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Lentils based pasta affect satiation, satiety and food intake in healthy volunteers

Iolanda Cioffi, Daniela Martini, Cristian Del Bo', Antonella Brusamolino, Maria Cristina Casiraghi, Marisa Porrini, Patrizia Riso *

Division of Human Nutrition, Department of Food, Environmental and Nutritional Sciences (DeFENS), Università degli Studi di Milano, 20133, Milan, Italy

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ABSTRACT

Plant-based diets represent a valid strategy to improve human health and increase food sustainability. The availability of legume-based products, a good source of proteins and fibers, could help consumers to promote healthy dietary patterns. The aim of this study was to examine the impact of different legume-based pastas on energy intake and appetite in healthy volunteers. Four *ad libitum* (protocol 1) and iso-caloric pre-load meals (protocol 2) were tested using a randomized repeated measure design. The test meals consisted of lentils pasta (LP), chickpeas pasta (CP); durum wheat pasta (DWP) and gluten free pasta (GFP), served with tomato sauce. Protocol 1: the *ad libitum* lunch meal was consumed then EI registered. Protocol 2: subjective appetite was assessed by visual analogue scale before and after the pre-load meal for 2 h until an *ad libitum* buffet was served to assess EI. Twenty (age: 39.2 ± 8.41 years; BMI: 23.4 ± 3.4 kg/m^2) and 40 (age: 42.6 ± 8.7 years; BMI: 23.8 ± 4.2 kg/m^2) healthy subjects were respectively recruited for each protocol. ANCOVA analysis showed an overall effect of meals and sex on EI within meal and at the subsequent meal, resulting in a lower EI after LP compared to DWP ($p < 0.05$). Appetite sensations were significantly influenced solely after the pre-load meal, where repeated measures ANCOVA showed increased post-prandial satiety after LP and CP ($p < 0.05$) compared to DWP in females, whereas a reduction in desire to eat and higher fullness was found following LP compared to the other meals in both sexes ($p < 0.05$). Overall, lentil-based pasta seemed to acutely affect EI both within and at the subsequent meal, especially in females. Consumption of legume-based pasta might enhance legume intake by modulating appetite feelings and increasing food sustainability. However, further studies are needed to support these results in the long-term and considering different target populations.

1. Introduction

Shifting towards plant-based diets, characterized by a high consumption of cereals, legumes, vegetables, fruit, and nuts with a concomitant reduction of animal food sources, seems to be the most viable and sustainable solution for improving population health (Becerra-et al., 2018; Tucci et al., 2024; Tucci et al., 2022) and food systems (Willett et al., 2019). Previous observational studies have shown consistent associations between plant-based foods, like legumes, and the reduction of non-communicable diseases, such as obesity, diabetes, cancers, and cardiovascular diseases (Bazzano et al., 2001; Hermsdorff et al., 2011; Marventano et al., 2017; McCrory et al., 2010; Papanikolaou and Fulgoni, 2008). Health-promoting effects of legumes, including green beans and peas, peanuts, soybeans, lupine, dry beans, broad beans, dry peas, chickpeas, and lentils (Bouchenak and Lamri-Senhadji, 2013), are substantially linked to their nutritional composition, being an excellent source of protein, dietary fibers, phenolic compounds and phytate (Barman et al., 2019; Rachwa-Rosiak et al., 2015; Singh, 2017).

A regular intake of legumes seems to improve appetite (McCrory et al., 2010; Clark et al., 2019; Zafar and Kabir, 2017; Li et al., 2014) with beneficial effects on weight management (Abete et al., 2009; Crujeiras et al., 2007; Jenkins et al., 2012) and glycemic control (Sievenpiper et al., 2009; Bajka et al., 2023). There are many mechanisms by which the composition of legumes may influence appetite (Li et al., 2014) and as a consequence eating behavior. Firstly, the type of fiber typically present within legumes can form a gelatinous bulk producing an increased gastric distension and a decreased emptying speed, resulting in an early satiation (i.e. process that leads to meal termination, i.e., intra-meal satiety) and then, in a prolonged feeling of satiety, which refers to eating inhibition (Blundell and Halford, 1994; Tan et al.,

* Corresponding author.
E-mail address: patrizia.riso@unimi.it (P. Riso).

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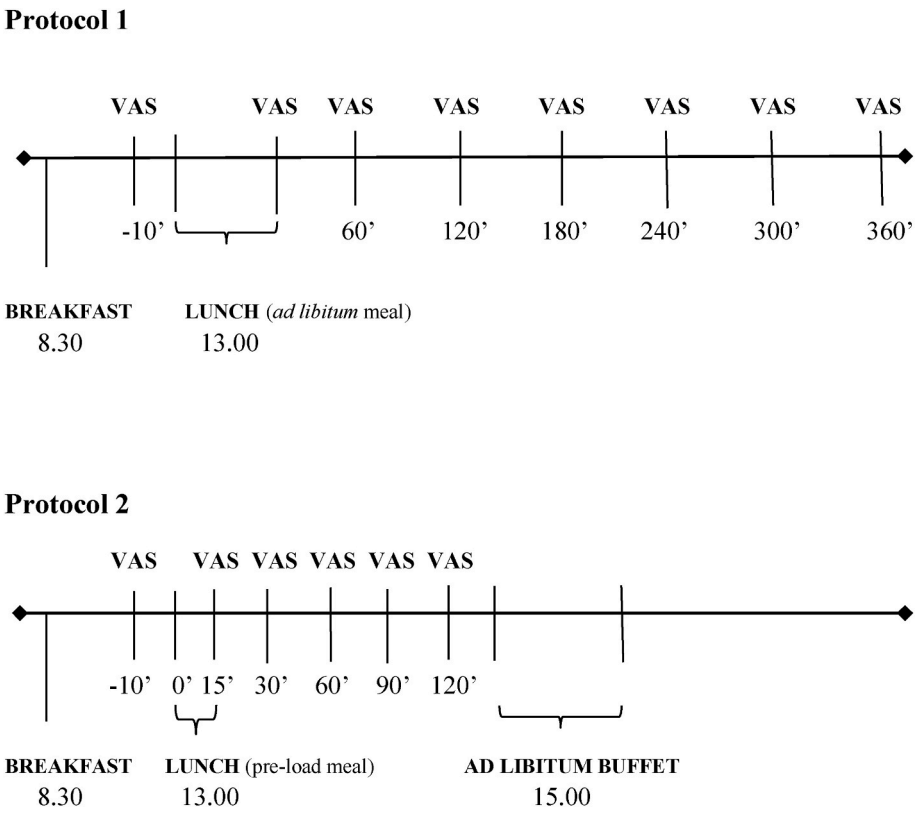

Fig. 1. Experimental protocol sessions
Protocols 1 (upper part) and protocol 2 (lower part). VAS = Visual Analogue Scale to measure the subjective appetite.

Table 1
Nutritional composition of 4 pasta formulations tested in the study.

	Energy kcal	Protein g	CHO g	Fat g	Dietary Fiber g
LP	335	26.4	45.7	2.4	12.6
CP	352	22.3	43.6	6.6	14.0
DWP	359	13.0	70.7	2.0	3.0
GFP	359	6.5	78.7	1.8	1.1

LP: lentils pasta; CP: chickpeas pasta; DWP: durum wheat pasta; GFP: gluten free pasta.
CHO: carbohydrates. Data are expressed as g/100g.

2016; Blundell et al., 2010). Also, their protein content is remarkable, if compared to other plant-based food, contributing towards a more satiating meal effect (Weigle et al., 2005; Kristensen et al., 2016). Finally, the presence of protease inhibitors lectins, phytoestrogens, saponins and phenolic compounds (Barman et al., 2019; Rachwa-Rosiak et al., 2015), seems to have specific activities involved in the modulation of some gut hormones able to regulate appetite (Weigle et al., 2005; Qin et al., 2021). Although legumes exert those beneficial effects (Martini et al., 2021; Patel et al., 2024), they are still not adequately consumed in Italy (Vitale et al., 2021).

Among plant-based foods, pasta is one of the most consumed in Italy, mainly in its refined form. Compared to many other starchy products such as breads or potatoes (Atkinson et al., 2008), pasta has a lower

Table 2
Nutritional composition of both *ad libitum* and preload meal-tests using 4 pasta formulations served with tomato sauce.

Meals	Ad libitum meal[a]					Pre-load meal[b]				
	Energy kcal	Protein g	CHO g	Fat g	Fiber g	Energy kcal	Protein g	CHO g	Fat g	Fiber g
Males										
LP + T	1568	110.8	212	16.4	57.6	509,1	35,99	68,89	5,33	19,52
CP + T	1636	94.4	203.6	33.2	65.6	532,1	30,69	66,19	10,79	21,32
DWP + T	1664	57.2	312	14.8	21.6	541,1	18,59	101,39	4,81	7,02
GFP + T	1664	31.2	344	14	14	541,1	10,14	111,49	4,55	4,55
Females										
LP + T	1176	83.1	159	12.3	45	430,7	30,43	58,33	4,51	16,54
CP + T	1230	70.8	152.7	24.9	49.2	449,7	25,93	55,93	9,13	18,04
DWP + T	1248	42.9	234	11.1	16.2	457,7	15,73	85,83	4,07	5,94
GFP + T	1248	23.4	258	10.5	10.5	457,7	8,58	94,63	3,85	3,85

Data are expressed as mean ± standard deviation. LP: lentils pasta; CP: chickpeas pasta; DWP: durum wheat pasta; GFP: gluten free pasta; CHO: carbohydrates.
Portions provided in both *ad libitum* and pre-load studies considering sex differences, as follows.
[a] Ad libitum meal: 400 g pasta +400 ml tomato sauce in men and 300 g pasta +300 ml tomato sauce (T) in women.
[b] Pre-load meal: 130 g pasta +130 ml tomato sauce in men and 110 g pasta +110 ml tomato sauce (T) in women.

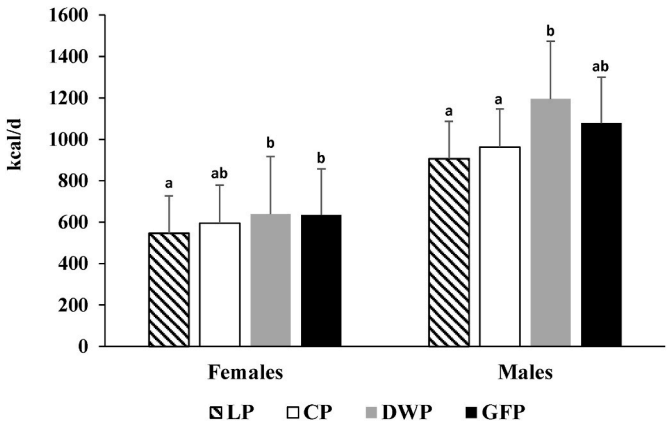

Fig. 2. *Ad libitum* energy intake following 4 different pasta meals in males and females
Data are expressed as unadjusted mean and standard error. LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta. Different letters indicate $p < 0.05$.

Table 3
Palatability ratings (cm) after consumption of 4 pasta formulations in the protocol 1.

	Pleasantness	Texture	Appearance	Colour	Taste
LP + T	3.9 ± 2.8 [b]	4.1 ± 3.2 [b]	7.7 ± 1.7 [b]	7.3 ± 1.9 [ab]	5.1 ± 2.4 [b]
CP + T	4.0 ± 2.4 [b]	3.5 ± 2.2 [b]	7.8 ± 1.9 [b]	7.4 ± 1.9 [ab]	4.7 ± 2.2 [b]
DWP + T	7.7 ± 1.9 [a]	8.9 ± 1.3 [a]	8.4 ± 1.5 [b]	8.3 ± 1.5 [b]	7.0 ± 2.3 [a]
GFP + T	4.7 ± 2.7 [b]	4.6 ± 3.6 [b]	5.3 ± 2.9 [a]	7.0 ± 2.1 [a]	5.7 ± 2.4 [ab]

Data are expressed as mean ± standard deviation. LP: lentils pasta; CP: chickpeas pasta; DWP: durum wheat pasta; GFP: gluten free pasta; T: tomato sauce. Different letters in the same column indicate $p < 0.05$.

glycemic index (GI) and the ingestion of low GI foods may have numerous positive effects on health by lowering glycemic response and increasing satiety (Cioffi et al., 2016a, 2016b; Kristensen et al., 2010). Hence, in the last years, pasta has been often reformulated by using a combination of different flours and/or specific ingredients, including different legume flours (Kristensen et al., 2016; Mollard et al., 2012, 2014), to obtain products with advantageous nutritional characteristics, including a higher percentage of fiber and/or protein (Kristensen et al., 2016; Martini et al., 2018), potentially affecting appetite feelings (Li et al., 2014; Cioffi et al., 2016a; Mollard et al., 2012) and possibly metabolic markers (Cioffi et al., 2016b, 2019; Mollard et al., 2014).

So far, only a limited numbers of studies have assessed the impact of legume intake, alone or in combination with other foods, on satiety and energy intake (EI), with contrasting results (Li et al., 2014; Wanders et al., 2011), at least partially depending on differences in the form and/or amount of legume consumed as well as in the choice of the control foods. For instance, Li et al. (2014) observed an impact on acute satiety but not second meal intake in nine trials in which dietary legumes were incorporated into test meals in different ways (e.g., cooked whole, used as flour in bread or served as a spread) and compared with different controls such as bread, potato or cheese. Moreover, sample sizes in most of these studies were often small. Still, fewer data were currently available on satiation (Mollard et al., 2012), defined by EI consumed within a meal, by determining meal size (Blundell et al., 2010). Whilst none of them assessed the effect of a pasta, a typical Italian product, made exclusively by legume flours on satiation, satiety and EI.

Given the optimal nutritional composition of legumes, we hypothesized that the consumption of legume-based pasta would induce early satiation and promote post-prandial satiety resulting in lowered EI. Addressing all these targets in a well-controlled setting within a cross-over, randomized, controlled intervention could contribute to overcome possible shortcomings for a bettering elucidation of the actual impact of such products on eating behavior. Therefore, the objectives of the current study were to examine the acute effect of four different types of pasta, based on lentils, chickpeas, durum wheat and gluten-free flours, on satiation, satiety, and EI in healthy adult volunteers.

2. Methods

2.1. Subjects

Healthy volunteers, mainly employees at the University of Milan, were recruited between April and May 2018 for participating in this randomized cross-over study. Participants of both sexes, aged between 27 and 55 years old, nonsmokers, not restrained eaters and habitual pasta consumers (at least 5 servings per week) were included. Exclusion criteria were pregnancy or lactation, known history of chronic illness such as diabetes, cardiovascular, hepatic, renal, or gastrointestinal diseases, following specific diets (e.g., vegetarian/vegan or macrobiotic), use of medications able to affect appetite sensation, and allergies or dislike to any food components provided in the study. Screening of participants was carried out using a semi-quantitative questionnaire focused on eating habits and food preferences (Martini et al., 2018; Berti et al., 2008). All participants provided written informed consent before participation in the study.

2.2. Study design

Four different *ad libitum* lunch meals and four different iso-caloric lunch meals were tested using two different protocols (1 and 2), with a randomized repeated measure design to respectively assess EI both within meal (i.e., satiation, process that leads to the termination of eating, therefore controls meal size - protocol 1) and at the subsequent meal (i.e., satiety, process that leads to inhibition of further eating and it is known as inter-meal satiety - protocol 2). The experimental designs are shown in Fig. 1. All participants attended all sessions, separated by at least 1 week wash out. On all test days, volunteers were instructed to consume the same low-fiber breakfast at home, at the same time (not later than 8.30 a.m.) and were not allowed to consume any other foods until the start of the test meal. At their arrival at the laboratory kitchen at 1 p.m., they were instructed to fill in a short questionnaire assessing their general well-being, including the feeling of nausea, headache, sleepiness and weakness, to avoid potential confounding factors on appetite sensation. The meal-tests were served with 1500 mL plain water. The research was conducted in accordance with the Helsinki Declaration (World Medical Association, 2013) and the protocol was approved by the Ethical Committee of the University of Milan (All 2 Verb_25.05.18).

2.2.1. Protocol 1

The *ad libitum* test meal was served to assess EI within meal (i.e., satiation) after different pasta formulations. After completing the questionnaire about well-being, subjects were instructed to eat until comfortably full and to complete the palatability questionnaire immediately after the test meal. Portions of the *ad libitum* meal differed according to sex, due to differences in energy requirements and habitual intake, as follows: 300 g (dry weight) of pasta with 300 g of tomato sauce for females and 400 g (dry weight) of pasta with 400 g of tomato sauce for males. Before consumption of each *ad libitum* pasta meal and every 60 min for a total of 6 h, the feelings of desire to eat, fullness and satiety were recorded (Martini et al., 2018).

2.2.2. Protocol 2

The preloading paradigm method was used to evaluate the effect of

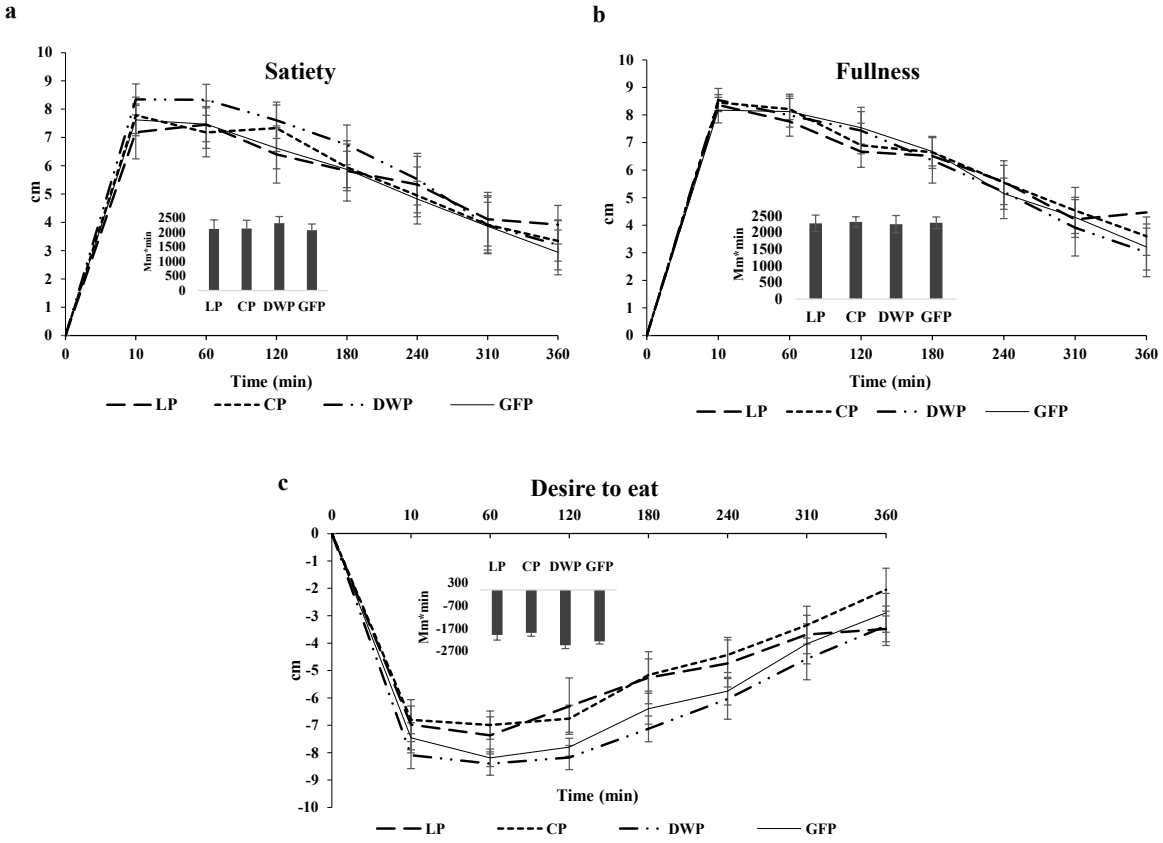

Fig. 3. Appetite ratings in healthy males
Unadjusted mean ratings with standard error of satiety (a), fullness (b), and desire to eat (c) during 6 h following 4 *ad libitum* meals in the protocol 1(LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta) and the corresponding AUCs expressed as mean ± standard error.

different pasta formulations on EI at the subsequent meal. In this protocol, the iso-caloric meals consisted of 110 g (dry weight) of pasta with 110 g of tomato sauce for females and 130 g (dry weight) of pasta dressed with the same amount of tomato sauce for males. Volunteers were asked to consume the whole portion within 15 min. Then, the preload meal was followed by an *ad libitum* buffet to assess EI after 2 h. Visual Analogue Scales (VAS) questionnaires (Flint et al., 2000) assessing desire to eat, fullness and satiety were administered and completed before (baseline), immediately after the meal consumption, and every 30 min until the *ad libitum* buffet. In addition, participants were asked to fill in the palatability questionnaire.

2.3. Test meals composition

In both *ad libitum* and preload meals, the following pasta formulations, based on different flours, and served with tomato sauce (T) were tested: i) lentils pasta (LP) ii) chickpeas pasta (CP); iii) durum wheat pasta (DWP) and iv) corn and rice flours, i.e., gluten free pasta (GFP). Nutritional characteristics of pasta are presented in Table 1, while the composition of the whole test meals (*ad libitum* and preload) is shown in Table 2. Each portion of pasta was cooked individually considering the following cooking time (8 min for LP and CP; 11 min for DWP and GFP) identified during the preliminary tests. To cook pasta, we followed the instruction recommended by the manufacturer (1 L of water and ~7 g of salt to cook 100 g of pasta) by adapting them to our portions.

The characteristics of each product provided in the *ad libitum* buffet is reported in Table S1. The buffet consisted of a variety of different foods (sweet, salted and yogurts) including: 38 g minicake (Barilla G. e R. Fratelli S.p.A, Italy), 50 g dry snack biscuits (Pavesi-Barilla G. e R. Fratelli S.p.A, Italy), 60 g low fat crackers (Barilla G. e R. Fratelli S.p.A, Italy), 250 g low fat blueberry or citrus fruits yogurt (Yomo, Italy), and 125 g vanilla or chocolate pudding (Danone, Italy). Subjects could eat each product as much as they liked. Energy and macronutrient intake of meals as well as of *ad libitum* buffet were calculated by using both nutritional food labeling and the Food Composition Database for Epidemiological Studies in Italy (http://www.bda-ieo.it/).

2.4. Appetite sensation and food palatability

VAS were used to evaluate appetite sensation (desire to eat, fullness and satiety) and food palatability (physical appearance, taste, texture, color and pleasantness) of the test meals (Martini et al., 2018). VAS consisted of a scale, 100 mm in length, with words anchored at each extremity, expressing the most positive and negative rating (Flint et al., 2000).

2.5. Sample size, calculations and statistical analyses

Given the magnitude effects of sex on both energy intake and appetite sensation (Cioffi et al., 2016a), data have been analyzed accordingly. As previously reported (Martini et al., 2018), a sample size of 18 subjects was calculated to be sufficient to detect 20% difference (power $1 - \beta = 0.80$; $\alpha = 0.05$) in satiety sensations following pasta intake selected as primary endpoint.

All data are presented as means ± standard deviations (SD) unless otherwise stated and the statistical significance level is defined as $p < 0.05$ All dependent variables were controlled for homogeneity of variance and normal distribution by investigation of residual plots and normal probability plots and histograms, respectively. The area under the curve (AUC) was calculated as the total area above zero for appetite

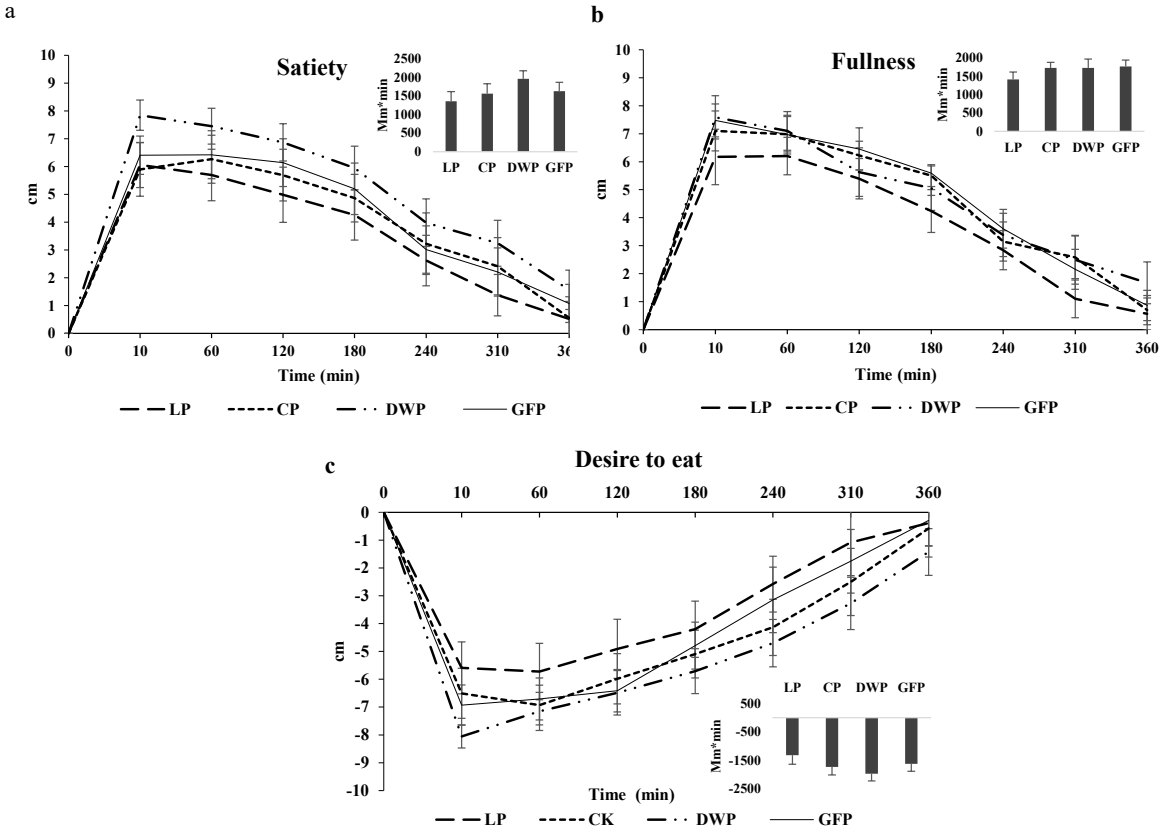

Fig. 4. Appetite ratings in healthy females
Unadjusted mean ratings with standard error of satiety (a), fullness (b), and desire to eat (c) during 6 h following 4 *ad libitum* meals in the protocol 1(LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta) and the corresponding AUCs expressed as mean ± standard error.

Table 4
Differences in EI from *ad libitum* buffet and cumulative EI (kcal) in females and males.

	Females (n = 20)		Males (n = 20)	
	EI Buffet	Cumulative EI	EI Buffet	Cumulative EI
LP + T	184 ± 83 [a]	615 ± 83 [a]	294 ± 154	804 ± 154
CP + T	264 ± 106 [b]	713 ± 106 [b]	298 ± 145	830 ± 148
DWP + T	243 ± 102 [ab]	700 ± 103 [b]	341 ± 200	887 ± 200
GFP + T	244 ± 115 [ab]	702 ± 115 [b]	329 ± 207	908 ± 208

Data are expressed as mean ± standard deviation. EI: energy intake; LP: lentils pasta; CP: chickpeas pasta; DWP: durum wheat pasta; GFP: gluten free pasta; T: tomato sauce. Cumulative EI = EI preload + EI buffet.
Different letters in the same column indicate $p < 0.05$.

feelings using the trapezoid model. An analysis of covariance (ANCOVA) was used to examine the effect of 4 different pasta meals on EI, palatability and AUCs, in which water intake and BMI were modeled as covariates, and sex was included as a fixed variable. For EI and AUCs data were shown separated by sex.

A repeated-measures ANCOVA analysis was used to examine the effect of meal and time and the meal × time interaction on the postprandial response of appetite measures, where BMI, baseline value and water intake were modeled as covariates, and post hoc pairwise comparisons were made where appropriate. Data were shown separated by sex. All statistical analyses were performed using the SPSS ver. 28 (IBM Corporation, Inc. Chicago, IL, USA).

3. Results

3.1. Protocol 1

Twenty healthy volunteers were recruited to assess the *ad libitum* EI within the meal after eating 4 pasta formulations. Since one dropped out due to personal reasons, a total of 19 subjects (10 males and 9 females), having a mean age of 39.2 ± 8.4 years and an average BMI of 23.4 ± 3.4 kg/m^2, completed the study. Based on their eating habits and food preferences, they showed comparable characteristics.

ANCOVA analysis adjusted for BMI and water intake showed an overall effect of meal ($p = 0.048$) and sex ($p < 0.001$) on *ad libitum* EI. Data showed an overall decrease of about 20% in EI after consuming LP and CP compared to DWP (LP:738 ± 47 kcal and CP:780 ± 47 kcal versus DWP:916 ± 47 kcal, $p = 0.009$, $p = 0.04$; respectively) unrelated to sex. However, as expected, males had a higher EI than females (M:1036 ± 278 kcal *vs*. W:604 ± 108 kcal; $p < 0.001$). Examining data per sex, we observed that EI was lower following the consumption of LP compared to both DWP ($p = 0.038$) and GFP ($p = 0.039$) in females. Similarly, *ad libitum* EI was reduced after consumption of both LP and CP compared to DWP in males (LP: 908 ± 68 kcal and CP: 955 ± 67 kcal versus DWP: 1194 ± 67 kcal, $p = 0.003$, $p = 0.001$; respectively) (Fig. 2).

ANCOVA analysis showed an overall effect of meals on pleasantness, texture, appearance, and taste ($p < 0.001$). Post-hoc pairwise comparison highlighted that DWP achieved the highest ratings for pleasantness, texture and taste compared to the other formulations ($p < 0.05$), while GFP showed the lowest score for appearance and color ($p < 0.05$), as reported in Table 3.

Repeated measures ANCOVA adjusted for baseline values, water intake and BMI showed a strong effect of time and sex ($p < 0.05$), but not

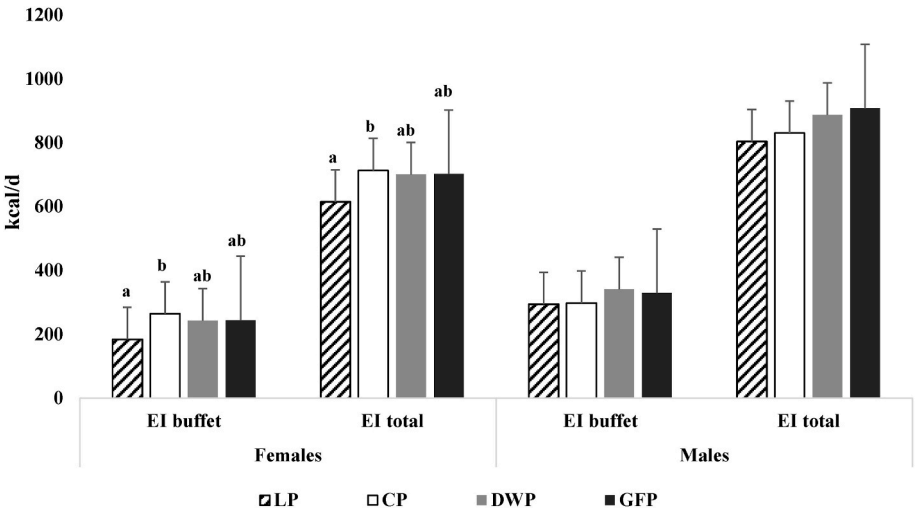

Fig. 5. Energy intake at the subsequent meal and total energy intake (preload + buffet meals) following 4 different preload pasta meals in males and females
Data are expressed as unadjusted mean and standard error. EI = energy intake, LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta. Different letters indicate $p < 0.05$.

Table 5
Palatability ratings (cm) assessed after consumption of 4 preload meals in the protocol 2.

	Pleasantness	Texture	Appearance	Colour	Taste
LP + T	4.1 ± 2.7 ^{b}	4.4 ± 1.8 ^{b}	7.0 ± 1.9 ^{ab}	6.7 ± 2.2 ^{ab}	5.3 ± 2.7 ^{b}
CP + T	4.0 ± 2.6 ^{b}	3.6 ± 2.9 ^{b}	6.4 ± 2.3 ^{b}	6.1 ± 2.2 ^{a}	5.3 ± 2.2 ^{b}
DWP + T	6.6 ± 2.3 ^{a}	7.9 ± 1.8 ^{a}	7.5 ± 1.8 ^{a}	7.5 ± 1.7 ^{b}	7.1 ± 2.2 ^{a}
GFP + T	5.2 ± 2.5 ^{ab}	5.2 ± 2.8 ^{ab}	6.1 ± 2.3 ^{b}	7.0 ± 1.8 ^{ab}	6.1 ± 2.3 ^{ab}

Data are expressed as mean ± standard deviation. LP: lentils pasta, CP: chickpeas pasta; DWP: durum wheat pasta; GFP: gluten free pasta, T: tomato sauce. Different letters in the same column indicate $p < 0.05$.

of meal, on the postprandial response of subjective appetite. Compared to DWP, both LP and CP showed a trend towards lower ratings of postprandial desire to eat in males ($p = 0.078$ and $p = 0.067$, respectively). Indeed, AUCs for desire to eat were lower for both LP and CP compared to DWP ($p = 0.047$; $p = 0.02$, respectively) (Fig. 3). On the contrary, neither appetite feelings nor the corresponding AUCs differed among meals in females (see Fig. 4).

3.2. Protocol 2

To assess EI after a preload meal, a sample of 40 healthy subjects was selected (20 females and 20 males), with a mean age of 42.6 ± 8.7 years and an average BMI of 23.8 ± 4.2 kg/m^2.

In Table 4 are reported EI from the *ad libitum* buffet consumed after 2 h from the preload meal. ANCOVA analysis, adjusted for BMI and water intake, demonstrated an overall effect of meals on EI in females ($p < 0.05$), with post-hoc analysis showing a lower EI following LP preload compared to CP ($p = 0.019$). While no difference on EI was found in males among different pasta formulations (Fig. 5). Also, buffet's macronutrients distribution was analyzed without showing any differences among participants.

With regard to the total EI (i.e., given by the preload EI plus *ad libitum* buffet EI), again an overall effect of meal was observed in females ($p = 0.014$), but not in males ($p = 0.24$), with a lower EI found after LP preload consumption compared to both DWP ($p = 0.022$), CP ($p = 0.004$) and GFP ($p = 0.007$) preloads (Fig. 5).

Palatability scores of the different pasta formulations are shown in Table 5. ANCOVA analysis, adjusted for BMI and water intake, showed a strong overall effect of meal on pleasantness ($p < 0.001$), texture ($p < 0.001$), appearance ($p = 0.010$), taste ($p = 0.002$) and color ($p = 0.02$). Post-hoc comparisons showed the highest ratings for all palatability parameters after consumption of DWP preloads, but also pleasantness and texture ratings were higher for GFP compared to LP and CP preloads ($p < 0.05$). Whilst color was perceived as different between DWP and CP only.

In the repeated measures ANCOVA, an overall effect of time and sex ($p < 0.05$) was found on postprandial appetite sensations. A reduced feeling of desire to eat following both LP and CP was found in males when compared to DWP ($p = 0.011$), whereas an increased fullness sensation after LP compared to both GFP ($p = 0.040$) and DWP ($p = 0.07$) (Fig. 6). No effect was observed for postprandial satiety. A strong overall effect of meal on iAUCs for desire to eat ($p < 0.01$) and fullness ($p < 0.01$) was found in males. Post hoc pairwise comparisons showed that LP resulted in lower iAUCs for desire to eat ($p < 0.05$) and in larger iAUCs for fullness ($p < 0.01$) compared to both DWP and GFP.

Compared to DWP, postprandial feelings of satiety increased for LP and CP ($p = 0.034$ and $p = 0.043$) in females. Still, an increase in fullness rating ($p = 0.023$) and a decrease in desire to eat ($p = 0.019$) were observed for LP in comparison with DWP and GFP ($p = 0.049$) (Fig. 7). Similarly, LP showed a larger iAUC for satiety compared to DWP ($p = 0.037$) and CP ($p = 0.047$), while no differences on iAUC for fullness and desire to eat were found.

4. Discussion

The aim of the current research was to examine the effects of four pasta formulations on satiation, satiety and relative EI. Findings reveal that consuming lentils-based pasta might acutely affect EI both within and at the subsequent meal, even though appetite sensations were significantly influenced solely after the pre-load meal, highlighting substantial sex differences (i.e. with higher impact on females). Perceived palatability, especially texture and taste, was lower for legume-based pasta compared to the traditional one, and able to affect EI within meal, but not appetite feelings.

Despite the beneficial effect of consuming legumes on human health (Marventano et al., 2017; Martini et al., 2021; Patel et al., 2024) and environmental sustainability (Tucci et al., 2022; Willett et al., 2019), the frequency of their consumption is still low among the Italian population (Vitale et al., 2021; Fiore, 2017) when compared to the National Dietary

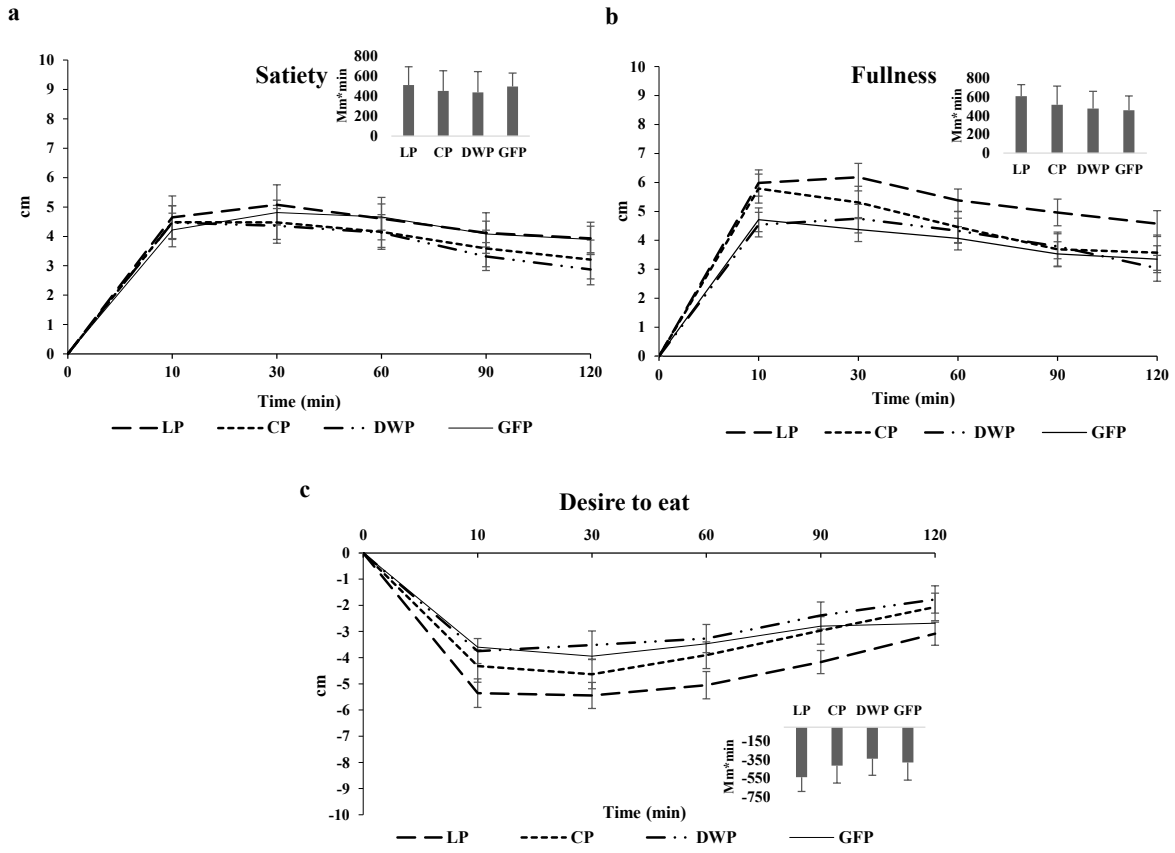

Fig. 6. Appetite ratings in healthy males
Unadjusted mean ratings with standard error of satiety (a), fullness (b), and desire to eat (c) during 2 h following 4 preload meals in the protocol 2 (LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta) and the corresponding AUCs expressed as mean ± standard error.

Guidelines recommendation (CREA, 2018). As such, the development of different and new alternatives to staple products, like legume-based pasta, might be a strategy to increase the variety of legume-based products and promote their consumption in the general population (Amoah et al., 2023).

To date, however, human studies looking into the impact of legumes on satiation and satiety are limited and provided mixed results (Li et al., 2014) for several reasons. First, the variability observed among the studies mostly depends on the form, amount and combination of legume consumed (Clark et al., 2019; Mollard et al., 2012, 2014). Second, food used as control treatment varied a lot, including white bread (Kristensen et al., 2010; Lee et al., 2006; Wong et al., 2009), different types of pasta (Cioffi et al., 2016b, 2019) or other foods (Abete et al., 2009; Sørensen et al., 2003). Similarly, study populations are quite heterogeneous, making those comparisons extremely challenging. Last, but not least, food or meal attributes such as macronutrient composition, energy density, physical properties of foods/meals and palatability may influence appetite differently (Sørensen et al., 2003; Cioffi et al., 2016c). However, given their optimal nutritional composition in terms of both protein and fibers, legume and legume-based products might help consumers to shift towards plant-based diets with positive effects on appetite, and consequently on their eating behaviors (Willett et al., 2019; Tucci et al., 2021).

In this context, to our knowledge, this is the first study assessing the effects occurring during the eating process of an *ad libitum* pasta meal, made exclusively by legume flours. Results showed that LP and CP determined a 20% lower EI compared to DWP, regardless of sex. Similarly, Mollard et al. (2012) observed an early satiation, i.e. lower *ad libitum* EI within meals, following consumption of legumes added to refined pasta, especially lentils, in healthy males. Although they did not test pasta made by legume flours, it is likely that the use of homogenized meals (pasta plus legumes) could have produced results on EI and appetite like those observed in the present study. The short-term effect might be explained by the ability of legume, even if in different form, to increase the volume of meal and its viscosity in the stomach due to the high fiber and protein content, resulting in a prolonged stomach distension (McCrory et al., 2010; Rebello et al., 2014). Similar results were reported by another study (Steinert et al., 2012) who showed that early satiation in the stomach was primarily affected by gastric distension. However, subjective appetite did not differ immediately after the *ad libitum* meals, indicating that the participants stopped eating at similar levels of fullness, nor differences were observed after 6 h from the meal, in accordance with previous studies assessing satiety(Cioffi et al., 2016b; Mollard et al., 2012). Interestingly, perceived texture and taste ratings differed significantly among meals, showing that both LP and CP achieved lower scores compared to DWP ($P < 0.05$) and suggesting that satiation, expressed by EI within meal, might be influenced by palatability, as previously reported (Sørensen et al., 2003). Sensory properties of foods such as taste, smell, texture, temperature and visual appearance determines palatability (Hyde and Witherly, 1993), which acts in stimulating early satiety signals, as described in the satiety cascade by Blundel et al. (Blundell et al., 2010). Studies measuring the effect of palatability on satiation by assessing *ad libitum* energy intake found elevated intake as palatability increases in the short term and vice versa (less palatable meals determine smaller meal sizes), unrelated to the effect of palatability on appetite sensations (Sørensen et al., 2003). For instance, in the present study, appetite ratings did not differ among meals. Generally, texture of food has an important role in the development of satiation, since it may influence chewing time (McCrickerd et al., 2017), and new textures can produce superior satiating power

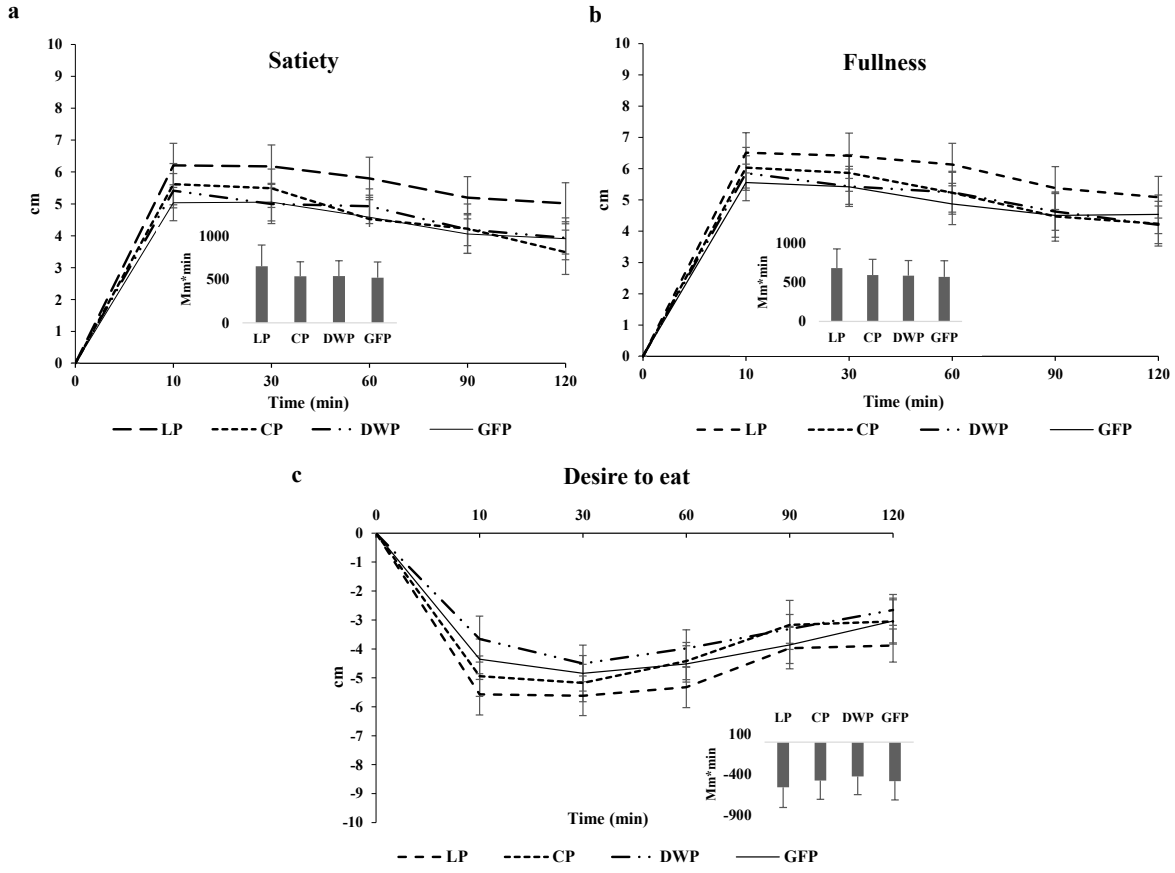

Fig. 7. Appetite ratings in healthy females
Unadjusted mean ratings with standard error of satiety (a), fullness (b), and desire to eat (c) during 2 h following 4 preload meals in the protocol 2 (LP = lentils pasta, CP = chickpeas pasta; DWP = durum wheat pasta; GFP = gluten free pasta) and the corresponding AUCs expressed as mean ± standard error.

compared to those for which people are more familiar (Amoah et al., 2023; Forde, 2018). Similarly, taste sensations can strongly affect EI. In fact, small changes in the taste of a food, for instance among the four types of pasta, can show relatively large effects on appetite and EI (McCrickerd and Forde, 2016), mostly depending on the individual's personal preferences and experience related to that food.

Still in the protocol 2 of the present study, the LP pre-load was the only one able to affect appetite sensations after 2 h in both sexes, resulting in a significant reduction of EI compared to CP at the subsequent meal in females, but not in males, as shown in Fig. 5.

Previously, Mollard et al. (2012) reported no difference on EI at the subsequent meal (after 4h), but solely on cumulative EI, in males. However, no variation in appetite ratings and palatability over the session was observed. On the contrary, here we showed that appetite ratings, especially fullness and desire to eat, differed among meals, resulting positively affected after LP compared to the other meals in both sexes. While, palatability was still reduced for legume-based pasta compared to the others, without being able to influence EI at the subsequent meal in males, but only in females. The effect of palatability on EI at the subsequent meal as well as on appetite sensations after a preload meal is still controversial (Sørensen et al., 2003). For instance, in the present study, LP and CP, perceived as less palatable, generated higher fullness and lower desire to eat compared to DWP (the most palatable), after 2 h. Indeed, the positive effect of LP on EI at the subsequent meal might be explained by the high content of fiber and protein in legumes along with the presence of antinutritional factors such as phytate, enzyme inhibitors, polyphenols (including tannins), lectins, and saponins, that may reduce the bioavailability of nutrients and inhibit enzymes involved in digestion and absorption, by slowing their rate (Singh, 2017) and potentially prolonging feeling of satiety. Interestingly, EI and eating behavior were different between males and females. Indeed, sex differences on appetite have been highlighted by previous studies(Cioffi et al., 2016a; Cornier et al., 2010). Cornier et al. (2010) showed with functional magnetic resonance imaging that there were important sex-based differences in the appetitive responses to food. They found that females had a greater satiety response to meals as compared to males, and the latter were more likely to overeat during *ad libitum* feeding, which is in line with our findings. While Cioffi et al. (2016a) showed different results between sex, even though portions were not adjusted for sex, but results might be affected by the small sample size. In the present study, we found that males ate more than females in both protocols, although the energy content of meals was adjusted for sex, with different effect on appetite, highlighting that sex-differences in food behavior should always be considered before any conclusions can be drawn (Cornier et al., 2010).

This study shows some limitations. First, the lack of metabolic markers, including those involved in appetite regulation, could be considered as a weakness, since this may have prevented us from having an overall picture of the mechanisms responsible for the effects of legume-based pasta on EI and appetite feelings. Second, among the selected types of pasta, wholegrain pasta was not included, and this product could represent a viable alternative, since legume pasta cannot be considered as a substitution to traditional pasta, due to its high protein content. Third, it might have been possible that analyzing participants' psychological approach toward food consumption at baseline by validated questionnaires might have provided more information to discuss our data on food behavior.

However, several strengths should be acknowledged. This is the first study assessing satiation and satiety by underlying sex-differences towards food intake in healthy volunteers following the consumption of

pasta exclusively made by legume flours in comparison to traditional pasta. Moreover, legume pasta, being an optimal source of vegetal protein, might be a valid alternative to other protein-based foods consumed within a healthy and sustainable dietary pattern. Indeed, this characteristic combined with fiber and other beneficial components typically provided by legume-based pasta may promote satiety related sensations and modulate eating behavior, being both mechanisms involved in preventing weight gain.

5. Conclusions

In conclusion, these results suggest a short-term effect of LP on EI both within meal and at subsequent meal, considering sex-based differences. Also, an overall increase in fullness sensation along with a decrease in desire to eat was reported between the pre-load and the *ad libitum* buffet. Again, sex was found to act as a modifier on food behavior. Results from the present study can support the importance of the development of new food products like pasta as vehicle of legumes to be consumed as alternative to other protein-rich foods. Indeed, seen in the light of public health policies, identifying and promoting familiar, legume-based products would be a strategy to enhance the habitual legume intake that is current much lower than dietary recommendations. Moreover, it will help consumers choose foods able to reduce EI at a meal, with beneficial health effect. Further research is needed to support the present findings on EI and appetite regulation in the long-term and considering different target populations and dietary habits.

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CRediT authorship contribution statement

Iolanda Cioffi: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Daniela Martini:** Methodology, Investigation, Writing – review & editing. **Cristian Del Bo':** Formal analysis, Writing – review & editing. **Antonella Brusamolino:** Data curation, Formal analysis, Writing – original draft. **Maria Cristina Casiraghi:** Writing – review & editing. **Marisa Porrini:** Conceptualization, Methodology, Writing – review & editing. **Patrizia Riso:** Conceptualization, Funding acquisition, Project administration, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Patrizia riso reports equipment, drugs, or supplies was provided by Barilla G. e R. Brothers. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crfs.2024.100858.

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