, Germany), equipped with a 10-blade Kramer cell and a 5 kN load cell. 25 g of pasta were cooked and then compressed and extruded with a 0.67 mm/s crosshead speed. Results are expressed as average values of firmness, i. e. the maximum compression force (N).

## 2.4 Gelatinized starch, resistant starch (RS) and starch hydrolysis index (HI)

The degree of gelatinized starch was measured in flours, pellets, and uncooked pasta samples through an enzymatic assay based on the enzymatic susceptibly of starch to the action of glucoamylase from *Aspergillus niger* (Optidex L-300, Genencor International s.r.l, US), as detailed by Di Paola et al. (2003). The degree of gelatinized starch was referred to the total starch content, the latter determined by the standard method AACC 76-13.01 (Cereals & Grains, 2011).

An enzyme assay kit (K-RSTAR 02/17, Megazyme International, Wicklow, Ireland; AOAC standard method 2002.02) was used for the quantification of RS in cooked to optimum pasta samples.

To measure the starch digestion potential of cooked pasta samples, a two-step static *in vitro* digestion was used (Giuberti et al., 2015). Briefly, the protocol includes a gastric (0.05 M HCl solution containing pepsin; Sigma P-7000, Sigma-Aldrich® Co., Milan, Italy) and a pancreatic phase (0.1 M sodium acetate buffer containing an enzyme mixture with an amylase activity of about 7000 U/ml) (Giuberti et al., 2015). After cooking, samples (5 g) were passed through a meat mincer to mimic mastication, inserted in glass tubes and immediately *in vitro* digested at 37°C for 30 min (gastric phase) and for further 180 min (pancreatic phase). Aliquots (2 ml) were carefully taken from each tube at 0 (prior to the pancreatic phase), 30, 60, 120 and 180 min after the pancreatic phase, then absolute ethanol was added and the amount of glucose was determined colorimetrically (GODPOD 4058, Giesse Diagnostic snc, Rome, Italy). The area under the hydrolysis curve (0-180 min) was measured and used to calculate the starch hydrolysis index (HI) with common white wheat bread as reference (Giuberti et al., 2015).

### 2.5 Damaged starch

Starch susceptibility to alpha-amylase was carried on flour, pellets, and uncooked pasta samples according to the standard method AACC 76-31.01 (Cereals & Grains, 2011). Results were referred to total starch content, determined by the standard method AACC 76-13.01 (Cereals & Grains, 2011).

### 2.6 Thermal properties

The thermal properties of flours, pellets, and uncooked pasta samples were studied through differential scanning calorimetry (DSC8000, Perkin Elmer Inc., USA). Samples were weighed into a steel pan, distilled water was added (1:3 w/w sample:water ratio) and the sealed pans were left at room temperature for 20 h. Then, samples were heated from 25 to 160 °C at a rate of 10 °C/min. The onset temperature ($T_0$), the peak temperature ($T_p$), the conclusion temperature ($T_c$) and the gelatinization enthalpy ($\Delta H$) were recorded using the software provided by the equipment.

### 2.7 Pasting properties

Pasting properties of flours, pellets and uncooked pasta were evaluated using a Micro Visco-Amylo-Graph, MVAG (Brabender GmbH., Duisburg, Germany). 12 grams of flour were dispersed in 100 ml of distilled water, scaling both sample and water weight on a 14% flour moisture basis. The suspensions were subjected to the following temperature profile: heating from 30 up to 95°C, holding at 95°C for 20 minutes and cooling from 95 to 30°C with a heat/cooling rate of 1.5°C/min. One representative curve for each sample was reported.

### 2.8 Statistics

Pasta color was determined on ten pieces of pasta, whereas data on water absorption, cooking loss, and texture come from five independent cooking trials. The degree of gelatinized starch, the RS content, the starch HI, and damaged starch, thermal and pasting properties were analysed in triplicate. The data was subjected to analysis of variance (ANOVA) to determine significant ($p < 0.05$) differences among the samples. ANOVA analysis was performed by utilizing Statgraphics Plus 5.1 (StatPoint Inc., Warrenton, VA, USA). When a factor effect was found to be significant ($p < 0.05$), significant differences among the respective averages were determined using Tukey's honest significant difference (HSD) test. For the comparison of two averages, in the case of cooking behavior analysis, statistical differences (t-test; two-tailed distribution) were evaluated using Statgraphics Plus 5.1 (Statpoint Inc., Warrenton, VA, USA). Differences at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***) were considered significant.

## 3. Results

### 3.1 Pasta color and cooking behavior

Images of dry pasta are shown in Figure 2, together with the color indices. The type of process did not affect pasta color but the b* value was higher in pasta from extrusion-cooking (Pa_EC) compared to pasta from conventional extrusion (Pa_CV), indicating a more yellow color. However, ΔE value suggests that the overall differences in color might not be perceived by the human eye (Fois et al., 2019).

As regards cooking behaviour, regardless of the type of extrusion, pasta samples exhibited similar optimal cooking time, water absorption, cooking loss and firmness (Table 1). Water absorption is an indicator of the water absorbed by the main pasta components during cooking, and utilized for the gelatinization of starch and hydration of proteins (Marti et al., 2015). Experimental pasta from YL showed lower water absorption compared to commercially available pulse pasta, that was above 100% (Turco et al., 2019). Cooking losses of YL pasta were similar to those reported for commercial pasta from either pulses (about 8 g/100 g and 17 g/100g for red lentil and pea pasta, respectively; Turco et al., 2019) or GF cereals/pseudocereals (about 6 g/100 g on average; Morreale et al., 2019), but higher compared to semolina pasta (generally lower than 4.5

g/100 g; Marti et al., 2017). As regards the texture, at the optimal cooking time the samples show significant differences only for compression energy which represents the total work done during the compression, shear, and extrusion of the pasta by the blades of the Kramer cell that simulate the chewing of the product (Table 1). This result is also confirmed in overcooking: Pa_EC showed significantly lower values for water absorption and higher values for firmness and compression energy.

### 3.2 Gelatinized starch, resistant starch and in vitro starch hydrolysis index

The type of process influenced the degree of the gelatinized starch in both the ingredients and in the final products, the latter analyzed in their uncooked state (Table 2). In particular, it follows the order YF < Pe < Pa_CV < Pa_EC. Accordingly, GF pasta produced by the conventional extrusion process exhibited a lower degree of starch gelatinization when compared to the extrusion-cooking counterpart (i.e., 57.6 *versus* 75.5 g/100g total starch, respectively; $p < 0.05$). A higher degree of starch gelatinization was expected for Pa_EC, due to the additional heating phase characterizing the extruder-cooker process (Figure 1). The RS content and the starch HI were analyzed on cooked to optimum samples, to investigate if the different extrusion conditions (conventional extrusion *versus* extrusion-cooking) could have additional nutritional implications in relation to the enzyme starch susceptibility. As reported in Table 2, cooked to optimum Pa_EC pasta sample exhibited the lower RS content and the higher starch HI when compared to Pa_CV, being 3.8 *versus* 6.5 g/100g total starch and 58.9 *versus* 46.6, respectively ($p < 0.05$), thus indicating that the different extrusion conditions induced changes in the enzyme susceptibility of the starch.

### 3.3 Damaged starch

The amount of damaged content - which reflects the amount of starch quickly susceptible to $\alpha$–amylase hydrolysis - followed the order: YF < Pe < Pa_CV < Pa_EC. The lowest values found in the native flour reflects the mechanical damage due to the milling process. Pe showed significantly higher values than YF because the latter undergoes an extrusion process at high shear stress and temperature that modify the physical and structural organization of starch granules. Even higher values of damaged starch were observed in pasta samples, likely due to the extrusion in the conventional press and the drying step. Increase in damaged starch due to the pasta-making process was also observed in rice pasta (Marti et al., 2010; Cabrera-Chávez et al., 2012). Pa_EC showed higher damaged starch content compared to Pa_CV because the action of shear and thermal stress in the extruder-cooker leads to an increase in the amount of damaged starch that is further damaged during conventional extrusion and the drying step. A similar effect was observed when parboiled rice was processed into pasta by conventional extrusion or extrusion-cooking (Marti et al., 2010; Marti et al., 2013).

### 3.4 Thermal properties

The thermal properties of ingredients and pasta samples are presented in Table 2. Pasta obtained by the conventional extrusion process was characterized by $T_0$, $T_p$, $T_c$, and $\Delta H$ mean values of 63.16 °C, 71.71 °C, 81.95 °C and 1.07 J/g dry matter, respectively. Marti et al. (2010) reported that 100% rice pasta made with a conventional extrusion process exhibited a gelatinization peak in the range of 55-73 °C, broadly in line with the current findings. The data indicated that the different pasta-making processes promoted differences in the thermal properties of the samples, probably due to differences in the starch network established during the processing. In particular, Pa_EC required higher temperature for gelatinization to begin (66.49 *versus* 63.16°C; $p < 0.05$), but less energy for gelatinization (0.97 *versus* 1.07 J/g dry matter; $p < 0.05$) with respect to Pa_CV. Accordingly, Marti et al. (2010) reported differences in the thermal properties of parboiled milled rice pasta produced by two different processes, being extrusion-cooking *versus* conventional extrusion. The authors indicated that rice pasta made by the extrusion-cooking process was characterized by the highest $T_0$ and the lowest $\Delta H$ values, in line with the current findings.

### 3.5 Pasting properties

Although showing a similar pasting profile (Figure 3), samples exhibited significant differences in pasting temperature (YL < Pe < P_CV < P_EC), maximum viscosity (YL = Pe > P_CV > P_EC) and final viscosity (YL > Pe > P_CV = P_EC) (Table 2). Pe and Pa_EC showed a higher pasting temperature compared to YL and Pa_CV, respectively (Table 2). This is due to both shear and thermal stress that occur during the extrusion-cooking process which involves starch gelatinization and therefore its retrogradation, leading to compact structure which requires higher temperatures to start gelatinizing (in agreement with the results on thermal properties in Table 2). Compared to YL and Pe, starch in pasta samples undergoes further reorganization during the drying step, resulting in a further increase in pasting temperature (Table 2). Moreover, regardless of the process, pasta samples had lower viscosities compared to YL and Pe. This is due to the combination of conventional extrusion and drying of both YL and Pe. During drying, starch swells and proteins coagulate, which may result in decreased swelling and hydration of the granule during the MVAG test, which would reduce pasting viscosity. The reduction in final viscosity through the pasta-making process can be explained by both starch reorganization during cooling/drying and greater amylose-lipid complexation, which occurred in pasta starches during gelatinization and may have restricted recrystallization of amylose in cool starch gel formation (Yue et al., 1999).

Comparing the two pasta samples, the pasting profile of Pa_EC suggests the presence of two starch “patterns'' that swell at different temperatures (79 °C and 83 °C, see arrow in Figure 3) and likely retrograde in two steps. Indeed, the pasting curve shows an initial reorganization of starch (visible by a great increase in viscosity) at the beginning of the cooling step (about 70 °C) followed by a slow increase, at about 55 °C (Figure 3).

## 4. Discussion

The pasta market is definitely very traditional, but it has been able to evolve by meeting the needs of consumers who are increasingly aware of the importance of maintaining a healthy and sustainable diet. In this context, pulse pasta is the latest response of the pasta industry to consumer request for convenience high-protein foods: for example, a portion (80 g) of yellow lentil pasta provides about 45 g of carbohydrates, 18 g of proteins and 4 g of fiber. Moreover, thanks to its non-gluten content, pulse pasta represents a good alternative to GF pasta based on cereals and/or pseudocereals, whose protein and fiber content are significantly lower compared to pulse pasta (Morreale et al., 2019).

As concerns cooking behavior, the weak structure of pulse pasta results in poor cooking quality, especially when compared to durum wheat pasta (Turco et al., 2019; Laleg et al., 2016). The reported studies focused on pasta from 100% faba, pea, black-gram, green or red lentil flours, whereas no information on yellow lentil pasta is available. In addition to raw material, processing also plays a significant role in determining pasta quality. GF cereal-based pasta can be produced by either conventional extrusion or extrusion cooking (Marti & Pagani, 2013). In the first approach, a pre-gelatinized flour is introduced in a conventional continuous press commonly used for durum wheat semolina pasta-making. In the second process, native flour is gelatinized directly inside the extruder-cooker and then formed in the conventional automatic press. Conversely, in the case of GF cereals, the combination of native flour and conventional extrusion process does not result in an acceptable product (Marti & Pagani, 2013). In the case of pulses - whose components are different from GF cereals in content, structure, and functionality - it is not yet clear what the most suitable technology is for pasta production. For this reason, this work investigated the effect of the pasta-making process (conventional extrusion *versus* extrusion-cooking) on the starch properties and cooking behavior of pasta from yellow lentils.

Regardless of the type of pasta-making process, it was possible to produce pasta from fair/good quality native lentil flour (Figure 2), capable of maintaining its shape even in overcooking (Table 1). Therefore, contrary to what is known for gluten-free cereals, a conventional pasta-making process is effective in producing pasta from native yellow lentils without the need for a pre-gelatinization step.

Some differences were observed in color, with the extrusion-cooking sample exhibiting higher yellow (b*) index, although not perceptible to the human eye (Figure 2). Moreover, the conventional extrusion sample manifested some white specks, likely due to incomplete flour hydration, thus indicating the need for water level optimization. However, the presence of such spots did not compromise the cooking behavior of the product. Indeed, cooking quality, in terms of optimal cooking time, water absorption, cooking loss, and firmness, was similar for both samples (Table 1). Generally, high values for water absorption and firmness and low values for cooking loss are desirable for good quality pasta (Marti et al., 2015).

Differences in type of pulse and pasta shape, as well as in processing conditions and cooking times, make it difficult to compare our results with those of either commercial or experimental pasta reported in previous studies. As far as cooking losses are concerned, they are recognized as an important index for determining pasta quality; being associated with the leaching of amylose from starch granules into the cooking water, high cooking loss values suggest significant alterations of product structure and consequently poorer overall pasta quality (Marti et al., 2015).

As regards textural properties, the extrusion-cooking of yellow lentil flours make for a pasta that requires higher energy to be compressed, cut, and extruded through the Kramer cell (Table 1). Differences in texture were even more pronounced when pasta was cooked almost 2 min after the optimal cooking time (+25%). At 8 min of cooking, pasta from extrusion-cooking resulted in more compact structure, with significantly lower water absorption and significantly higher firmness and compression energy (Table 1).

Marti et al. (2010) compared the effect of extrusion conditions on both structure and cooking behavior of pasta from parboiled rice flour. The combination of parboiled rice and extrusion-cooking led to a product with lower cooking loss and higher firmness compared to pasta from the conventional process. However, in our study, the difference in pasta quality resulting from the extrusion process was less pronounced than that observed for rice (Marti et al., 2010). The type and amount of starch, as well as other components such as fiber and proteins affect starch gelatinization and thus, its retrogradation. Such phenomena are the starting point for creating a structure from non-gluten containing raw materials (Marti & Pagani, 2013). In the case of pulses, the effect of extrusion-cooking on starch organization might have been further mitigated by their high protein content. Pulses mainly contain soluble globulins and albumin with minor glutelin and prolamine fractions (Tiwari & Singh, 2012). It has been reported that conventional extrusion and low temperature drying (55 °C) of faba, green lentil, or black-gram flours result in only minor formation of covalent linkages compared to protein organization in the raw material (Laleg et al., 2016). Indeed, in pasta made from those pulses, more than 90% of their whole proteins were linked by electrostatic, hydrogen and/or hydrophobic interactions and only a small portion was stabilized by covalent bonds (Laleg et al., 2016). Cooking these kinds of pasta result in higher molecular changes, with proteins undergoing further aggregation through disulfide bonds (Laleg et al., 2016). The effect of extrusion conditions (conventional extrusion vs extrusion-cooking) on protein aggregate formation was studied in pasta from parboiled rice (Barbiroli et al., 2013). Regardless of the type of process, proteins in rice pasta were stabilized by hydrophobic interactions; however, the treatment of the flour in the extruder-cooker was effective in promoting disulfide linkages (Barbiroli et al., 2013). Although the authors recognize the potential role of proteins in affecting the cooking behaviour of pulse pasta and do not exclude future interest in this component, the present study focused on starch, the main component of pulses.

The relationship among extrusion conditions, starch changes and cooking behavior were investigated by adopting various procedures, involving different skills and techniques that vary in time and cost, which are important selection criteria for implementing a method in the food industry. Specifically, the effect of extrusion conditions on starch properties was investigated through the assessment of: (1) starch susceptibility to quick hydrolysis from alpha-amylase (namely damaged starch); (2) the degree of starch gelatinization; (3) viscosity changes during heating and cooling phases (namely pasting properties); (4) energy and temperatures required for starch gelatinization (namely thermal properties). Moreover, these methods provide information on specific starch properties and altogether may provide an insight into the relation between processing conditions and pasta quality.

Damaged starch content in flours refers to the effect of milling on starch granules; in the final product, it provides information on process-related changes to starch: the higher the value, the higher the degree of gelatinization (Bresciani et al., 2021). It is worth noting that cooling of the material after processing results in starch retrogradation, resulting in decreased susceptibility to starch hydrolysis (Marti et al., 2010). As already reported in pasta from rice (Marti et al., 2010) and corn (Bresciani et al., 2021), after processing, the damaged starch content increased as a consequence of starch gelatinization (Table 2). The highest increase was observed in the case of extrusion-cooking, due to the combination of both thermal and mechanical stresses that led to starch gelatinization. However, since the test measures the amount of glucose released due to quick hydrolysis (i.e., 10 min), it provides information of the molecular organization at the external regions/surface of the granules. This information is in agreement with the high level of pregelatinized starch in Pa_EC (Table 2).

In the case of rice pasta, starch from extrusion- cooking) is characterized by an external region in which molecules are organized in an amorphous structure, and an internal core characterized by a crystalline structure (Marti et al., 2011). The combination of these two regions - or the two stages in which starch is organized - reflects product behavior during heating. The pasting profile showed that starch in Pa_EC undergoes an increase in viscosity in two steps - at about 79 °C and 83 °C - and at higher temperatures than

Pa_CV (Figure 3). Also starch reorganization - notable by the further increase in viscosity upon cooling - occurs at two stages, at about 70 °C and 55 °C (Figure 3).

The higher gelatinization and pasting temperatures (Table 2) detected in the product from extrusion-cooking could indicate higher thermal stability in the product, resulting in better cooking behavior especially in overcooking (Table 1). A similar effect was observed in rice pasta (Marti et al., 2010; Marti et al., 2011) and related to the stabilization of amylopectin crystallites (Yue et al., 1999). At the same time, in the extruded-cooked pasta the gelatinization process required less energy (low enthalpy) and was completed in a limited temperature range, suggesting a lower crystalline order (Marti et al., 2010). Indeed, about 75% of the total starch was gelatinized during the process (Table 3). Overall results suggest that in Pa_EC the non gelatinized starch fraction might be organized in a more organized structure.

In this work, the effect of the different extrusion conditions was evaluated considering possible nutritional implications by focusing on the *in vitro* starch digestion. Thus, two parameters were studied: the RS content and the starch HI. In particular, the RS fraction is defined as the fraction of starch that escapes digestion in the small intestine to be fermented in the large bowel, thus promoting a series of health-related benefits comparable to those of dietary fibre (Sajilata et al., 2006; Miketinas et al., 2020). Indeed, the starch HI is a commonly used *in vitro* metric to predict the likely *in vivo* glycemic response of food of interest (Singh et al., 2010). Our findings indicated that the conventional pasta-making process has proven more effective in maintaining a greater proportion that tested as RS in the final product as compared to the pasta obtained through the extrusion-cooking method, even after cooking at the same optimal cooking time (i.e., 6.5 min). This may be related to the different degree of starch gelatinization in uncooked samples induced by the two applied pasta-making process. Similar results were reported by Bresciani et al. (2021) while studying the effect of two different pre-gelatinization methods (i.e., tank *versus* a conveyor belt) on the RS in corn-based pasta. Besides, other than the level of starch gelatinization, structural changes occurring for non-starchy components (mainly protein and fiber) induced by the different extrusion methods and their possible interaction with starch could also play a role in influencing the starch accessibility towards enzymes (Petitot et al., 2009; Petitot and Micard 2010). This certainly deserves future investigation. Lastly, as the RS fraction does not contribute to the release of glucose during the *in vitro* enzyme hydrolysis, lower starch HI can be expected as the level of RS increased in a certain food product (Sajilata et al., 2006). Accordingly, lower starch HI was measured in Pa_CV as compared to Pa_EC. The presence of RS in food products can also partially affect the susceptibility of the available starch fractions to digestion, due to the encapsulation of gelatinized starch between layers of RS that have greater resistance to enzyme hydrolysis (Tian and Sun, 2020). Taking together, present findings indicated that the conventional pasta-making process may contribute to formulating a 100% yellow lentil pasta with favorably slower *in vitro* starch digestion properties and greater RS content than the extrusion-cooking method.

## 5. Conclusions

In this study, the effect of extrusion conditions on the cooking quality of 100% yellow lentil pasta was investigated for the first time. In addition, the relation between processing conditions and starch properties was elucidated for pulse pasta. We demonstrated that it is possible to produce pasta from yellow lentils from either conventional extrusion or extrusion-cooking processes. Therefore, contrary to what has been shown for gluten-free cereals, yellow lentils con be processed into dry pasta even without a pre-gelatinization step. However, pasta from extrusion-cooking exhibited higher stability during cooking and resistance to overcooking, resulting in firmer pasta. As for starch properties, this study showed that the shear and thermal stresses induced by extrusion-cooking promoted a high degree of gelatinization but, at the same time, the un-gelatinizable fraction seems to be organized in a more compact structure that required higher temperature for melting, thus resulting in better cooking behavior. In addition, the different pasta-making process may also have some nutritional implications in relation to the enzyme susceptibility of the starch fraction. Although starch is the main component in pasta, further studies are underway to assess the effect of extrusion-cooking on overall protein organization and how this relates to pasta cooking behavior. At the same time, the acceptability of yellow lentil pasta needs to be confirmed by sensory analysis.

## Credit authorship contribution statement

**Andrea Bresciani:** Formal analysis, Data curation, Visualization, Writing - original draft. **Gianluca Giuberti:** Writing - review & editing. **Mariasole Cervini**: Formal analysis. **Alessandra Marti:** Conceptualization, Supervision, Writing - review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that influenced the work reported in this paper.

## Acknowledgements

The authors thank Mr. Antonio Barabba Terno (Consiglio per la ricerca in agricoltura e l’analisi dell’economia agraria - Centro di Ricerca Zootecnia e Acquacoltura - CREA-ZA), Mr. Ivan Ribani (Università degli Studi di Milano) for technical support during the pasta-making trials.

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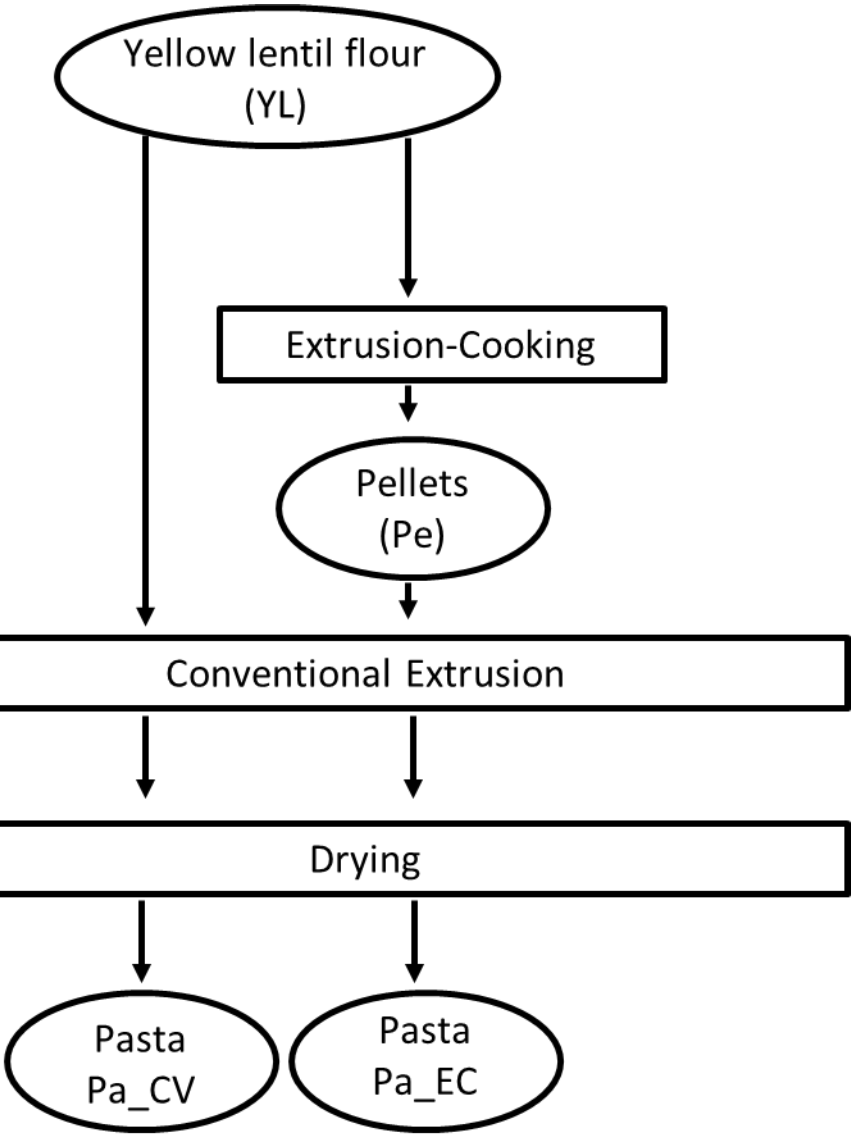
## Figure captions

**Figure 1.** Flow-sheet of pasta-making process from yellow lentil flour. Pa_CV, pasta from conventional extrusion; Pa_EC, pasta from extrusion-cooking.

**Figure 2.** Images and color indices of yellow lentil pasta produced with conventional extrusion (Pa_CV) or extrusion-cooking (Pa_EC). L*, Brightness; a*, redness; b*, yellowness; ΔE, color difference. Mean (n= 10) ± standard deviation. # indicates significant differences ($p<0.05$; t-test).

**Figure 3.** Pasting profiles of yellow lentil flour (black dotted line), pellets (grey dotted line) and pasta produced with conventional extrusion (black line) or extrusion-cooking (grey line). BU, Brabender Units. s. Arrows indicate swelling/beginning of gelatinization and reorganization of the two starch structures.



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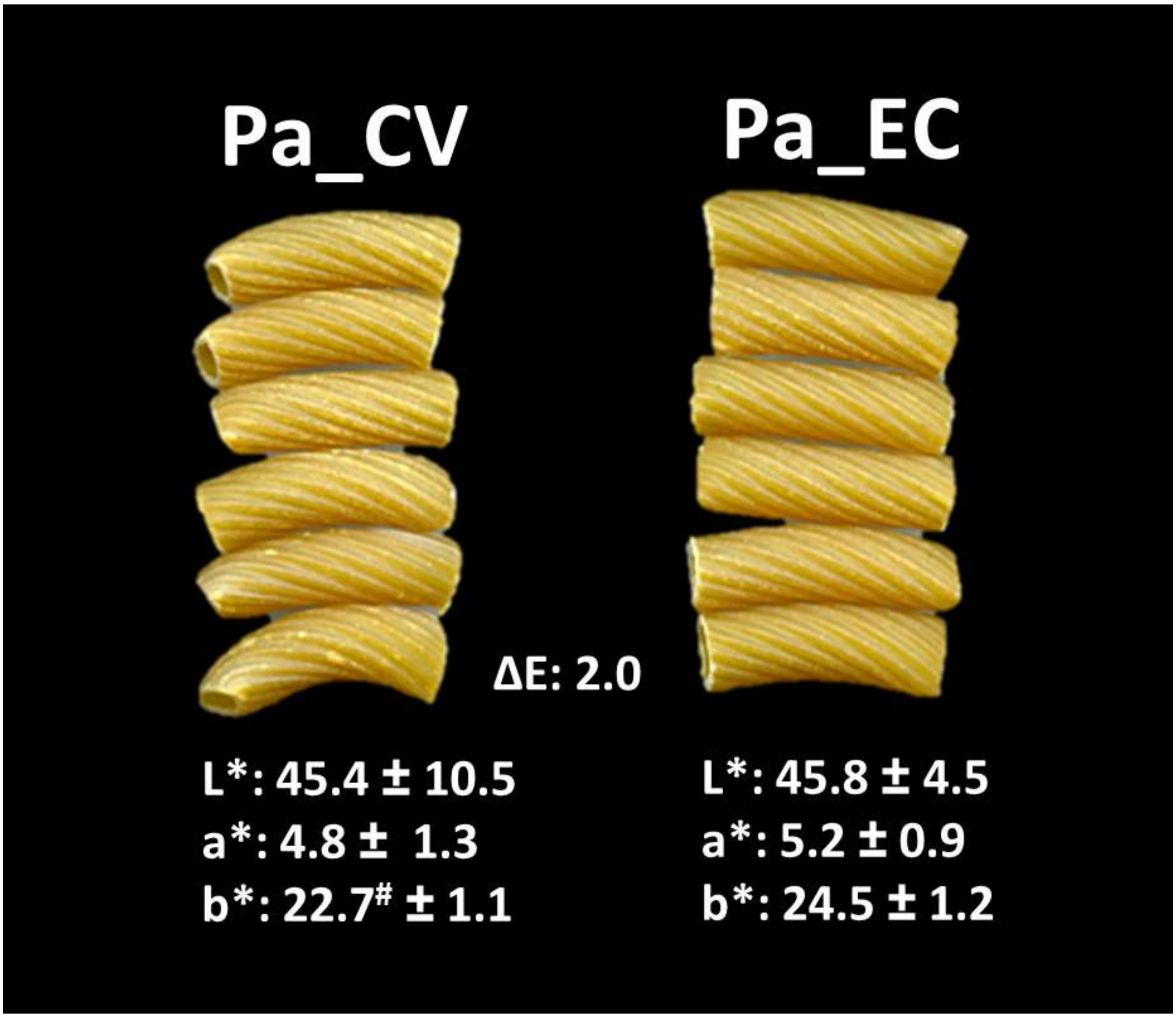

**Figure 2.** Images and color indices of yellow lentil pasta produced with conventional extrusion (Pa_CV) or extrusion-cooking (Pa_EC). L*, Brightness; a*, redness; b*, yellowness; ΔE, color difference.

Mean (n= 10) ± standard deviation. $^{\#}$ indicates significant differences ($p<0.05$; t-test).

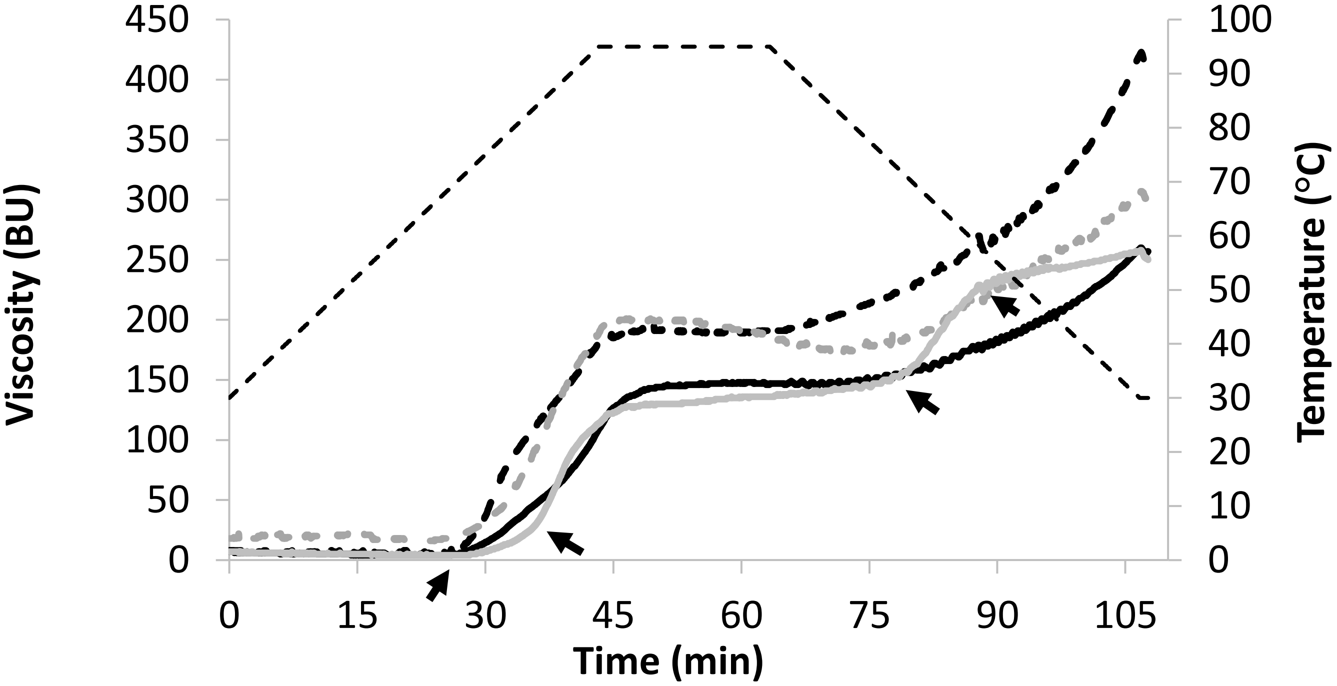

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**Table 1**. Cooking quality of yellow lentil pasta produced with conventional extrusion (Pa_CV) or extrusion-cooking (Pa_EC).

| Sample | Cooking time | Water absorption (g/100 g) | Cooking loss (g/100 g $_{\text{d.m.}}$) | Firmness (N) | Compression energy (N*mm) |
|---|---|---|---|---|---|
| **Pa_CV** | Optimal (6.5 min) | 78 ± 2$^{ns}$ | 7.0 ± 0.1 $^{ns}$ | 530 ± 49 $^{ns}$ | 2448 ± 168$^{*}$ |
| **Pa_EC** | | 76 ± 1 | 7.1 ± 0.3 | 609 ± 30 | 2898 ± 113 |
| **Pa_CV** | Overcooking (8 min) | 93 ± 1 $^{**}$ | 7.7 ± 0.2 $^{ns}$ | 418 ± 13$^{**}$ | 2125 ± 126 $^{*}$ |
| **Pa_EC** | | 87 ± 1 | 7.9 ± 0.5 | 513 ± 17 | 2468 ± 132 |

Mean (n= 5) ± standard deviation. Significant differences within the same column and referred to the same cooking time are expressed as: * ($p<0.05$), ** ($p<0.01$) (t-test). Non-significant differences within the same column and referred to the same cooking time are expressed as: ns (t-test). d.m., dry matter.

**Table 2**. Starch properties of yellow lentil flour (YL), pellets (Pe) and pasta produced with conventional extrusion (Pa_CV) or extrusion-cooking (Pa_EC).

| | | **YL** | **Pa_CV** | **Pe** | **Pa_EC** |
|---|---|---|---|---|---|
| **Damaged starch (g/100 g $_{t.s.}$)** | | 4.6 ± 0.1 $^{a}$ | 7.6 ± 0.2 $^{c}$ | 6.8 ± 0.1 $^{b}$ | 9.6 ± 0.4 $^{d}$ |
| **Gelatinized starch (g/100 g $_{t.s.}$)** | | 2.9 ± 0.2 $^{a}$ | 57.6 ± 1.9 $^{b}$ | 51.8 ± 1.6 $^{b}$ | 75.5 ± 1.2 $^{c}$ |
| **Resistant starch (g/100 g $_{t.s.}$)** | | n.a. | 6.5 ± 0.2 $^{a}$ | n.a. | 3.8 ± 0.3 $^{b}$ |
| **Starch hydrolysis index** | | n.a. | 46.6 ± 1.26 $^{a}$ | n.a. | 58.9 ± 1.06 $^{b}$ |
| **Thermal properties** | **Onset temperature (°C)** | 63.09 ± 0.18 $^{a}$ | 63.16 ± 0.25 $^{a}$ | 64.16 ± 0.07 $^{b}$ | 66.49 ± 0.15 $^{c}$ |
| | **Peak temperature (°C)** | 72.10 ± 0.29 $^{bc}$ | 71.71 ± 0.09 $^{b}$ | 72.94 ± 0.10 $^{c}$ | 70.06 ± 0.39 $^{a}$ |
| | **End temperature (°C)** | 80.07 ± 0.40 $^{a}$ | 81.95 ± 0.11 $^{b}$ | 81.16 ± 0.32 $^{ab}$ | 80.60 ± 0.36 $^{a}$ |
| | **Enthalpy (J/g $_{d.m}$)** | 0.74 ± 0.01 $^{a}$ | 1.07 ± 0.03 $^{d}$ | 0.86 ± 0.04 $^{b}$ | 0.97 ± 0.01 $^{c}$ |
| **Pasting properties** | **Pasting temperature (°C)** | 71.5 ± 0.1 $^{a}$ | 74.7 ± 0.1 $^{c}$ | 72.8 ± 0.7 $^{b}$ | 79.1 ± 0.2 $^{d}$ |
| | **Maximum viscosity (BU)** | 201.0 ± 7.1 $^{c}$ | 143.0 ± 0.1 $^{b}$ | 209.5 ± 12.0 $^{c}$ | 129.0 ± 5.7 $^{a}$ |
| | **Final viscosity (BU)** | 410.0 ± 5.7 $^{c}$ | 263.0 ± 8.5 $^{a}$ | 314.5 ± 19.1 $^{b}$ | 253.0 ± 4.2 $^{a}$ |

Mean (n =3) ± standard deviation. Means within a row with different superscripts are significantly different (Tukey's honest significant difference test; $p<0.05$). n.a., not analysed; t.s., total dry starch. The starch hydrolysis index was measured referenced to common white wheat bread (starch hydrolysis index = 100 by definition).