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Use of malted pulses to formulate gluten-free fresh-egg pasta

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ORIGINAL ARTICLE

Abstract

In spite of the fact that legumes are rich in proteins, dietary fibers, and micronutrients, their average per capita consumption is limited because of their lengthy cooking period, unpleasant flavor, low-digestible proteins, and gastrointestinal problems. This study was aimed at assessing the effectiveness of the malting process of three typical pulse seeds of the Italian Latium region (i.e. *Gradoli Purgatory* beans [GPB]; *Onano* lentils [OL]; and *Solco Dritto* chickpeas [SDC]) to minimize their anti-nutrient content and test their use as ingredient in the preparation of gluten-free fresh egg pastas. All these fresh egg pastas were devoid of flatulence-inducing oligosaccharides with low phytate content (0.6–0.80 g/100 g of dry matter, dm), a crude protein content of around 20 g/100 g dm and *in vitro* glycemic index ranging from 28% to 38%. However, the only fresh egg pasta, including malted GPB flour, exhibited not only a significantly smaller glycemic index (28%±3%) but also a resistant starch–total starch ratio by far greater than the threshold value (14%) specified by the European Commission Regulation 432/2012 to label foods with the health claim indicating improvement in postprandial glucose metabolism.

Keywords: dehulled malted pulse flour; fresh egg pasta; *Gradoli Purgatory* beans; *in vitro* glycemic index; *Onano* lentils; *Solco Dritto* chickpeas; texture profile analysis

Introduction

Currently, a great deal of interest exists toward gluten-free, pulse-based food products appropriate for celiac, diabetic and hyperlipidemic patients (Abu-Ghannam and Gowen, 2021). Being rich in proteins, dietary fibers, and micronutrients, legumes have a high nutritional profile (Maphosa and Jideani, 2017) and their cultivation has a low environmental impact (Nemecek *et al.*, 2008). Nevertheless, legume per capita consumption is quite small globally, being around 21 g/day (Rawal and Navarro, 2019). This is in all probability due to their lengthy cooking period, unpleasant flavor, low-digestible proteins, gastrointestinal problems (de Almeida Costa *et al.*, 2006), and high anti-nutrient contents (e.g. phytic acid, tannins, enzyme inhibitors, and flatulence-inducing oligosaccharides) (Gebrelibanos *et al.*, 2013).

The global production of pulses was near to 89 million metric tons (MT) in 2021 (Shahbandeh, 2023), the production of dry beans, chickpeas and lentils being approximately 27.7 million MT, 14.3 million MT and 5.7 million MT, respectively. India is the largest world producer of dry beans and chickpeas with about 6.1-million MT and 9.9-million MT production per year, respectively. Canada is the top producer of lentils with an approximate production of 3.23 million MT/year. The second top producer of dry beans, chickpeas and lentils is Turkey, with 630×10^3 MT, Brazil with 2.9×10^6 MT and India with 1.06-million MT production, respectively.

In 1960, the Italian production of dried legumes was as high as 640,000 MT but dropped to as low as 135,000 MT in 2010 (Confimi Industria, 2018). In spite increase in production, the domestic consumption of legumes is highly

dependent on imports, which represent about 95% of the annual consumption of beans, 59% of that of chickpeas and 98% of that of lentils. In 2022, the annual Italian production of dry beans, chickpeas and lentils was around 7,822, 24,990, and 4,216 MT, respectively (http://dati.istat.it/Index.aspx?QueryId=37850, accessed 10 July 2023).

Among the numerous pulse varieties grown in Italy, it is worth mentioning the three typical varieties of the Latium region, namely the *Gradoli Purgatory* beans (GPB), *Solco Dritto* (straight furrow) chickpeas (SDC), and *Onano* lentils (OL) (Di Giovannantonio *et al.*, 2019). GPBs are small, round, and whitish seeds, such as Cannellini beans but with a thinner skin, SDCs are smooth, yellow-beige-skinned seeds, and OLs are round and light brown in color with shades ranging from dark lead to pinkish ashen, marbled on the surface. All these pulses have been traditionally farmed in the province of Viterbo (Italy), specifically in the towns of Gradoli, Acquapendente, and Onano, in hilly volcanic soils, rich in potassium and poor in calcium, located at 300–400 m above sea level (m asl) under the mild climate conditions assured by the nearby lake of Bolsena. The production of SDCs and OLs dates back to the time of Etruscans, while that of GPBs was taken from the traditional menu of the Purgatory lunch, this having been served at Gradoli on the first day (Ash Wednesday) of the Lenten since the 17th century (Slow Food Foundation, n.d.a). SDCs derive their name from the furrow tracing carried out in the plains beneath the town of Valentano on the 14th August of every year, the straightness of which presages an excellent harvest (Slow Food Foundation, n.d.b). OL were awarded with the Protected Geographical Indication (PGI-IT-02651) marked by the European Commission (2022).

Several traditional (i.e. dehulling, soaking, steaming, boiling, pressure cooking, moist and dry heating, sprouting and fermentation, roasting, extrusion, ultrafiltration, and isoelectric precipitation) and emerging (i.e. microwave, infrared or dielectric heating, extrusion, γ-irradiation, ultrasonication, and high hydrostatic pressure processing) techniques have been applied to reduce the pulse anti-nutrient content (Das *et al.*, 2022; Sharma *et al.*, 2022).

In previous works (Cimini *et al.*, 2021, 2023a, 2024), the main operating variables of the three steps, namely soaking, germination, and kilning, of the malting process of the three dry pulse varieties examined here were identified at the bench-top laboratory scale. For instance, the resulting dehulled malted chickpeas were cooked in boiling water in about 45 min, the 16-h presoaked raw counterparts having to be cooked for as longer as 75 min (Cimini *et al.*, 2023b), while the dehulled malted OL flour was used to prepare a fresh egg-pasta high in raw protein (24 g/100 g) and low in phytate (0.6 g/100 g) and *in vitro* glycemic index (GI; 41%) with no trace of oligosaccharides (Cimini *et al.*, 2024).

In this work, *Solco Dritto* chickpeas and *Gradoli Purgatory* beans, presented to the malting process depicted in Figure 1 and converted into decorticated malted GPB or SDC flours low in phytate and α-galactosides, were used to prepare fresh egg pastas to assess their cooking quality and *in vitro* GI.

Materials and Methods

Raw materials

The two varieties of legumes used in this work were the GPBs (*Phaseolus vulgaris*), and SDCs (*Cicer arietinum*), which were produced and supplied by Il Cerqueto Srl (Acquapendente, Viterbo, Italy). A common wheat flour

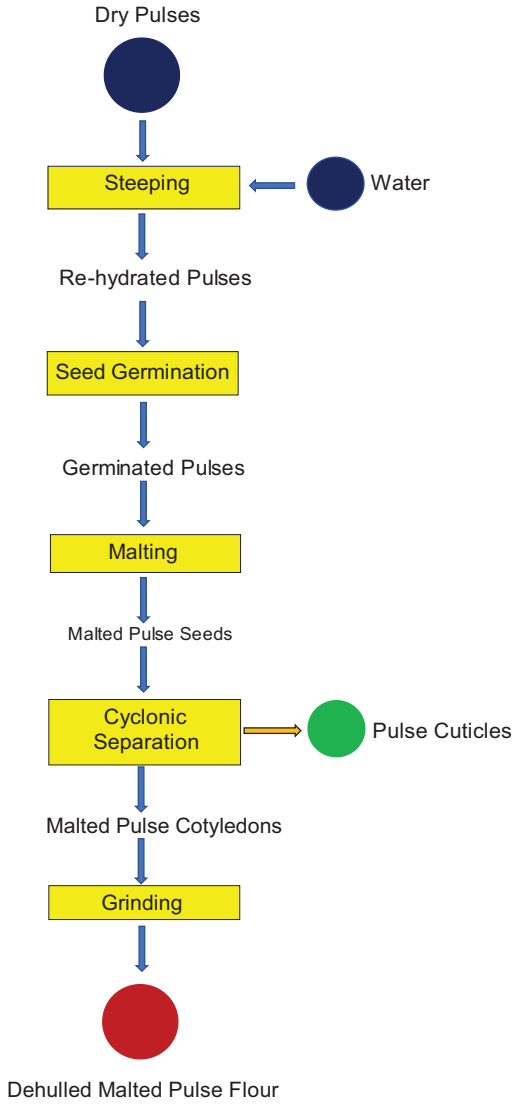

Figure 1. Schematic of the dehulled malted pulse flour production process set up previously (Cimini *et al.*, 2021, 2023a, 2024).

type 00 (Molino Profili Giuseppe sas, Viterbo, Italy) having a dough strength (W) of 180–200 (10^{-4} J) and an Alveograph ratio [P/L ratio between maximum pressure (P in mm) and extensibility (L in mm)] of 0.5–0.6 was used to prepare reference fresh egg pasta.

Malting process of dry pulses

Both seeds were malted in a bench-top plant as described in the past (Cimini *et al.*, 2021) and shown in Figure 2a. The bench-top plant consisted of several chambers, each one equipped with two stainless steel perforated baskets (Figure 2b) having a maximum capacity of 1 kg of seeds, and a low-temperature immersion circulator type IB-Tastemaker Compact 10 (Klarstein Chal-Tec GmbH, Berlin, Germany). The steeping step for GPBs and SDCs was carried out at 25 °C for 3 h (Cimini *et al.*, 2023a). Seed moisture was determined using a Kern DAB 100-3 thermostatic scale (Kern & Sohn GmbH, Balingen, Germany) set at 110 °C for about 20 min. At the end of the steeping step, the moisture content of GPB and SDC seeds increased from 12% (w/w) to 52.2±3.6 and 43.5±3.4 % (w/w), respectively. The stainless steel baskets were then moved to the germination chamber, which was equipped with a sensor, type CJMCU-1080 HDC1080 (Texas Instruments, Dallas, TX, USA) to measure the relative humidity (RH) and temperature (T) of air with an accuracy of ±2% RH and ±0.2 °C, respectively. The germination chamber was also equipped with a temperature probe, type DS18B20 (Maxim Integrated, San Jose, CA, USA), to keep seeds at 25 °C, with an accuracy of ±0.5 °C.

Water spraying was scheduled at 1 min/h, and germinating seeds were manually mixed at every 24 h in an effort to homogenize seed moisture and disrupt the aggregates formed by sprouting roots. After 72-h germination, the seeds were dehydrated to 10±2% (w/w) at 50 °C for 24 h and then at 75 °C for 3 h through Nobel Pro 6 ventilated dryer (Vita 5, Gronsveld, the Netherlands). Such malted seeds were submitted to slight abrasion and split into two fractions using a laboratory-scale cyclone. The cotyledon-rich fraction represented 86±1% and 85±2% of the input GPB and SDC malt, respectively, and was crunched using an electric stone mill (Mockmill 200, Wolfgang Mock, Otzberg, Germany), its fineness being regulated at level 2 out of 10. Total starch (TS) and resistant starch (RS) fractions in seeds were determined using the corresponding kits by Megazyme Ltd. (Bray, Ireland), while the raw protein fraction was assessed by Method 992.23 (Association of Official Analytical Chemists [AOAC], 1998) with a nitrogen conversion factor of 6.25. The seed levels of α-galactosides and phytic acid were measured using the raffinose/sucrose/D-glucose and phytic acid assay kits (Megazyme Ltd., Bray, Ireland), respectively. The colors of decorticated and splitted seeds in original and malted were measured by the CIELAB color space using a portable color-measuring instrument model D25-PC2 (Hunterlab, Restow, VA, USA) with a diffused (0/45°) illuminating viewing geometry. The main chemico-physical properties of the studied pulse seeds in original or malted were determined in the past (Cimini *et al.*, 2023a, 2024) and are shown in Table 1.

Fresh pasta production and testing

Any dehulled malted pulse flour or all-purpose common bread flour was mixed with whole egg in a ratio of 63:37 g/g using a pasta machine PF40E (Fimar Spa, Villa Verucchio, Italy) as schematically illustrated in Figure 3.

The dough was extruded in the form of long strands having a thickness of approximate 3 mm. These were kept in closed aluminum trays at +4 °C and assayed in less than a couple of days. The optimum cooking time

Figure 2. Pictures of the bench-top plant used in this work: (A) insulated chamber, and (B) perforated baskets.

Table 1. Main chemico-physical properties and CIELAB coordinates (L*, a* and b*) of original and malted (M) *Gradoli Purgatory* bean, *Solco Dritto* chickpea, and *Onano* lentil seeds as assessed previously (Cimini *et al.*, 2023a, 2024).

Parameter	GPB	MGPB	SDC	MSDC	LO	MLO	Unit
Raw proteins	22.7±1.7^{b}	23.4±2.1^{b}	22.3±1.7^{b}	23.6±1.9^{b}	26.1±2.0^{a,b}	28.7±2.2^{a}	g/100 g
Total starch (TS)	33.81±1.66^{c}	34.96±0.19^{c}	46.8±0.6^{b}	45.2±2.0^{b}	50.9±0.4^{a,b}	52.1±2.8^{a}	g/100 g
Resistant starch (RS)	23.59±0.34^{a}	22.0±1.8^{a}	1.77±0.22^{b,c}	1.19±0.43^{c}	2.30±0.17^{b}	1.88±0.47^{b}	g/100 g
Phytic acid (PA)	1.15±0.12^{a}	0.78±0.13^{b}	1.15±0.12^{a}	0.79±0.09^{b}	1.09±0.09^{a}	0.80±0.02^{b}	g/100 g
Raffinose (R)	5.31±0.28^{a}	1.95±0.20^{c}	3.80±0.15^{b}	1.65±0.11^{c}	3.78±0.04^{b}	0.79±0.07^{d}	g/100 g
L*	71.0±1.7^{b,c}	73.3±1.5^{a,b}	69.5±1.6^{c}	75.1±1.8^{a}	64.6±1.6^{d}	65.2±3.0^{d}	-
a*	0.6±0.5^{b,c}	0.01±0.61^{c}	3.7±0.5^{a}	2.3±0.6^{b}	5.7±1.6^{a}	1.3±0.7^{b}	-
b*	15.6±1.7^{c}	19.0±1.9^{c}	27.0±2.3^{b}	27.0±1.3^{b}	44.3±3.2^{a}	40.9±2.5^{a}	-

In each row, values with the same superscripted letters have no statistically significant difference at $p < 0.05$.

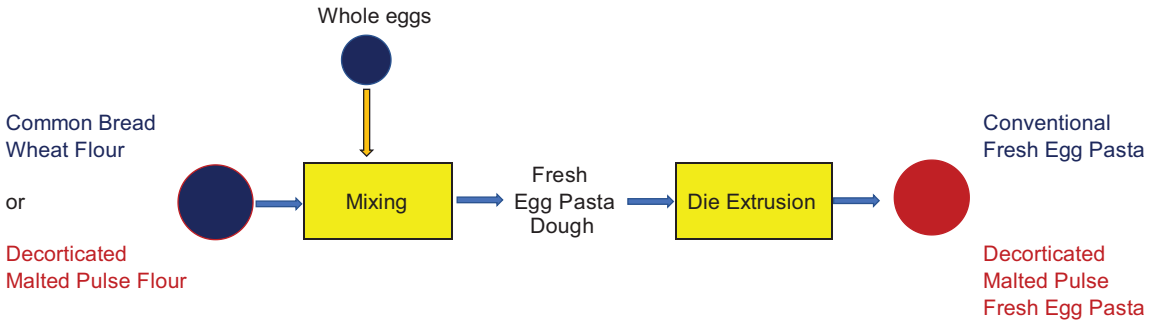

Figure 3. Schematic of fresh egg pasta production process using common bread wheat flour or decorticated malted pulse flour.

(OCT) of conventional fresh egg pasta was determined according to the International Organization for Standardization (ISO, 2016), while that of fresh egg pasta made from malted GPB or SDC flour was determined by six trained panelists, who tasted the firmness of cooked pasta at every 30 s starting from 4 min of cooking. Fifty grams of each egg pasta were cooked in a lidded stainless steel pot using a 2-kW induction hob model INDU (Melchioni Spa, Milan, Italy) using a water–pasta ratio of 10 L/kg (Cimini *et al.*, 2020). The pasta cooking process was prolonged up to the corresponding OCT. A digital power meter type RCE MP600 (RCE Srl, Salerno, Italy) was used to measure the electricity supplied by induction hob (E_S) so as to estimate the specific energy consumption per unit of fresh pasta cooked (e_{CP}). Cooked pasta strands were recovered from pasta water using a colander, and cooled according to Method 66–50.01 of the American Association of Cereal Chemists (AACC, 2009). Both fractions were weighted; this allowed the calculation of water absorbed by cooked pasta (m_{WPA}) and that evaporated (m_{WE}) throughout the cooking process as follows:

$$m_{WPA} = m_{CP} - m_{PA}, \quad (1)$$

$$m_{WE} = m_{W0} - m_{WPA} - m_{WF}, \quad (2)$$

where m_{CP} and m_{PA} are the masses of cooked and raw pastas, respectively, and m_{W0} and m_{WF} are the masses of cooking water and residual pasta water, respectively.

The solids dispersed in the cooking water were assessed upon drying overnight at 105 °C and referred to the mass of fresh pasta used (AACC, 2009), thus yielding the so-called cooking loss (CL). The specific water uptake (WU) was determined by dividing m_{WPA} by m_{PA}.

The textural properties of cooked fresh pasta were assessed using a Universal Testing Machine UTM model 3342 (Instron Int. Ltd., High Wycombe, UK), equipped with a 1,000-N load cell. As described previously (Cimini *et al.*, 2019a, 2019b), 17 cooked strands were aligned over a stainless steel plate and tested using a trapezoidal cutting probe. The average thickness (s_{CP}) of cooked strands was calculated as the difference between the total displacement of the probe at the contact point with the platen and sample; this resulting in a force of 0.05 N. Each test was carried out by setting probe speed at 1 mm/s. The first bite was performed by submitting the strands to a 30% compression. The probe was raised to its starting position. After a short relaxation time of 5 s, it was lowered to submit strands to a second 70% compression and finally returned to its initial position.

According to Bourne (2002), the force peak at the first and second compression cycle was defined as the pasta hardness at 30% (F_{30}) or 70% (F_{70}) deformation. The ratio between the force versus time area (AC_{70}) during the second compression and the force versus time area (AC_{30}) during the first compression was defined as cohesiveness or cohesion energy resilience (CER). The distance that strands recovered their height during the time elapsed between the end of the first bite and the start of the second bite was called springiness (*S*). Each test was repeated for five times.

Total starch and RS contents in cooked pastas were assayed using the corresponding kits (Megazyme Ltd., Bray, Ireland). RS was tested in cooked pasta samples, and TS was assessed in dried and crunched pasta samples.

In vitro digestion of pasta starch was executed as suggested by Zou *et al.* (2015). All the tests were replicated for at least three times. The time course of the concentration of the glucose released, $C_G(t)$, was assayed by D-Glucose assay procedure K-GLUC 07/11 (Megazyme) to plot the so-called digestogram. The area under each digestogram (AUC) was numerically calculated for a total digestion time (t_f) of 180 min using the Trapezoidal Rule, and was related to the corresponding AUC estimated using white bread, a reference product, according to Giuberti *et al.* (2015) and Singh *et al.* (2021). Such starch hydrolysis index (SHI) was expressed as a percentage and used to compute *in vitro* GI using the following empirical formula (Granfeldt *et al.*, 1992):

$$GI = 8.198 + 0.862 \times SHI, \quad (3)$$

where SHI of white bread was equal to 100.

Statistical analysis of data

The statistically significant difference between the parameters tested was analyzed by Tukey Test at $p = 0.05$. One-way analysis of variance (ANOVA) was also carried out using SYSTAT, version 8.0 (SPSS Inc., Chicago, IL, USA, 1998).

Results

Production and characterization of dehulled malted pulse flours

The crude protein, phytic acid, and raffinose contents on a dry matter basis of GPBs, SDCs, and OLs did not differ from those of various varieties cultivated worldwide (Basso Los *et al.*, 2018; Cappa *et al.*, 2018; de Barros *et al.*, 2016; Frias *et al.*, 2000; Johnson *et al.*, 2013; Rawal and Navarro, 2019; Rawal *et al.*, 2019; Sparvoli *et al.*, 2015; Xu *et al.*, 2019).

The 72-h germination process reduced the flatulence-inducing raffinose equivalent content in decorticated malted GPBs and SDCs to 37±4% and 43±3% of their original content, respectively, the difference between these reduction yields being not statistically significant at $p = 0.05$ (Cimini *et al.*, 2023a). Similarly, the phytic acid content in both malted seeds was lessened to approximately 68% of the original content (Cimini *et al.*, 2023a). On the contrary, in decorticated malted OLs, the raffinose and phytate contents were lowered to 21±2% and 73±2%, respectively, of the original content (Cimini *et al.*, 2024).

With respect to the conventional barley malting process (Food and Agriculture Organization [FAO], 2009), which lasts for on average 9 days and consists of a 48-h steeping phase, a 96-h germination step, and a 24-h kilning phase, followed by the rootlet separation and grain calibration step, the pulse malting process examined here was shorter, since it involved a soaking step at 25 °C of 3 h, a germination step of 72 h, and a drying step of 27 h (Cimini *et al.*, 2023a, 2024). The average barley–malt ratio was about 1.267 g/g, and the ratio between original legume and the malted one varied from 1.16 g/g, 1.17 g/g, and 2.22 g/g in GPBs, SDCs, and OLs, respectively. Further tests in the pilot scale were scheduled to assess the specific consumption of water and thermal and electric energy per kilogram of pulse undergoing malting, as related to barley malting, which consumes about 7 L of water, 0.75 kWh of thermal energy (99% attributable to the drying phase), and 0.13 kWh of electricity per kilogram of barley (FAO, 2009).

Once split, the GPB, SDC, and OL seeds before and after the malting process were characterized by different CIELAB color coordinates (defined by the International Commission on Illumination [CIE]; Table 1) even if split GPBs, SDCs, or OLs, either in original form or malted, exhibited a light cream color, a dark tan color, or golden metallic color, respectively, in the Avery list (https://convertingcolors.com; accessed 9 October 2023).

Upon grinding, each decorticated malted pulse flour exhibited the same raw protein, TS, RS, raffinose, and phytic acid contents of the corresponding decorticated malted pulse cotyledons (Table 1). It is worth noting that of these, the dehulled GPB malt flour had the lowest TS content (~35 g/100 g dm) but the highest content of RS (~22 g/100 g dm). Such concentration of RS was within the common bean systematic map extracted from the Scopus and Web of Science databases by Bozkir *et al.* (2023) and was characterized by an average value

of 16.4 g/100 g dm and a standard deviation as high as 12.8 g/100 g dm. Since such a flour had an RS–TS ratio of about 63%, it might represent a valuable ingredient for the formulation of functional foods with a final content of RS ≥ 14% of TS; these being awarded a health claim indicating an improvement in postprandial glucose metabolism according to European Commission Regulation 432/2012 (2012).

Fresh egg pasta production

The fresh egg pasta samples were prepared by mixing whole eggs and common bread wheat flour type 00 or dehulled malted GPB or SDC flour in a weight ratio of 37:63 g/g, as shown in Figure 3. Their appearance is shown in Figure 4, while their proximate composition is reported in Table 2.

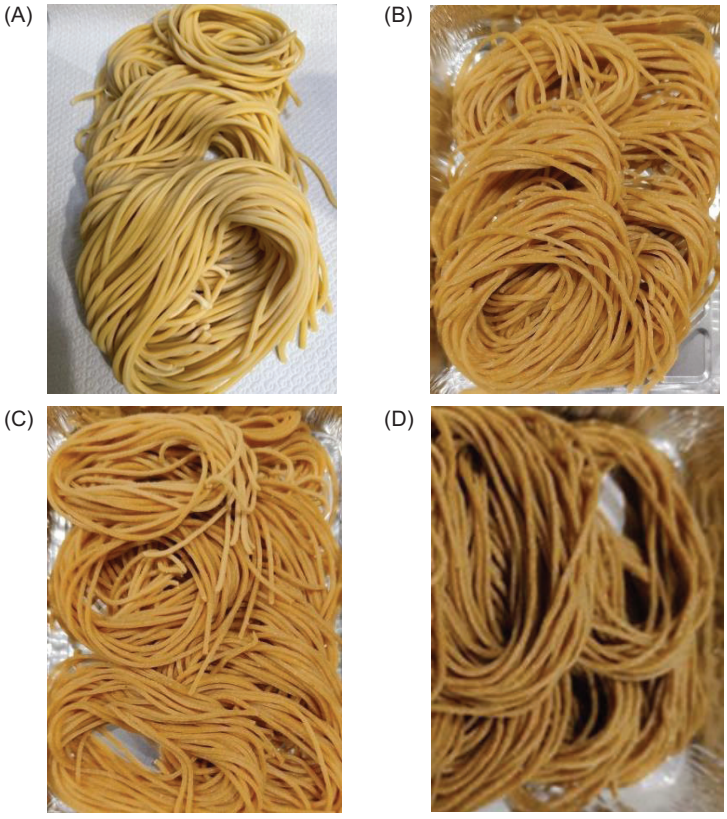

Figure 4. Pictures of fresh egg pastas made from (A) whole egg and common bread wheat flour type 00 or (B) dehulled malted GPB flour, (C) SDC flour, or (D) OL flour; the latter being extracted from Cimini *et al.* (2024).

Table 2. Proximate composition of egg pastas obtained by mixing whole egg with common bread wheat flour type 00, or dehulled malted GPB, SDC, or OL flour as compared to some commercial pulse dry pastas.

Component (g/100 g dm) Pasta type	Raw proteins	Total starch (TS)	Resistant starch (RS)	Phytic acid	Raffinose
Egg Pasta	16.6±1.5^{c}	71.4±1.5^{a}	0.54±0.04^{d}	0.03±0.01^{c}	0^{b}
Malted GPB egg pasta	20.8±1.9^{b}	32.4±2.3^{c}	20.3±1.8^{a}	0.84±0.03^{a}	0^{b}
Malted SDC egg pasta	20.0±1.8^{b}	51.3±2.5^{b}	1.1±0.8^{c}	0.58±0.01^{b}	0^{b}
Malted OL egg pasta	23.6±2.1^{a,b}	46.75±2.3^{b}	1.63±0.22^{b}	0.60±0.05^{b}	0^{b}
Commercial chickpea pasta	22.0*	47.2±1.3^{b}	nd	0.88±0.04^{a}	1.17±1.02^{a}
Commercial lentil pasta	26.0±1.0^{a}	50.6±1.0^{b}	nd	0.90±0.07^{a}	0.61±0.3^{a}

In each column, values with the same superscripted letter have no significant difference at $p < 0.05$.
nd: not determined.
*Value extracted from the nutritional label.

The conventional fresh egg pasta exhibited the highest TS content but the lowest contents of crude protein, RS, and phytic acid. The RS fraction is not hydrolyzed in the small intestine but partially or totally fermented in the large intestine (Lal *et al.*, 2021). The RS level in fresh egg pasta, including malted SDC or OL flour, was about two or three times more than that present in conventional fresh egg pasta, while RS in fresh egg pasta with malted GPB flour was as high as 20.3±1.8 g/100 g dm.

All fresh egg pastas, including any of the malted pulse flours examined here, were practically devoid of α-galactosides with a crude protein content not statistically different from that of the commercial lentil or chickpea spaghetti acquired in a local supermarket at 95% confidence level, but with 67% less phytate content. It is worth noting that the commercial lentil and chickpea pastas had a raffinose equivalent content of around 0.6 and 1.2 g/100 g dm, respectively (Table 2).

The OCT of conventional fresh egg pasta was approximate 8 min but reduced to 6 min in the case of its counterparts made from dehulled malted pulse flour (Table 3). Under these circumstances, the specific electric energy consumed per kilogram of fresh pasta (e_{PA}) was about 1.75±0.16 kWh/kg. Having cooked fresh pasta samples in a lidded pot with induction hob regulated at 0.4 kW, the energy consumption was about 17% less than the default pasta cooking energy requirement according to *Environmental Product Declarations* (EPD, 2022), that is, 0.18 kWh for boiling 1 kg of water, and 0.05 kWh/min for cooking 1 kg of pasta. Moreover, 9.3±1.4% of the cooking water used (m_{W0}) was absorbed by cooked pasta, 7.8±0.7% was evaporated, and the remaining 83±2% (i.e. pasta water) was drained in the sink. This agreed with the previous findings of cooking conventional durum wheat semolina dry pasta (Cimini *et al.*, 2020) or fresh pasta enriched with high amylose wheat flour (Cimini *et al.*, 2022).

The relative water uptake (WU = 0.76±0.10 g/g) and cooking loss (CL = 0.048±0.002 g/g) of fresh egg pasta were definitively smaller than those characterizing fresh egg pasta, including any dehulled malted pulse flour (WU = 0.98±0.08 g/g; CL = 0.09±0.01 g/g). Whereas water uptake was in line with those typical of good quality pasta (Pasqualone *et al.*, 2016), the release of solid matter was more than that observed during cooking conventional dry pasta (0.040–0.058 g/g) (Cimini *et al.*, 2020) or fresh pasta made from 100% high-amylose wheat flour (0.076±0.009 g/g) (Cimini *et al.*, 2022).

Table 4 lists key textural properties (i.e. hardness at 30% and 70% compression, F_{30} and F_{70}; cohesiveness; springiness; and initial diameter) of different pasta strands

Table 3. Main results of the cooking tests using different fresh egg pasta types examined in this work: fresh pasta (m_{PA}) and cooking water (m_{W0}) masses; cooking water–pasta ratio (wpr); cooked pasta (m_{CP}), pasta water (m_{WF}), and water evaporated (m_{We}) masses; specific cooking energy consumed (e_{PA}); water uptake (WU), and cooking loss (CL).

Pasta type	OCT (min)	m_{PA} (min)	m_{W0} (g)	WPR (L/kg)	m_{CP} (g)	m_{WF} (g)	m_{We} (g)	e_{PA} (kWh/kg)	WU (g/g)	CL (g/g)
Egg pasta	8.0±0.1^{a}	50.1±0.1^{a}	500±0^{a}	9.98±0.02^{a}	88±5^{b}	428±15^{a}	34±10^{a}	1.71±0.10^{a,b}	0.76±0.10^{b}	0.048±0.002^{c}
Malted GPB egg pasta	6.0±0.1^{b}	50.2±0.0^{a}	500±0.0^{a}	9.96±0.00^{a}	97±8^{a,b}	413±16^{a}	41±8^{a}	1.56±0.07^{b}	0.93±0.16^{a,b}	0.096±0.007^{a}
Malted SDC egg pasta	6.0±0.1^{b}	50.1±0.1^{a}	500±0.0^{a}	9.98±0.02^{a}	97±3^{b}	413±3^{a}	40±1^{a}	1.81±0.24^{a,b}	0.94±0.07^{b}	0.080±0.002^{b}
Malted OL egg pasta	6.0±0.1^{b}	50.4±0.1^{a}	500±0.0^{a}	9.92±0.01^{a}	105±1^{a}	405±9^{a}	41±10^{a}	1.87±0.06^{a}	1.08±0.01^{a}	0.101±0.015^{a}

In each column, values with the same superscripted letter have no significant difference at $p < 0.05$.

Table 4. Main textural properties (hardness at 30% [F_{30}] and 70% [F_{70}] compression; cohesiveness [CER]; springiness [S]; and initial diameter [s_{CP}]) of cooked fresh egg pasta strands examined here when using the conventional water–pasta ratio of 10 L/kg.

Pasta type	F_{30} (N)	F_{70} (N)	CER (-)	*S* (mm)	s_{CP} (mm)
Egg pasta	6.6±0.8^{c}	16.5±1.1^{b}	5.3±0.7^{a}	2.13±0.10^{a}	3.07±0.09^{a}
Malted GPB egg pasta	8.4±1.0^{b,c}	11.8±0.9^{c}	2.1±0.7^{b,c}	1.39±0.16^{b,c}	2.86±0.14^{a}
Malted SDC egg pasta	8.1±0.8^{b,c}	16.3±1.5^{b}	3.3±0.6^{b}	1.50±0.07^{b}	2.59±0.07^{b}
Malted OL egg pasta	9.3±0.6^{b}	12.5±0.7^{c}	1.8±0.2^{c}	1.27±0.11^{c}	2.86±0.06^{a}
Commercial lentil pasta	11.8±0.9^{a}	28.6±0.6^{a}	4.7±0.5^{a}	1.47±0.04^{b}	2.40±0.02^{c}

In each column, values with the same superscripted letter have no significant difference at $p < 0.05$.

examined here when cooked with a conventional water–pasta ratio of 10 L/kg. Despite some variations in TA parameters, the cooked fresh egg pasta samples with any malted pulse flour exhibited almost the same diameter (2.8±0.2 mm), hardness at both 30% (8.6±0.6 N) and 70% (14±2 N) deformation, cohesiveness (2.4±0.6), and springiness (1.4±0.1 mm). It was noted that the cooked lentil dry pasta samples exhibited a greater hardness at both deformation levels tested.

The simulated starch digestion process for the cooked fresh egg pasta samples examined here yielded the digestograms (plot of glucose concentration, C_G, as discharged by enzymatic treatments against digestion time, t) shown in Figure 5.

The area under each digestogram up to an overall incubation period of 180 min was calculated using the Trapezoidal Rule as shown in Table 5. It reduced from about 81 g min/L for white bread to ~51 g min/L for the conventional fresh egg pasta sample and to 19–28 g min/L for the counterparts containing any malted pulse flour. The chickpea dry spaghetti exhibited an average AUC of more than that pertaining to the lentil dry spaghetti at $p = 0.05$, and the difference between the latter (AUC = 26.8±3.1 g min/L) and that estimated for fresh egg pasta, including malted OL flour (28±4 g min/L), was not significant statistically at $p = 0.05$. Thus, the malting process did not alter the GI trait of lentil flours. This cannot be extrapolated to chickpeas, since the average AUC (23.0±1.2 g min/L) for fresh egg pasta with malted SDC flour was definitively smaller than that (33.8±1.4 min/L) for chickpea dry pasta.

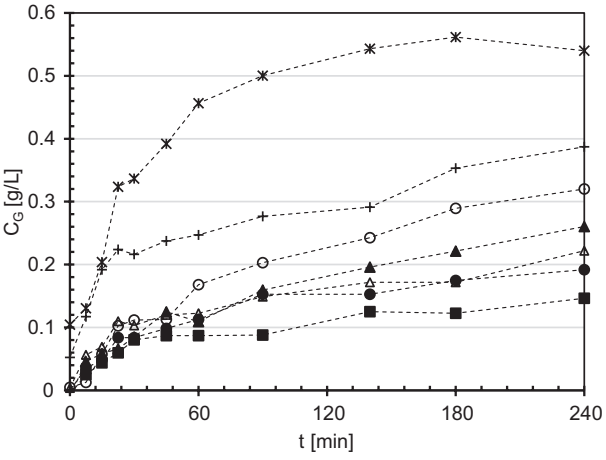

Figure 5. Time course of simulated *in vitro* starch digestion using white bread (∗), cooked fresh egg pasta samples containing 37% (w/w) whole egg, and 63% (w/w) common bread wheat flour (+); malted *Gradoli Purgatory* bean (■), *Solco Dritto* chickpea (•), and *Onano* lentil (▲) flour; and cooked commercial chickpea (○) or lentil (△) dry pasta.

By dividing AUC values by that of the reference product (white bread), it was possible to calculate SHI and *in vitro* GI by using Equation (3). Such an index was introduced to classify high carbohydrate-containing foods according to their effect on post-prandial blood glucose content into three categories: low (<55), medium (55–69) and high (>70) GI foods (Foster-Powell *et al.*, 2002). According to this classification system, which was confirmed by Atkinson *et al.* (2021), fresh egg pasta made with any of the dehulled malted pulse flours tested here displayed an *in vitro* GI ranging from 28% to 38%, and thus can be classified as low *in vitro* GI foods.

These results agree with the previous studies executed with other pulse-based products (Singh *et al.*, 2021), including pasta enriched with legumes (Di Pede *et al.*, 2021; Fujiwara *et al.*, 2017; Turco *et al.*, 2019). Thus, the consumption of such foods would limit not only the uptake of flatulence-inducing oligosaccharides and phytic acid responsible for mineral malabsorption, but also increase in the post-meal level of glucose in the blood, thus the reducing the long-term risk of type 2 diabetes mellitus and protecting against obesity and metabolic risk factors, such as coronary heart disease (Brand-Miller *et al.*, 2003).

Table 5. Estimation of the areas (AUC) enclosed by the digestograms of a few food products (i.e. white bread, fresh egg pasta samples, and chickpea and lentil dry pastas) for a digestion time of 180 min, starch hydrolysis index (SHI) and *in vitro* glycemic index (GI) calculated using Equation (3), and their classification according to the so-called GI chart.

Food product	AUC (g min/L)	SHI (%)	GI (%)	GI chart
White bread	81.2±0.4^{a}	100.0±0.5^{a}	94.4±0.4^{a}	High
Fresh egg pasta with soft wheat flour	51.4±4.0^{b}	63.3±4.9^{b}	62.8±4.2^{b}	Medium
Fresh egg pasta with malted GPB flour	19.0±2.8^{e}	23.4±3.5^{e}	28.4±3.0^{e}	Low
Fresh egg pasta with malted SDC flour	23.0±1.2^{d,e}	28.4±1.5^{d,e}	32.7±1.3^{d,e}	Low
Fresh egg pasta with malted OL flour	28.0±4.0^{c,d}	34.4±4.9^{c,d}	37.9±4.3^{c,d}	Low
Chickpea dry pasta	33.8±1.4^{c}	41.7±1.7^{c}	44.1±1.5^{c}	Low
Lentil dry pasta	26.8±3.1^{d}	33.0±3.8^{d}	36.6±3.2^{d}	Low

In each column, values with the same superscripted letter have no significant difference at $p < 0.05$.

More specifically, the fresh egg pasta with malted OL flour displayed an *in vitro* GI of about 38%, which was not statistically different from the GI estimated for fresh egg pasta with malted SDC flour (~33%) but absolutely greater that that evaluated for fresh egg pasta with malted GPB flour (~28%). Actually, only fresh egg pasta made of malted GPB flour having a low TS content (~32 g/100 g) and a high RS content (~20 g/100 g) was characterized by an RS–TS ratio of about 63%, by far greater than 14%. This threshold value has been specified by the European Commission Regulation 432/2012 (2012) to label foods with a permitted health claim referring to an improvement in postprandial glucose metabolism.

Conclusions

The malting of three typical pulse varieties (i.e. GPB, SDC, and OL) cultivated in the Alto Lazio region of Italy was studied at laboratory scale. The resulting decorticated malted pulse flours were used to prepare fresh egg pastas, devoid of flatulence-inducing oligosaccharides, and with a low phytate content (0.6–0.80 g/100 g), a crude protein content of around 20 g/100 g and low *in vitro* GI. Among such fresh egg pastas, including malted GPB flour, exhibited not only a significantly smaller GI (28±3%) but also an RS level by far greater than the threshold value (14%) specified by the European Commission Regulation 432/2012 (2012) to label foods with the health claim indicating an improvement in postprandial glucose metabolism.

Further work is needed to validate the malting process of pulses at a pilot scale and assess specific water and energy consumption yields and processing costs. The future work must test the consumer acceptability of these novel gluten-free decorticated malted pulse fresh egg pastas.

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Author Contributions

Conceptualization, A.C. and M.M.; methodology, A.C., M.M.; validation, A.C., A.P., L.M.; formal analysis, A.C. and M.M.; investigation, A.C., A.P., and L. M.; resources, A.C. and M.M.; data curation, M.M.; writing—original draft preparation, M.M.; writing—review and editing, A.C., A.P., L.M. and M.M.; visualization and supervision: A.C., and M.M.; project administration, A.C.; funding acquisition, A.C., and M.M. All authors have read and agreed to the published version of the manuscript.

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