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In vitro dialyzability of essential minerals from white and whole grain pasta

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ABSTRACT

The aim of the present investigation was to study the *in vitro* mineral dialyzability of pasta made with white and whole-grain flours obtained from two genotypes (Klein Guerrero and Baguette Premium 11) with different mineral contents. Pasta samples were made from white flour (FP), and whole grain flour from cyclonic mill (WFAP) and blade mill (WFBP). Mineral content and *in vitro* digestion were determined on all samples to study starch variation and mineral dialyzability. Whole-grain pasta contained significantly higher amounts of minerals than FP, since bran and embryo are richer in minerals than endosperm. In addition to the low content of mineral composition observed in FP, the dialyzability of some minerals (Cu, Fe, Mg and Zn) was higher than whole-grain pasta even when the percentage of starch hydrolyzed after intestinal digestion was higher than FP. These results can also be useful for developing wheat-based products rich in the desired minerals.

1. Introduction

Pasta products are largely consumed worldwide, not only for their nutritional advantages as rich sources of complex carbohydrate, low sodium and fat contents, but also because of their sensory attributes and convenience for transportation and preparation (Chillo, Laverse, Falcone, Protopapa, & Del Nobile, 2008; Kaur, Sharma, Nagi, & Dar, 2012). Pasta is traditionally manufactured with durum wheat flour; however, since in Central and Northern Argentina durum wheat is not grown, bread wheat is used in spaghetti and pasta in local industries (Martínez, Ribotta, Añón, & León, 2013).

The structure of cooked pasta is generally described as a compact matrix, with the starch granules trapped in the network formed by the gluten proteins (Bonomi et al., 2012). In recent years pasta has become even more popular due to its nutritional properties, being regarded as a product "with low glycemic index" (Björk, Liljeberg, & Ostman, 2000). Research has shown that sugars are progressively liberated from pasta during digestion, leading to low postprandial blood glucose and insulin responses in humans and possible reduction of esophageal cancer risk (Bosetti et al., 2000). The slower release of starch degradation has been mainly attributed to the compact structure of pasta resulting from the extrusion process and to the interactions with other components such as dietary fiber (Tudorica, Kuri, & Brennan, 2002).

Consumption of whole grain products, such as pasta, has been linked to reduced risks of cardiovascular disease, type II diabetes, and cancer (Liu, 2007). Nutritional benefits include dietary fiber, minerals, and phytochemicals that are located mostly on bran and aleurone layers (Manthey & Schorno, 2002).

It has been widely studied that whole-grain pasta presents higher amounts of nutritional minerals than white flour pasta, so that using whole-grain flour would increase its nutritional quality and consumers' health benefits. However, as far as we know, there is little information on pasta mineral bioavailability or the amount of available minerals in the gastrointestinal tract for absorption after pasta consumption.

Throughout the years, *in vitro* screening methods have been developed and refined for the determination of nutrient bioaccessibility and bioavailability from foods. These methods can provide useful information, especially considering the vast number of factors that can affect nutrient absorption. Bioaccessibility, which is the amount of nutrient released from the food matrix and accessible for absorption, is dependent only on digestion and release from the food matrix. Bioavailability, which is defined as the amount of an ingested nutrient that is absorbed and available for physiological functions, is dependent on digestion, release from the food matrix, absorption by intestinal cells, and transport to body cells (Hall, 2011). Since bioavailability includes the bioactivity of compounds in the target cells, during *in vitro* methods dializability is determined. Dialyzability assays were introduced in 1981 by Miller, Schricker, Rasmussent, & Van Campen as a means to estimate compounds that will be available for absorption in the small intestine (Etcheverry, Grusak, & Fleige, 2012; Miller, Schricker, Rasmussent, & Van Campen, 1981).

Although minerals are widely distributed in foods, variations in the bioaccesibility and dializability of minerals have been found among different foods. The dializability of food minerals depends on the

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presence of various factors, such as proteins, phytic acid, other minerals, and dietary fiber (Sanz-Penella, Laparra, Sanz, & Haros, 2012; Hemalatha, Platel, & Srinivasan, 2007).

Besides this, information on the potentially bioaccessible and dialyzable minerals from white flour and whole-grain flour pasta is limited. Such information would be useful for computing the recommended dietary allowances and establishing, for instance, whether there is a need for supplementation, which minerals should be supplemented (in bioaccessible form), and at what levels. The aim of the present investigation was to study the *in vitro* dialyzability of minerals from pasta made with white and whole-grain flours obtained from two genotypes with different mineral contents. Besides starch hydrolysis kinetics was determined in order to evaluate the potential glycemic response of each type of pasta and consider if this parameter affect mineral dializability.

2. Materials and methods

2.1. Plant materials

Triticum aestivum flours were obtained from two commercial varieties: Klein Guerrero and Baguette Premium 11, both provided by INTA (Instituto Nacional de Tecnologia Agropecuaria).

Grains were milled into flour using three different mills. White refined flour (F) was obtained by milling grains with a four-roller laboratory mill (AQC 109-Agromatic AG, Laupen, Switzerland); two sets of whole-grain flour (WF) were obtained by using a cyclonic mill (A) (Cyclotec 1093, Foss, Barcelona) and a blade mill (B) (Decalab, Argentina).

2.2. Pasta making

All pasta samples were prepared according to Vignola, Bustos, and Pérez (2018). Pasta samples made from white flour (FP) and whole-grain flour from cyclonic mill (WFAP) and blade mill (WFBP), were cooked until optimum cooking time for subsequent determinations (FP: 17 min; WFAP: 13 min and WFBP: 15 min). Particle size distribution of whole-grain flours was different even though both whole-grain flours presented the same proportions of all grain wheat components.

2.3. Mineral content of cooked pasta

Concentrations of major and trace elements, including Zn, Cu, Mn, Fe, Ca, K, and Mg were determined in all cooked pasta samples (previously freeze-dried) using HNO_3 and H_2O_2 on heat for 24 h, following Podio et al. (2013) method. They were analyzed by a flame atomic absorption spectrometry (AAS-3, Zeiss spectrometer). Trace element certified reference material (CRM) wheat flour 1567a was obtained from the National Institute of Standards and Technology (Gaithersburg, MD, USA). The best estimate values for constituent elements in CRM 1567a are detailed in the accompanying certificate of analysis provided by the manufacturer.

2.4. In vitro digestion of pasta samples and mineral dialyzability

Digestive enzymes: amylase from porcine pancreas (A3176), pepsin from porcine gastric mucosa (P7000), pancreatin from porcine pancreas (P7545), and bile salts (B8756) were purchased in Sigma-Aldrich (Argentina). Others chemicals used in this study were of analytical grade.

An *in vitro* digestion method was performed according to Fabek, Messerschmidt, Brulport, and Goff (2014), involving simulated gastrointestinal digestion with suitable modifications in order to study the dializability of minerals from cereal-based food products.

Chewing, oral, gastric and intestinal digestions were carried out in all pasta samples according to Bustos, Vignola, Pérez, and León (2017). Additionally, in the last dialyzability analysis step, one segment of dialysis tubing (MWcutoff = 10 kDa) containing a solution of sodium bicarbonate in concentration equimolar to sodium hydroxide, as determined by titratable acidity, was incubated in the same flask.

Aliquots of 1 ml were withdrawn at time 0, after salivary and gastric steps and at 10, 90 and 150 min of intestinal step in order to monitor hydrolysis degree of starch by determining the reducing sugar content using the 3,5-dinitrosalicylic acid (DNS) method.

A non-linear model was applied to describe the kinetics of starch hydrolysis (Bustos et al., 2017). The first order equation has the following formula:

$$C= C_{\infty} * (1-e^{(-K*t)}) \quad (1)$$

where C corresponds to the percentage of starch hydrolyzed at time t; C_{∞} is the equilibrium percentage of starch hydrolyzed after intestinal digestion; K is the kinetic constant and t is the time (min). Parameter estimation was carried out using ORIGIN PRO software, version 8.

Additionally, an aliquot of dialysis bag was taken from intestinal step to determine the amount of dialyzable Ca, Mg, Mn, Zn, Fe, K and Cu by the flame atomic absorption spectrometry method (AAS-3, Zeiss spectrometer) as described in 2.4 section.

Dialyzability (%) was calculated as follows: 100*Y/Z, where Y is the element content inside the dialysis tubing (mg mineral element/100 g pasta), and Z is the element content in pasta sample (mg mineral element/100 g pasta).

2.5. Total, resistant and digestible starch content of cooked pasta

Total and resistant starch were measured in cooked pasta until their optimal cooking time, according to AACC 32-40.01 (American Association of Cereal Chemists, 2000). Starch classifications based on the rate of hydrolysis were also determined: rapidly digestible (digested within 20 min) starch (RDS), slowly digestible (digested between 20 and 180 min) starch (SDS), and resistant (undigested after 180 min) starch (RS).

2.6. Statistical analysis

Statistical analyses were performed using Infostat/Professional statistical software (Di Rienzo et al., 2012). Data were examined by ANOVA and results were compared by Fisher's test at a significance level of 0.05. The differences among genotypes and between flour or pasta types were analyzed and the results were expressed as the mean of two repetitions. Two replications were carried out depending on the determination.

3. Results and discussion

3.1. Mineral content of cooked pasta

The contents of all minerals determined on pasta samples are listed in Table 1. As expected whole-grain pasta contained significantly higher amounts of minerals than FP ($p < 0.05$) (Table 1) because bran and embryo are richer in minerals than endosperm (de Brier et al., 2015). In addition, Sanz-Penella et al. (2012) found larger amounts of minerals on whole-grain breads than on breads made of refined flours. Na and K were the two major minerals while Cu and Zn were the minor ones in all the extruded pasta samples. Similar results were found by Cubadda, Aureli, Raggi, and Carcea (2009) on durum wheat commercial pasta.

Fe and Zn average content found on FP (15.34 and 7.87 mg/Kg) were similar to those found by Albrecht, Asp, and Buzzard (1987) on macaroni cooked in distilled water (13 and 7 mg/kg respectively). In addition, Zook, Greene, and Morris (1970) found that in bread made from whole wheat flour Mn and Zn values were similar to those found for whole-wheat pasta.

Table 1
Mineral content (mg/kg) of cooked pasta made from two cultivars.[a,b]

		Ca	Cu	Fe	K	Mg	Mn	Zn
FP	Baguette Premium 11	127.92 aA	1.00 aA	15.40 aA	282.98 aA	102.97 aA	–	3.85 aA
	Klein Guerrero	139.20 aA	1.05 bA	15.28 aA	424.29 bA	145.14 bA	–	11.88 bA
WFAP	Baguette Premium 11	216.78 aB	3.53 aC	35.12 aB	650.33 aB	648.32 bB	40.33 aA	22.35 aC
	Klein Guerrero	272.45 bB	3.93 bC	44.86 bB	802.66 bB	580.95 aB	44.05 bA	34.75 bC
WFBP	Baguette Premium 11	253.76 aC	2.54 aB	42.63 aB	634.39 aB	788.16 bB	50.75 aB	22.34 aB
	Klein Guerrero	402.40 bC	2.15 aB	42.38 aB	982.91 bB	509.10 aB	59.37 bB	28.20 bB

[a] FP: white flour pasta; WFAP: whole flour A pasta; WFBP: whole flour B pasta.
[b] Different capital letters within the same column represent significant pasta differences (P ≤ 0.05) while different lowercase letters within the same column represent significant genotype differences on each pasta (P ≤ 0.05).

Milling significantly reduced the concentrations of all elements on FP ($p < 0.05$), with average losses ranging from 20.18% for Na to 80.87% for Mg. These results agree with our earlier research in relation to a decrease of all elements upon milling (26.6%–81% respectively) in white flours compared with whole-grain ones (Vignola, Moiraghi, Salvucci, Baroni, & Pérez, 2016).

There were statistically significant variations on mineral concentration among whole-wheat pasta (WFAP and WFBP) for Cu, Ca, Mn, Na and Zn. WFBP presented a significant higher amount of Ca, Mn and Na content compared with WFAP, which contains the maximum concentrations of Cu and Zn. Meanwhile, there were no significant differences in either whole-grain pasta, in terms of Fe, K or Mg content. These results may be related to particle size distribution of both whole-wheat flours. More than 50% of particle was equal to or smaller than 125 µm in WFAP, while in WFBP more than 40% was equal to or larger than 500 µm (Vignola et al., 2018). A different particle size distribution may lead to a differential mineral loss during pasta cooking.

In general, pasta made from Klein Guerrero presented higher amounts of almost all elements, except for Mg and Na, than pasta made from Baguette Premium 11. This was expected because in a previous study (Vignola et al., 2016), genotype Klein Guerrero showed higher content of these elements on both white and whole-wheat flours than Baguette Premium 11.

If we consider each mineral content of both cultivars on each extruded pasta, we observe the differences displayed in Table 1. These observations can be explained by the different proportion of each element in the morphological sections of the wheat kernel, which depends on the genotype and the varieties among cultivars (Lyons, Genc, Stangoulis, Palmer, & Graham, 2005).

3.2. Recommended daily intake

Taking into account both the standard portion of pasta is 80 g (dry pasta) and the recommended daily intake (RDI) (according to Insitute of Medicine, 1997, 2001) of each mineral (mg) for a man (Cu: 0.9; Fe: 8; K: 4700; Mg: 420; Zn: 11), we estimated the percentage of RDI covered for each mineral by a white flour and whole-grain flour pasta dish. Results are shown in Table 2.

Whole-grain flour pasta covered higher percentages of RDI of all minerals than FP as expected, considering the highest content reported above.

Consumption of WFAP made from Klein Guerrero contributed to the highest requirements of Cu, Fe, K and Zn micronutrients in an adult man. For Mg, consumption of WFAP and WFBP made from Baguette Premium 11 would satisfy the highest requirements.

On average, a dish of pasta can cover up to 32.61% of Fe and 14.95% of Zn daily requirements.

Table 2
Percentages of recommended daily intake (RDI) covered for each mineral by a pasta portion (80 g) for an adult man.[a,b]

		Cu	Fe	K	Mg	Zn
FP	Baguette Premium 11	8.89 aA	15.40 aA	0.48 aA	1.96 aA	2.80 aA
	Klein Guerrero	9.33 bA	15.28 aA	0.72 bA	2.76 bA	8.64 bA
WFAP	Baguette Premium 11	31.38 aC	35.12 aB	1.11 aB	12.35 bB	16.25 aB
	Klein Guerrero	34.93 bC	44.86 bB	1.37 bB	11.07 aB	25.27 bB
WFBP	Baguette Premium 11	22.58 bB	42.63 aB	1.08 aB	15.01 bB	16.25 aB
	Klein Guerrero	19.11 aB	42.38 aB	1.67 aB	9.70 aB	20.51 bB

[a] FP: white flour pasta; WFAP: whole flour pasta A; WFBP: whole flour pasta B.
[b] Different capital letters within the same column represent significant pasta differences (P ≤ 0.05) while different lowercase letters within the same column represent significant genotype differences on each pasta (P ≤ 0.05).

3.3. In vitro digestion of pasta

3.3.1. Starch in vitro digestion

Nutritional quality of pasta, in terms of its digestibility, was determined by an *in vitro* method and adjusted starch hydrolysis curves for each product are displayed in Fig. 1 (A and B). Experimental values for each pasta were adjusted to the function $C = C\infty * (1 - e(-K * t))$ to calculate K (kinetic constant) and $C\infty$ (equilibrium percentage of starch hydrolyzed after *in vitro* digestion) (Table 3). The R^2 values of the fitted curves were above 0.93 in all cases, which may prove that the model described the data adequately.

The trend of starch hydrolysis was similar for both cultivars on all samples, but it was very different when whole-grain pasta was compared with FP.

Whole-grain pasta starch hydrolysis increased sharply within 30 min and then gradually at a slow, steady rate for 150 min. Starch hydrolysis in the FP sample was more gradual. Starch from whole-grain pasta was more digested than FP, as shown by the higher hydrolyzed starch value at each time point and $C\infty$ values (Table 3). The slower release of FP starch degradation in comparison with whole-grain pasta may be attributed to the compact structure of FP characterized by a very close protein network that entraps starch granules and delays α-amylase activity (Fardet et al., 1999).

Moreover, whole-grain pasta presented the highest K values; this may be due to the structural differences between whole-grain and white flour pasta. Inclusion of the high quantities of insoluble fiber present in bran on whole-grain pasta may disrupt the protein matrix, giving rise to a highly porous structure. The starch granules become more accessible, hence more susceptible to enzyme degradation (Tudorica et al., 2002). Between both whole-grain pasta types, no differences were detected during the first 30 min of digestion, although WFBP presented a higher

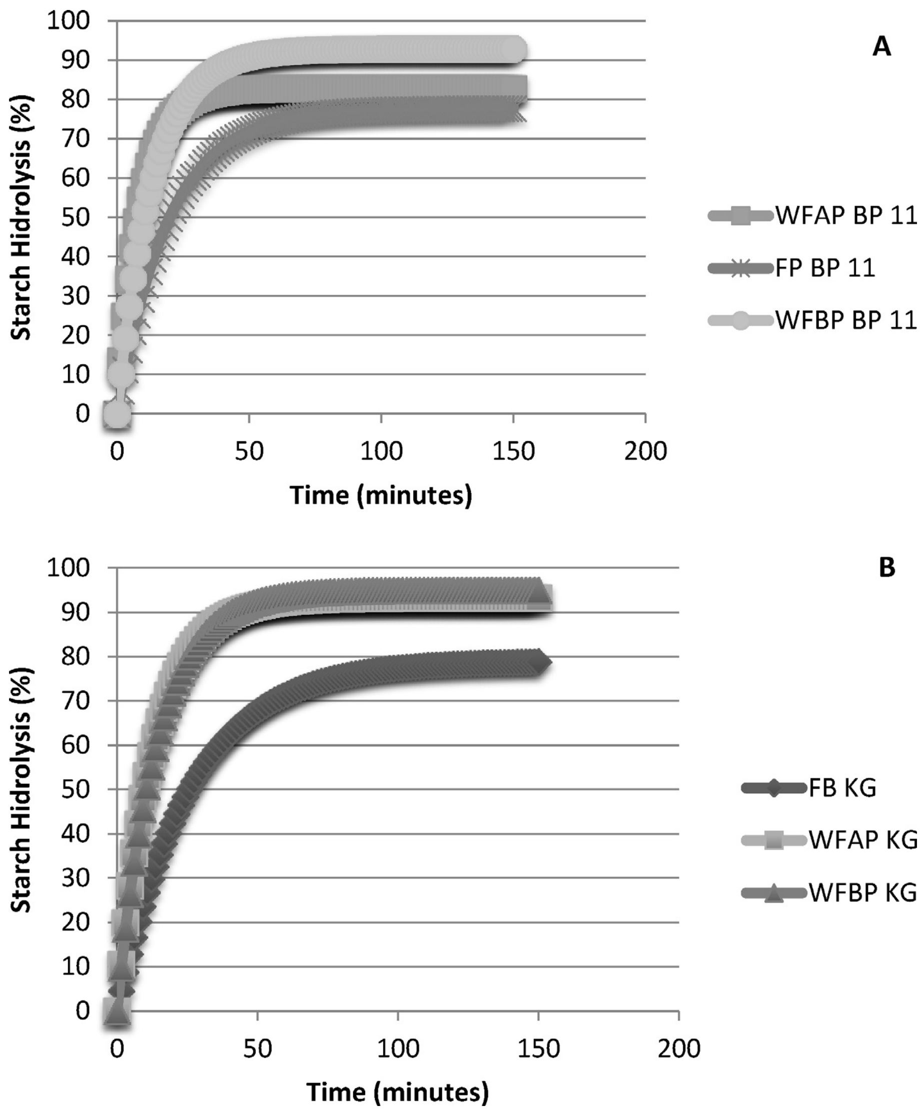

Fig. 1. A: Hydrolysis curve for all pasta made from Baguette Premium 11. B: Hydrolysis curve for all pasta made from Klein Guerrero.

final starch hydrolysis.

Different authors have documented the weakening of pasta structure with added bran (Manthey and Schorno, 2002; Chillo, Laverse, Falcone, Protopapa, & Del Nobile, 2008), as well as the differences in structure that affect the rate and extent of starch digestion (Biney and Beta, 2014).

Considering physiological effects and according to the rate of digestion, starch has been classified into four fractions: total starch, rapidly digested starch (RDS), slowly digested starch (SDS) and resistant starch. As a result, from starch hydrolysis curves (Fig. 1), we calculated the fraction digested within 20 min (RDS), between 20 and 120 min (SDS), the fraction that remains undigested (resistant starch) and the total fraction (Table 3).

Table 3 shows significant differences between FP and whole-grain pasta on total starch content, probably due to the dilution effect of bran, and RDS content; meanwhile no significant differences were found in

Table 3
Equilibrium percentage of starch hydrolyzed after intestinal digestion ($C\infty$), kinetic constant (K), total, rapidly digested (RDS), slowly digested (SDS) and resistant starch content of pasta sample made from two genotypes.[a,b]

Pasta	Genotype	C_∞ (%)	K (S^{-1})	Total Starch (g/100 g)	RDS (g/100 g)	SDS (g/100 g)	Resistant Starch
FP	BP 11	76.4 aA	0.058 aA	65.90 aB	52.04 aA	24.22 aA	nd
	Klein Guerrero	82.3 aA	0.039 aA	64.28 aB	44.87 aA	36.72 aA	nd
WFAP	BP 11	81.6 aB	0.094 aB	49.81 aA	70.37 aB	16.62 aA	nd
	Klein Guerrero	91.9 bB	0.082 aB	45.88 aA	73.89 aB	18.02 aA	nd
WFBP	BP 11	91.9 aC	0.081 aB	51.11 aA	73.21 aB	18.16 aA	nd
	Klein Guerrero	96.6 aC	0.071 aB	50.68 aA	73.78 aB	23.20 aA	nd

[a] FP: white flour pasta; WFAP: whole flour pasta A; WFBP: whole flour pasta B.
[b] Different capital letters within the same column represent significant pasta differences ($P \leq 0.05$) while different lowercase letters within the same column represent significant genotype differences on each pasta ($P \leq 0.05$).

Table 4
Dialyzability (%) of minerals from pasta during *in vitro* digestion.[a,b,*]

		Cu	Fe	Mg	Zn	K
FP	Baguete	82.95 bB	10.21 aB	49.73 bB	7.24 aB	–
	Premium 11	(0.07)	(0.13)	(4.10)	(0.02)	
	Klein	34.48 aB	10.92 aB	37.81 aB	15.52 bB	22.3[*]
	Guerrero	(0.04)	(0.13)	(4.39)	(0.15)	(5.05)
WFAP	Baguete	23.71 aA	3.20 bA	33.10 bA	2.52 bA	25.68 aB
	Premium 11	(0.09)	(0.09)	(17.17)	(0.04)	(13.36)
	Klein	31.87 bA	3.10 aA	30.02 aA	2.40 aA	42.90 aB
	Guerrero	(0.07)	(0.11)	(13.95)	(0.07)	(27.55)
WFBP	Baguete	22.91 aA	3.86 aA	19.37 aA	5.21 bA	33.15 aB
	Premium 11	(0.05)	(0.13)	(12.20)	(0.09)	(16.82)
	Klein	29.31 aA	4.15 aA	33.04 bA	0.93 aA	39.79 bB
	Guerrero	(0.05)	(0.14)	(13.46)	(0.02)	(31.29)

[a] FP: white flour pasta; WFAP: whole flour pasta A; WFBP: whole flour pasta B.
[b] Different capital letters within the same column represent significant pasta differences ($P \le 0.05$) while different lowercase letters within the same column represent significant genotype differences on each pasta ($P \le 0.05$).
[*] Values in parenthesis indicates the amount of dialyzable mineral (mg) after *in vitro* digestion considering a pasta dish (80 g of dried cooked pasta).

SDS values. Resistant starch content was not detectable, which means that all samples present less than 2% w/w (detection limit). The content of total starch varied from 45.88 to 65.90 g/100 g and this parameter was significantly higher on FP than whole-grain pasta. No significant differences between whole-grain pasta and genotypes were found for any starch parameter analyzed. All samples presented higher amounts of RDS, although the highest values were found on whole-grain pasta due to its porous structure.

Starch in whole-grain pasta was rapidly digested and only less than 22% was digested between 20 and 120 min (SDS), while in FP the compact structure delayed starch hydrolysis (Zou, Sissons, Gidley, Gilbert, & Warren, 2015) and around 30% of starch was SDS.

3.3.2. Mineral dialyzability

Dialyzability of mineral (%) has been widely employed in the literature to estimate mineral bioavailability (Wolters et al., 1993).

Elements such as Mn and K were not determined in any of the samples as their content was below the detection limit of the equipment. Ca could not be measured due to the high level of this element in the buffers used in *in vitro* digestibility.

As can be noted from the data in Table 4, the dialyzability percentages of the minerals varied significantly in all samples. Factors that influence dialyzability include the chemical species of the nutrient, its release from the food matrix (bioaccessible), its interactions with other food components, the presence of suppressors and other cofactors, and the formation of stable compounds that are slowly metabolized (Parada and Aguilera, 2007).

The minerals that presented the highest dialyzability percentage were Cu, Mg and K. In addition to the low content of mineral composition observed in pasta made from refined flour, the dialyzability of some minerals (Cu, Fe, Mg and Zn) was higher on FP than whole-wheat pasta. These results are in agreement with different authors' who also found the same trend in diverse products made with white and whole-grain wheat flours: bread (Wolters et al., 1993; Sanz-Penella et al., 2012, Eagling et al., 2014), chapattis (Kloots, Op den Kamp, & Abrahamse, 2004), and bread made with whole quinoa flour (Iglesias-Puig, Monedero, & Haros, 2015). On the other hand, only K presented higher dialyzability in whole pasta than in flour pasta.

Fe average dialyzability on FP and whole-grain pasta samples were 10.55% and 3.57% respectively, while Zn dialyzability was 11.38% and 2.76% for FP and both whole grain pasta, respectively.

No significant differences between any whole-grain pasta were found for any elements, indicating that the different particle size of whole-grain flour would not affect mineral dialyzability. In a previous work (Vignola et al., 2018) we evaluated both whole-grain pasta quality. Results showed no big differences between WFAP and WFBP cooking loss and texture profile, which indicates that both pastas presented a similar structure and, consequently, a similar release of minerals. This finding suggests that although whole-wheat pasta had higher mineral content, after *in vitro* digestion, the dialyzability of minerals, in average, was lower than FP.

Regarding genotypes, pasta made from Klein Guerrero had higher K dialyzability values, while for the remaining minerals different behaviors on both cultivars were reported for each extruded pasta (Table 4). Fe dialyzability presented no significant differences between cultivars on FP and WFBP. However on WFAP, Klein Guerrero showed the highest value. As for Zn dialyzability, the highest percentage was observed in FP made from Klein Guerrero, while whole-grain pasta displayed opposite results; pasta made from Baguette Premium 11 had the highest dialyzable contents on both pastas (WFAP and WFBP).

Whole-grain pasta presented lower dialyzability values even when the percentage of starch hydrolyzed after intestinal digestion was higher than FP. This could be due to the specific composition of pasta in terms of, for instance, the quantity and quality of proteins and the presence of compounds such as fibers, polyphenols and phytates, which can inhibit the bioaccessibility of mineral, as well as the chemical form of the elements and nutrient interactions (Vitali, Vedrina, & Šebečić, 2008). Although they were not analyzed in our samples, vast amounts of data in the literature suggest that white flour has a much lower concentration of phytic acid than whole-grain flour, since phytic acid is localized on bran layers (Lazarte, Carlsson, Almgren, Sandberg, & Granfeldt, 2015; Kloots et al., 2004). It has been reported that phytate (myo-inositol-6-phosphate) is the main inhibitor of Zn bioaccesibility and that it affects the releasing of other divalent minerals, mostly Fe, Ca, Mg and Mn (Bohn, Davidsson, Walczyk, & Hurrell, 2004). According to Sandberg (2002), the fiber and phytates present in some legumes and vegetables form insoluble complexes with positively charged proteins and cations of Ca, Cu, Mg, Zn at intestinal pH. Consequently, the bioaccesibility of these elements can be reduced.

Considering that Zn and Fe deficiency have a strong impact on human health, the dialyzability of those minerals was analyzed in detail. Several dietary components form soluble and insoluble complexes with trace elements under gastro-intestinal conditions that affect that parameter, also the negative impact of Ca content of food on the bioavailability of Fe and Zn is well recognized (Etcheverry et al., 2012, Hemalatha et al., 2007). The differences between Zn and Fe dialyzabilities from food grains can be attributed to the different chemical forms of these metals (valence states), the different physicochemical environment, their possible different localizations in the grains, as well as the different linkages and associated constituents.

Another contributing factor to the difference in Fe and Zn dialyzability between pasta made with white and whole-grain flour may be the content of phenolic acids. On a previous study, we observed that the amount of phenolic acids was significantly lower in FP than in whole-grain pasta (Vignola et al., 2018). These results are in concordance with Eagling et al. (2014) who found that polyphenols are a group of substances known to interfere with Fe absorption. However, it must be noted that other components can affect Fe availability. Fiber components, such as cellulose, hemicellulose, pectins, other polysaccharides and lignin, may form insoluble complexes with mineral elements, and thus reduce their bioaccesibility and/or dializability. Hemalatha et al. (2007) also found a negative effect of cereal fiber on Zn dialyzability, in addition to the phytate content. The higher amount of Ca observed in whole-wheat pasta compared with FP, as well as the higher amount of fiber in whole cereals could explained the observed results (Bosscher, Van Caillie-Bertrand, & Deelstra, 2001).

3.4. Amount of mineral available after pasta consumption

Table 4 also shows the amount of mineral that could cross the dialysis membrane and be available to the organism after eating a pasta dish (80 gr of dried cooked pasta).

Consuming a whole-grain pasta portion could provide the body higher K and Mg content than FP pasta after digestion that could be more available for target cells. In relation to Fe results, the largest contribution would be given both by FP and WFBP, while Zn largest contribution was provided by FB sample made from Klein Guerrero cultivar. Between the three types of pasta (FP, WFAP and WFBP) there was no statistical difference on Zn quantity available; this means that no matter what kind of pasta we eat, the body would have the same amount of Zn available.

4. Conclusion

Starch hydrolysis as well as mineral dialyzability are both very important nutritional attributes present on pasta. The increase in the amount of starch digested (C_∞) as a result of increase in RDS upon the use of whole-grain wheat in pasta formulation is an indication of the presence of a weaker gluten network which increased the susceptibility of starch granules to amylolysis. Even that, the low amount of total starch in whole-grain pasta samples will leads to a low amount of reducing sugars released compared to control pasta besides the increased rate that they will be released (K). It than therefore be inferred that the effect of using whole-grain on the carbohydrate digestibility of pasta is based on the dilution of available carbohydrates (starch) rather than on a mechanism which slows downs their breakdown.

The information on the evaluation of mineral dialyzability in refined and whole flour pastas reported in this work is useful for taking decisions about dietary interventions that may address existing mineral deficiencies in the population. Not only is the initial amount of minerals in cooked pasta important; the chemical form in which dietary minerals are presented during digestion may also have a profound influence on the bioavailability of the minerals. As expected, whole-grain pasta contained significantly higher amounts of minerals than white flour pasta because bran, aleurone and germen are richer in minerals than white flour. Milling significantly reduced the concentrations of all elements in white flour pasta. Despite the high content of mineral composition observed in pasta made from whole-grain flour, after *in vitro* digestion, the dialyzability of minerals, in average, was comparatively lower than pasta from white flour. These results demonstrate that different endogenous factors affect the solubility of minerals upon digestion. Moreover, no significant differences between both whole-grain pasta samples were found for any elements which indicates that flour particle size should not affect mineral bioaccesibility. These results can also be useful for developing wheat-based products rich in the desired minerals.

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