Effect of different fibers on batter and gluten-free layer cake properties

Márcia Arocha Gularte [1,2], Esther de la Hera[3], Manuel Gómez[3], Cristina M. Rosell[1]

[1] Food Science Department, Institute of Agrochemistry and Food Technology (IATA-CSIC), Avda Agustín Escardino 7, 46980-Paterna, Valencia, Spain. E-mail: crosell@iata.csic.es

[2] University Federal of Pelotas – Food Science Department (UFPel-DCA), Brazil

[3] Universidad de Valladolid - Ingenierías Agrarias de Palencia (Departamento Tecnología de los Alimentos), Spain.

Running title: Cake enrichment in fibers

Correspondence should be sent to: Cristina M. Rosell. E-mail: crosell@iata.csic.es

Tel 34 963900022, Fax 34 963636301

ABSTRACT

The effect of different fibers, added individually or in combination, to improve the functional properties of gluten free layer cakes was examined. Soluble (inulin and guar gum), and insoluble (oat fiber) fibers were used to replace up to 20% of rice flour in gluten free layer cakes formulation. The incorporation of fibers increased the batter viscosity, with the exception of inulin. Fiber enriched gluten free cakes containing blends of oat fiber-inulin resulted in improved specific volume. Significantly brighter crust and crumb was obtained in the presence of fibers, excepting the crumb of oat-guar gum containing cake. Fibers and its blends increased the crumb hardness; but the smallest effect was observed with the addition of oat, individually or combined with inulin. Enriched cakes increased significantly their dietary fiber content, which was connected to the nature of the fibers added. Fibers significantly affected the *in vitro* hydrolysis of starch fractions, being the most pronounced

effect the decrease in the slowly digestible starch. Overall combination of oat fiber-inulin resulted in better gluten-free cakes.

Highlights:

- Insoluble and soluble fiber incorporation in gluten free layer cakes was examined
- Gluten free cakes containing blends of oat fiber-inulin have better specific volume
- Combination of soluble and insoluble fibers provides enriched gluten free cakes

Key words: gluten free; cakes; fibers; starch; rice flour.

1. Introduction

Breakfast cereals and bakery products are the most preferred vehicles for fiber enrichment (Rosell, 2011). Traditionally, wholemeal cereals were eaten with that purpose, but lately alternative fibers from different sources are available, like fruit extracts, resistant starch, beta-glucans and so on (Rodrígues, Jiménez, Fernándes-Bolaños, Guillén & Heredia, 2006). More attention should be paid to gluten free bakery products that are prepared with gluten-free cereals and commercial grain products and often tend to have reduced quantities of proteins, B vitamins, iron, and fiber compared with products containing gluten (Thompson, Dennis, Higgins, Lee & Sharrett, 2005; Matos & Rosell, 2011). Therefore, a re-design of the gluten free bakery goods is needed for obtaining gluten free baked products with similar nutritional composition to that of their gluten counterparts. Those products would allow celiac patients and/or population with other allergic reactions and intolerances caused by proteins or another component of cereals to meet dietary guidelines without changing their dietary pattern.

Research on gluten free cakes has been focused on the effect of wheat flour replacement by rice flour in traditional recipes, as steamed leavened rice cakes (Mohamed & Hamid, 1998; Perez & Juliano, 1988), layer cakes (Bean et al., 1983; Perez & Juliano, 1988) and muffins (Johnson, 1990). Some authors have also used some hydrocolloids, emulsifiers or enzymes for improving the quality of those cakes (Preichardt et al., 2011; Ronda et al., 2009; Sumnu et al., 2010; Turabi et al., 2008), but scarce investigations were aimed at determining the nutritional profile of those products.

Different attempts have been made for protein enrichment of gluten free products with soy bean or legume proteins (Marco & Rosell, 2008 a, b; Gularte, Gómez & Rosell, 2011). However, scarce research has been carried out with high levels of purified fibers. Different fiber sources like cereals bran, legume outer layer and processing by-products of apple and potato industry have been used for enriching wheat cakes and muffins. Gómez, Moraleja, Oliete, Ruiz & Caballero (2010a) studied the effect of insoluble fibers, obtained from fruits, cereals, modified celluloses and resistant starch, on the quality of wheat layer cakes. Results showed that acceptable fiber enriched wheat based cakes could be obtained when fiber addition only goes up to 10% (w/w, wheat flour), and in general fiber incorporation results in low volume and minor acceptance.

Numerous commercial fibers are available in the market, which differed in solubility, particle size, hydration properties and viscosity, among other characteristics (Rosell, Santos & Collar, 2009). Inulin is a non-digestible polysaccharide and acts as prebiotic by stimulating the growth of 'healthy' bacteria in the colon (Gallagher, Gormley & Arendt, 2004). Guar gum is a galactomanan polymer used mainly as thickener and stabilizer. Dartois, Singh, Kaur & Singh (2010) suggested that the physiological action of hydrocolloids in the upper gut could be related to their ability to produce high viscosity in the gut lumen, thereby affecting the nutrient absorption and postprandial plasma nutrient levels. Lately, oat fibers are being used as insoluble fibers that contained cellulose, hemicellulose and lignin. In spite of its nutritional role, no study has been carried out about the effect of this insoluble fiber on the cakes and batters, neither on the gluten free cakes. Regardless the extensive use of fibers in food technology, there is no information about the individual and combined effect of soluble and insoluble fibers and their possible synergistic action concerning the quality parameters of gluten free cakes. The objective of this study was to investigate the potential of different dietary fibers, soluble and insoluble, on batter properties and on the technological and nutritional quality of gluten free layer cakes. The effect of those fibers on *in vitro* starch digestibility was also considered due to the relevance of starch in gluten free bakery products.

2. Materials and methods

2.1 Materials

Rice flour (7.85% of protein and particle size<200μm) from Harinera los Pisones (Zamora, Spain) was used. Inulin (Orafti®HPX, Beneo-orafti) and guar gum (Guar gum – 3500, EPSA, Spain) were used as soluble fibers, and oat fiber (Vitacel HF 600, J. Rettenmaier & Sönne, Rosenberg, Germany) as source of insoluble fiber. Sugar, sunflower oil, pasteurized whole eggs, fresh milk and double-action baking powder were purchased from the local market. Pancreatin from porcine pancreas (Cat. No. P-1625, activity 3_USP/g) was purchased from Sigma Chemical Company (St. Louis, MO, USA). Amyloglucosidase (EC 3.2.1.3., 3300 U/mL) and glucose oxidase–peroxidase assay kit GOPOD (Cat. No. K-GLUC) were purchased from Megazyme (Megazyme International Ireland Ltd., Bray, Ireland).

2.2 Methods

2.2.1 Cake preparation

A single-bowl mixing procedure was used for making yellow layer cakes. The basic recipe and the fiber enriched formulations replacing up to 20g/100g rice flour are detailed in Table 1. All ingredients were mixed during 1 min at speed 4, and 9 min at speed 6 using a Kitchen-Aid Professional mixer – KPM5 (KitchenAid, St. Joseph, Michigan, USA). 180 g of cake batter were placed into rectangular (109 mm x 159 mm), metallic, oil coated pans (430ml of capacity), and were baked in an electric oven ST-02 (Salva Industrial S.A., Lezo, Guipuzcoa, Spain) for 30 min at 190 ºC. After baking, the cakes were removed from the pans, left at room temperature for one hour to cool down, and put into plastic pouches to prevent drying. Two different sets for each cake recipe were made in different days. Four cakes from the same batter were used for physical measurements that were carried out one day after baking. One cake from each set was freeze dried for further determination of the *in vitro* enzymatic hydrolysis of starch.

2.2.2 Batter measurements

Batter density was measured using an Elcometer 1800 (Elcometer, Manchester, UK), which is a cup that consisted of a 50ml cylindrical container and a cover with a hole for removing excess of liquid. The cup is initially weight empty for calibration and then after filling with the batter. Density was calculated by dividing the weight and the volume. Each formulation was measured twice.

Viscosity of batter was measured using a Rapid Viscoanalyser (RVA-4) (Newport Scientific model 4-SA, Warriewood, Australia). Batter sample (28 g) was placed in the RVA aluminum canister with a plastic paddle that ensures the uniformity of the sample. Viscosity of the batter with recorded at 30ºC after one minute stirring at 160rpm. The reported values are means of duplicate measurements.

2.2.3 Cake quality evaluation

The digital caliper was used to measure collapses, ie, the difference in height of the cakes when they are removed from the oven and after 1 hour. Cake volume was determined, 24 h after baking, using a laser sensor, with the volume analyzer BVM-L 370 (TexVol Instruments, Viken, Sweden). The specific volume was evaluated by the ratio between the cake volume and its weight. Three replicates were measured from each cake set; therefore values were the average of six measurements.

Crumb texture was determined, 24 h after baking, by a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) provided with the software *"Texture Expert"*. An aluminum 25 mm diameter cylindrical probe was used in a *"Texture Profile Analysis"* double compression test (TPA) to penetrate to 50% depth, at 2 mm/s speed test, with a 30 s delay between first and second compression. Cake slices of 20mm thickness were used. Hardness (*N*), springiness, cohesiveness and resilience were calculated from the TPA graph (Gómez, Ronda, Caballero, Blanco & Rosell, 2007). Averaged results of eight determinations (2 slices from the central part of the cakes on two different cakes of each set) are presented.

2.2.4 Nutritional measurements

Nutritional parameters of gluten-free layer cake include: moisture (method 44-15A); ash (method 08-01); crude fat (method 30-25) and crude protein (method 46-13) using N x 6.25, all were determined using AACC (2000) methods. The available carbohydrate content of the samples was calculated by difference subtracting 100 g minus the sum of protein, ash and fat expressed in grams/100 grams FAO (2003). The components were converted to food energy using conversion factors (16,75 kJ g^{-1} for proteins and available carbohydrates; 37,68 kJ g^{-1} for fats and 8.37 kJ g^{-1} for dietary fiber) (FAO, 2003). For the estimation of dietary fiber, the defatted residues of cake samples obtained during the course of analysis of crude fat were finally powdered to pass through a sieve of 250 µm. This fine powder was utilized for the estimation of total dietary fiber (TDF), insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) contents following the method 37-02 (AACC, 2000).

2.2.5 In vitro starch digestibility

Starch digestibility of cakes was determined in the freeze dried cakes as described by Gularte & Rosell (2011). Briefly, cake sample (100 mg) was incubated with porcine pancreatic α-amylase (10 mg) and amyloglucosidase (3.3 U/ml) in 4 ml of 0.1 M sodium maleate buffer (pH 6.0) in a shaking water bath at 37 ºC for 16 h. The remnant starch after 16 hour hydrolysis was solubilized with 2 ml of 2 M KOH using a Virtis homogenizer (3 x 10 s strokes at 16000 rpm). The homogenate was diluted with 8 ml 1.2 M sodium acetate pH 3.8 and incubated with 100µl amyloglucosidase (330 U) at 50ºC for 30 minutes in a water shaking bath. After centrifuging at 2,000 *x g* for 10 min, supernatant was kept for glucose determination. The glucose content was determined using a glucose oxidase-peroxidase (GOPOD) kit.

The in vitro digestion kinetics was calculated in accordance with the procedure established by Goñi, Garcia-Alonso & Saura-Calixto (1997). A non-linear model following the equation [$C = C_{\infty}(1 - e^{-kt})$] was applied to describe the kinetics of enzymatic hydrolysis, where C was the concentration at t time, C_{∞} was the equilibrium concentration or maximum hydrolysis extent, k was the kinetic constant and t was the time chosen. The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve (0–180 min) of the sample by the area of a standard material (white bread) over the same period of time. The expected glycemic index (eGI) was calculated using the equation described by Granfeldt, Björck, Drews, & Tovar (1992): eGI = 8.198 + 0.862HI. The percentage of total starch hydrolyzed at 90 minutes (H90) was also calculated.

2.2.6 Statistical analysis

Experimental data were statistically analyzed by using Statgraphics V. 5.1 (Warrenton, USA)) to determine significant differences among them. When ANOVA indicated significant *F* values, multiple sample comparison was also performed and Fisher's least significant difference (LSD) procedure was used to discriminate among the means.

3. Results and discussion

3.1 Effect of fiber on batter properties

Batter properties of gluten-free layer cakes in the presence of different fiber added are shown in Table 2. Cakes containing 20% guar gum showed excessive consistency and it was not possible to pour it into the pans (results not showed). Regarding the batter density, only the one containing 20% inulin showed significant ($p<0.05$) differences compared to the control. The inulin decreased the batter density thus inulin favors the air incorporation during mixing. Gómez et al. (2010a) reported that the addition of insoluble fibers could increase the density of wheat based batter, but that effect was dependent on the level and particle size of the fibers. Those authors did not find significant differences when oat was added. The addition of fibers increased the batter viscosity, regardless the batter containing 20% inulin. Those results agree with those reported by Gómez et al. (2010a) when using different insoluble fibers in cake formulation, and with Lee, Inglett & Carriete (2004) findings when added Nutrim® oat bran. Batter viscosity increase might be attributed to the high water retention capacity of the fibers (Rosell, Santos & Collar, 2009), since the presence of 10% guar gum or oat fiber can increase up to 32g water/g solid or 10g water/g solid the water retention capacity of wheat flour, respectively. In fact, the largest effect was observed with the addition of guar gum, which greatly affects the starch swelling and the paste viscosity (Rosell, Yokoyama & Shoemaker, 2011). The batter viscosity has been related to its ability for retaining air during the baking. In fact, it has been stated that low batter consistency gives cakes of low volume (Lakshminarayan, Rathinam, & KrishnaRau, 2006; Lee, Kim, & Inglett, 2005), whereas excessive consistency might limit the batter expansion, although the ability to incorporate air must be taken into account (Gularte et al., 2011)

3.2 Effect of fiber on cake quality properties

Main characteristics of the cakes are fixed during baking, when the air bubbles entrapped within the batter expand due to the temperature increase and the chemical leavening. In some cases, coalescence is observed besides starch gelatinization and protein denaturation that altogether give the cake structure (Yang & Foegeding, 2010). The effect of fibers on the quality properties of gluten-free layer cake is shown in Table 2 and 3.

Cakes made with 20% guar gum showed very poor quality concerning specific volume and texture, because of that they were discarded (results not showed). Cakes containing oat-guar blend showed the lowest specific volume, which might be due to an earlier increase of batter viscosity that refrained the oven expansion. Gómez et al. (2007) reported that guar gum, like other hydrocolloids, could improve the cake volume when added at low levels (1%) without compromising the batter viscosity. Cake expansion is greatly dependent on starch gelatinization temperature, obtaining better dough expansion at high gelatinization temperatures. Guar gum decreases the onset temperature during gelatinization process and the temperature at the peak viscosity (Rosell, Yokoyama & Shoemaker, 2011), thus lower cake expansion and in turn lower specific volume would be expected.

Oat fiber at the level added in this study (20%) did not modify the cake specific volume, compared to control, although it has been reported that lower addition improves the volume of wheat based cakes (Gómez et al. 2010a). Some authors reported a decrease in the cake volume when fibers from different fruits were incorporated (Chen, Rubenthaler, Leung &

Baranowski, 1988; Grigelmo-Miguel, Carreras-Boladeras & Martin-Belloso, 1999). Those differences pointed out the importance of the fiber source for cake enrichment. The highest cake volume was obtained with the blend oat-inulin. Nevertheless, cakes containing inulin showed the highest collapse after baking. Therefore, likely oat fiber confers gives some strength to the network during thermal treatment that counteracted the collapse observed with inulin, which would explain the results obtained with the blend oat fiber-inulin.

Despite the collapse observed with inulin addition, cakes had similar volume to control. That result could be only explained by higher expansion during baking, but the structure was not strong enough to hold the expansion, resulting in a reduced volume after cooling.

Fibers increased the hardness and cohesiveness, and also lowered the resilience (Table 3). Inulin also significantly reduced the springiness. Those results agree with finding of Gomez et al. (2010a) when added high levels of insoluble fiber to wheat based cakes. In general, crumb hardness follows opposite trend to specific volume (Gomez, Ruiz-Paris, Oliete & Pando 2010b). Cakes containing the blend oat-guar gum showed the highest hardness, which might be related to the decrease of specific volume besides the low weight loss induced by the presence of guar gum. However, taking into account the pronounced effect of guar gum on increasing the viscosity during rice starch gelatinization (Rosell, Yokoyama & Shoemaker, 2011), it is envisaged that hardness increase and cohesiveness reduction, due to impeding the intermolecular interaction among ingredients (Gómez, Ronda, Caballero, Blanco & Rosell, 2007).

3.3 Effect of fiber on nutritional properties

Nutritional composition of the gluten free cakes is shown in Table 4. No significant differences were observed in the moisture content of the cakes (25 g/100 g). The replacement of rice flour by fibers resulted in a reduced protein content. As expected, the presence of fibers did not significantly ($p<0.05$) modify the fat content, neither the minerals content, with the exception of inulin that significantly decreased it.

The fibers content significantly ($p<0.05$) increased with the incorporation of different source of fibers (Figure 1). The total dietary fiber in the cakes varied from 1.5 – 8.7 g/100 g. Therefore the formulations proposed could result in an increase of the dietary fiber content of up to 5.8 times higher than that of the control cake. The main fraction in the total dietary fiber was the insoluble one (approximately 5.5 times compared to control). The insoluble fiber content increased in the presence of oat fiber when added either individually or blended with soluble fibers. The inulin incorporation, although increased the content of soluble fiber, did not result in the expected enhancement. Presumably, the analysis method was underestimating the amount of soluble fiber. According to FDA (1998) any food claimed as fiber rich for its health benefit should contain at least 4 g/100 g TDF and 0.75 g/100 g SDF. Considering the Codex Alimentarius (2007), solid foods can be classified as high fiber containing ≥ 6 g/100 g and source fiber containing ≥ 3 g/100 g. Taking into consideration both regulations, cakes containing the oat fiber, individually or blended with other fibers, fall in the classification of high-fiber and with health benefit.

Cakes containing fibers showed a significant reduction of the available carbohydrate, with the exception of the inulin (Table 4). Consequently, the replacement of rice flour by different fiber sources reduced the energy provided by these gluten free cakes, due to the high fiber content and low available carbohydrate and proteins. Vitali, Dragojevic & Sebecic (2009) reported a decrease of available carbohydrates and energy on wheat based biscuits enriched with different fiber sources and inulin blends.

3.4 Effect of fiber on starch *in vitro* digestibility

Bakery gluten free products are mainly comprised of starch, which explained why the assessment of the physiological functionality of the starch becomes very important (Matos & Rosell, 2011). In Figure 2 the effect of fibers on the different starch fractions can be observed. Rapidly digestible starch was the predominant starch fraction, followed by slowly digestible starch and minor amount of resistant starch was detected in rice based caked used as gluten free cake control. The incorporation of fibers added singly or in combination, did not modify the trend observed in the starch fractions. Regarding the specific effect on each starch fraction, fiber containing cakes had significantly higher RDS fraction, with exception of the cake containing only inulin as a fiber source. The presence of fibers also lowered the SDS fraction, being the most prominent effect observed when oat was the unique source of fiber. The incorporation of soluble fibers partially counteracted the reduction in SDS fraction promoted by the oat fiber. High value of SDS fraction is more desirable than RDS fraction, since SDS is slowly digested in the small intestine and induces gradual increase of postprandial plasma glucose and insulin levels (Jenkins et al, 1978). Hydrocolloids significantly modified the *in vitro* digestibility of starch. It has been reported that guar gum induces an increase of the RDS fraction with a concomitant decrease of the SDS fraction when blended with corn starch (Gularte & Rosell, 2011). Nevertheless, the combination of guar gum with potato starch leads to a decrease of the RDS but without significantly affecting the SDS. Therefore, hydrocolloid addition might result in a shift between digestible and non-digestible fractions, which is dependent on the starch source.

Fibers did not significantly modify the amount of resistant starch in the layer cakes, excepting inulin containing cakes that reduced the amount of RS. Likely, the polymeric structure of the inulin interacts with the starch polymeric chains avoiding the starch recrystallization and thus the formation of RS after the thermal treatment. Goñi et al. (1997) reported that the RS content of foods is influenced by the chemical composition, physical form, thermal treatments and also by starch interactions with other food components, having a direct consequence on the glycemic response of the carbohydrate based products (Fardet et al., 2006).

The parameters derived from the in vitro digestion of cakes and blended of different fibers are listed in Table 5. Those parameters included equilibrium concentration of hydrolyzed starch ($C\infty$), kinetic constant (k), of total starch hydrolysis at 90 min (H_{90}), area under the hydrolysis curve after 180 minutes (AUC 180), hydrolysis index (HI) and estimated glycemic index (eGI).

The maximum hydrolysis, $C\infty$, or hydrolysis degree when the enzymatic r eaction reaches a plateau, of gluten free cakes was very high. Similar trend has been observed with gluten free breads and it was associated with the high levels of rapidly hydrolyzed starch (Matos & Rosell, 2011). Only the individual addition of inulin yielded a marked decrease of this parameter. The kinetic constant (*k*), indicative of the hydrolysis rate in the early stage, was comprised between 0.061 and 0.099 min^{-1}. That parameter only showed significant increase when oat or the blend oat-inulin was incorporated in the gluten free cakes. Values obtained for the kinetic constant agree with the ones reported by Matos & Rosell (2011) for gluten free breads. The high values obtained for these products have been associated with the high susceptibility of these starchy products to enzymatic hydrolysis. The high values obtained for HI_{90} also confirmed that susceptibility, which increased in the presence of fibers, although, was only significant in the oat-guar containing cake. Considering the effect of high levels of guar gum on increasing swelling ability of starch (Rosell, Yokoyama & Shoemaker, 2011), results with guar gum supported that starch susceptibility to enzymatic hydrolysis increases with the swelling ability.

The estimated glycemic index (eGI) values were between 79.6 and 93.4, which indicate a rapid hydrolysis of the starch present in the gluten free layer cakes. The eGI was significantly reduced with the incorporation of inulin or oat added individually. However, no synergistic effect was observed when their blend was incorporated in the cake formulation. Gluten free breads also showed similar eGI range (Matos & Rosell, 2011) and therefore they are considered high glycemic index. The present study showed that the effect of fibers on *in vitro* starch hydrolysis was dependent on the specific starch-fiber combination, and at the levels tested a general tendency to increase the hydrolysis rate was observed. Huang et al. (2008) reported that high water holding capacity of insoluble dietary fiber is related to low digestibility, high volume and weight of feces in *in vivo* experiments. In addition, present results showed that insoluble fiber accelerates the starch hydrolysis, thus it seems that other factors should be taken into account.

4. Conclusion

Overall results showed that gluten free layer cakes enriched in soluble and insoluble fibers of acceptable quality can be obtained, without affecting significantly the specific volume and only slightly the crumb texture. Oat fiber blend with inulin or guar gum is proposed for increasing the fiber content of gluten free cakes. Rice flour replacement up to 20 g/100g by dietary fibers modifies the batter properties, the technological qualitative parameters (volume, texture) and nutritional composition of the cakes.

Due to health benefits derived from the intake of fiber containing foods and the recommendation to still balance the consumption of soluble and insoluble fibers, the blend of oat-inulin (insoluble-soluble fiber) showed advantages in front of the blend oat-guar gum, pertaining nutrition and quality of enriched gluten free layer cakes. Future studies will be undertaken for determining the sensory quality and consumer acceptance of enriched gluten free cakes by organizing a consumer test with coeliac patients.

Acknowledgements

Authors acknowledge the financial support of Association of Coeliac Patients (Madrid, Spain), Spanish Scientific Research Council (CSIC) and the Spanish Ministry of Economy and Sustainability (Project AGL2011-23802/ALI). Dr. Gularte would like to thank postdoctoral incentive by Departamento de Ciencia de Alimentos - Universidade Federal de Pelotas, Brasil, RS.

References

AACC International. (2000). *Approved Methods of the American Association of Cereal Chemists*. St Paul, Mn (USA): American Association of Cereal Chemists.

Bean M. M., Elliston-Hoops E. A., & Nishita K. D. (1983). Rice flour treatment for cake-baking applications. *Cereal Chemistry*, *60*(6), 445-449.

Codex Alimentarius Commission. (2007). Draft revised standard for gluten free foods (ALINORM 08/31/26). In *Codex Committee on Nutrition and Foods for special Dietary Uses*, 29nd session, Germany.

Chen, H., Rubenthaler, G. L., Leung, H. K., & Baranowski, J. D. (1988). Chemical, physical, and baking properties of apple fiber compared with wheat and oat bran. *Cereal Chemistry*, *65*, 244–247.

Dartois, A., Singh, J., Kaur, L., & Singh, H. (2010). Influence of guar gum on the in vitro starch digestibility – rheological and microstructural characteristics. *Food Biophysics*, *5*, 149–160.

FAO Food and Nutrition, Paper 77 (2003). Food energy – methods of analysis and conversion factors, Food and Agriculture Organization of the United Nation, FAO, Rome, Italy, Washington DC, USA.

Fardet, A., Leenhardt, F., Lioger, D., Scalbert, A., & Rémésy, C. (2006). Parameters controlling the glycemic response to breads. *Nutrition Research Reviews*, 19, 18–25.

FDA (1998). Food labeling, health claims: soluble fiber from certain foods and risk of coronary heart disease. 21 CFR© 101.81, *Code of Federal Regulations*. Washington DC.

Gallagher, E., Gormley, T. R., & Arendt, E. K. (2004). Recent advances in the formulation of gluten-free cereal-based products. *Food Science & Technology*, *15*, 143-152.

Gomez, M., Ronda, F., Caballero, P. A., Blanco, C. A., & Rosell, C. M. (2007). Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food Hydrocolloids*, *21*, 167-173.

Gomez, M., Moraleja, A., Oliete, B., Ruiz, E., & Caballero, P. A. (2010a). Effect of fibre size on the quality of fibre-enriched layer cakes. *LWT-Food Science and Technology*, *43*, 33-38.

Gomez, M., Ruiz-Paris, E., Oliete, B., & Pando, V. (2010b). Modeling of texture evolution of cakes during storage. *Journal of Texture Studies*, *41*, 17-33.

Goñi, I., Garcia-Alonso, A., & Saura-Calixto, F. (1997). A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research*, *17*, 427-437.

Granfeldt, Y., Björck, I., Drews, A., & Tovar, J. (1992). An in vitro procedure based on chewing to predict metabolic responses to starch in cereal and legume products. *European Journal of Clinical Nutrition*, *46*, 649-660.

Grigelmo-Miguel, N., Carreras-Boladeras, E., & Martin-Belloso, O. (1999). Development of high-fruit-dietary fibre muffins. *European Food Research and Technology*, *210*, 123-128.

Gularte, M.A., Gómez, M., & Rosell, C.M. (2011). Impact of legume flours on quality and in vitro digestibility of starch and protein from gluten-free cakes. *Food Bioprocess Technology*. DOI: 10.1007/s11947-011-0642-3.

Gularte, M. A. & Rosell, C. M. (2011). Physicochemical properties and enzymatic hydrolysis of different starches in the presence of hydrocolloids. *Carbohydrate Polymers*, 85, 237-244.

Huang, Y. L., Sheu, F., Lee, M. H. & Chau, C. F. (2008). Effects of particle size reduction of insoluble fibres by micron technology on various caecal and faecal indices. *Journal of the Science of Food and Agriculture*, 88, 435-441.

Jenkins, D. J. A., Wolever, T. M. S., Leeds, A. R., Gassull, M. A., Haisman, P., Dilawari, J., Goff, D. V., Metz, G. L., & Alberti, K. M. (1978). Dietary fibres, fibre analogues, and glucose tolerance: importance of viscosity. *British Medical Journal, 1*, 1392-1394.

Johnson F.S. (1990). Characteristics of muffins containing various levels of waxy rice flour. *Cereal Chemistry*, *67*(2), 114-118.

Lakshminarayan, S.M., Rathinam, V., & KrishnaRau, L. (2006). Effect of maltodextrin and emulsifiers on the viscosity of cake batter and on the quality of cakes. *Journal of the Science of Food and Agriculture*, *86*, 706-712.

Lee, S., Inglett, G. E., & Carriete, C. (2004). Effect of nutrim oat bran and flaxseed on rheological properties of cakes. *Cereal Chemistry, 81*, 637-642.

Lee, S., Kim, S., & Inglett, G.E. (2005). Effect of shortening replacement with oatrim on the physical and rheological properties of cakes. *Cereal Chemistry*, *82*, 120-124.

Marco, C., & Rosell, C.M. (2008 a). Breadmaking performance of protein enriched gluten free breads. *European Food Research and Technology, 227*, 1205-1213

Marco, C., & Rosell, C.M. (2008 b). Functional and rheological properties of protein enriched gluten free composite flours. *Journal of Food Engineering, 88*, 94-103.

Matos, M.E., & Rosell, C.M. (2011). Chemical composition and starch digestibility of different gluten free breads. *Plant Foods for Human Nutrition*. DOI: 10.1007/s11130-011-0244-2, *66*, 224-230.

Mohamed S., & Hamid N.A. (1998). Effects of ingredients on the characteristics of rice cakes. *Journal of the Science of Food and Agriculture, 76*, 464-468.

Perez C.M., & Juliano B.O. (1988). Varietal differences in quality characteristics of rice layer cakes and fermented cakes. *Cereal Chemistry, 65* (1), 40-43.

Preichardt L.D., Vendruscolo C.T., Gularte, M.A., & Moreira A.S. (2011) The role of xanthan gum in the quality of gluten free cakes: improved bakery products for coeliac patients. *International Journal of Food Science and Technology*, *46*, 2591-2597

Rodrígues, R., Jiménez, A., Fernándes-Bolaños, J., Guillén, R., & Heredia, A. (2006). Dietary fibre from vegetable products as source of functional ingredients. *Trends in Food Science & Technology*, *17*, 3-15.

Ronda, F., Gomez, M., Caballero, P.A., Oliete, B., & Blanco, C.A. (2009). Improvement of Quality of Gluten-free Layer Cakes. *Food Science and Technology International*, *15,* 193-202.

Rosell, C. M., Santos, E., & Collar, C. (2009). Physico-chemical properties of commercial fibres from different sources: A comparative approach. *Food Research International*, *42*, 176-184.

Rosell, C. M., Yokoyama, W., & Shoemaker, C. (2011). Rheology of different hydrocolloids-rice starch blends. Effect of successive heating-cooling cycles. *Carbohydrate Polymers*, *84*, 373–382.

Rosell, C. M. (2011). The nutritional enhancement of wheat flour. In: Breadmaking: Improving quality. Second Edition. Ed S. Cauvain. Woodhead Publishing, UK.

Sumnu G., Koksel F., Sahin S., Basman A., & Meda V. (2010). The effects of xhantan and guar gums on staling of gluten-free rice cakes baked in different ovens. International *Journal of Food Science and Technology*, *45*, 87-93.

Thompson, T., Dennis, M., Higgins, L.A., Lee, A. R., & Sharrett, M. K. (2005). Gluten-free diet survey: are Americans with celiac disease consuming recommended amounts of fibre, iron, calcium and grain foods? *Journal of Human Nutrition and Dietetics*, *18*, 163-169.

Turabi, E., Sumnu, G., & Sahin, S. (2008). Optimization of baking of rice cakes in infrared-microwave combination oven by response surface methodology. *Food and Bioprocess Technology*, *1*(1), 64-73.

Vitali, D., Dragojevic´, I.V., Šebecˇic´, B. (2009). Effects of incorporation of integral raw materials and dietary fibre on the selected nutritional and functional properties of biscuits. *Food Chemistry*, 114, 1462-1469.

Yang, X. & Foegeding, E. A. (2010). Effects of sucrose on egg white protein and whey protein isolate foams: Factors determining properties of wet and dry foams (cakes). *Food Hydrocolloids*, *24*, 227-238.

FIGURE CAPTIONS

Figure 1. Total (black bars), soluble (clear grey bars) and insoluble dietary fiber (dark gray bars) content, expressed as gram/100 grams (as is basis), in different fiber enriched gluten free cakes.

Figure 2. Starch digestibility in different gluten free cakes determined by *in vitro* enzymatic hydrolysis. RDS or rapidly digestible starch (black bars); SDS or slowly digestible starch (clear grey bars); RS or resistant starch (dark grey bars), expressed as gram/100 grams (as is basis).

Table 1. Formulations of gluten-free layer cakes (g/100g flour or flour-fiber blends).

Formulation	Control	Oat-guar gum	Oat-Inulin	Oat	Inulin
Rice flour	100	80	80	80	80
Oat fiber 600	0	15	15	20	0
Inulin	0	0	5	0	20
Guar gum	0	5	0	0	0
Milk	75	75	75	75	75
Eggs	62.5	62.5	62.5	62.5	62.5
Sunflower oil	37.5	37.5	37.5	37.5	37.5
Sugar	112.5	112.5	112.5	112.5	112.5
Baking powder	3.75	3.75	3.75	3.75	3.75
Total (g)	391.25	391.25	391.25	391.25	391.25

Table 2. Effect of fibers on gluten free batter and quality properties of gluten-free layer cakes.

Cake	Batter viscosity 30 ºC (mP.s)			Batter density (g/cm^{-3})			Collapse (cm)			Cake specific volume (cm^3/g)		
Control	2131±	17.7	d	1.0±	0.0	a	1.5±	0.1	b	2.7±	0.0	b
Oat-guar gum	7787±	87.8	a	1.1±	0.1	a	1.2±	0.9	b	2.5±	0.0	c
Oat-inulin	3827±	90.7	c	1.0±	0.1	a	1.4±	0.2	b	2.9±	0.0	a
Oat	4189±	80.7	b	1.0±	0.0	a	1.2±	0.2	b	2.7±	0.0	b
Inulin	2106±	29.2	d	0.9±	0.0	b	2.6±	0.3	a	2.7±	0.0	b

Values followed by different letters in each column indicate significant differences ($p \leq 0.05$).

Table 3. Effect of fibers on texture in gluten-free layer cakes

Cakes	Hardness (*N*)	Springiness	Cohesiveness	Resilience
Control	4.5± 0.4 d	0.77± 0.10 ab	0.31± 0.20 c	0.17± 0.0 a
Oat-guar gum	10.3± 0.8 a	0.79± 0.10 a	0.40± 0.10 a	0.15± 0.02 b
Oat-inulin	5.3± 0.4 c	0.74± 0.21 b	0.39± 0.00 ab	0.14± 0.09 b
Oat	5.3± 0.1 c	0.75± 0.02 b	0.40± 0.00 ab	0.14± 0.10 b
Inulin	6.1± 0.1 b	0.68± 0.03 c	0.34± 0.10 bc	0.12± 0.03 c

Mean of duplicates. Values followed by different letters in each column are significantly different ($p \leq 0.05$).

Table 4. Effect of fibers on chemical composition of gluten-free layer cakes.

Cake	**Protein (g/100 g)**	**Fat (g/100 g)**	**Ash (g/100 g)**	**Available carbohydrate (g/100 g)**	**Energy (kJ)**
Control	6.2± 0.0 a	13.0± 0.3 a	1.7± 0.1 a	54.3± 0.0 a	1464± 4 a
Oat-guar gum	5.4± 0.0 d	13.5± 0.3 a	1.7± 0.0 a	48.1± 0.0 b	1426± 4 c
Oat-inulin	5.5± 0.0 c	13.6± 0.2 a	1.8± 0.2 a	48.0± 0.0 b	1429± 4 c
Oat	5.5± 0.1 b	13.2± 0.1 a	1.8± 0.1 a	47.6± 0.0 b	1419± 8 c
Inulin	5.4± 0.0 d	12.8± 0.4 a	1.4± 0.3 b	54.5± 0.0 a	1442± 4 b

Mean of three replicates. Values followed by different letters in each column are significantly different ($p \leq 0.05$).

Table 5. Kinetic parameters of the in vitro starch hydrolysis and estimated glycemic index

Samples	C∞ (g/100g)		k (min^{-1})		AUC 180		H90		HI		eGI	
Control	90.7	b	0.061	b	3626	b	69.9	b	89.3	b	85.2	b
Oat-Guar gum	99.0	a	0.082	ab	4012	a	98.7	a	98.9	a	93.4	a
Oat-Inulin	88.4	bc	0.098	ab	3602	bc	88.2	ab	88.7	bc	84.7	b
Oat	85.8	cd	0.099	ab	3525	c	85.8	b	86.9	c	83.0	c
Inulin	83.1	d	0.072	ab	3364	d	82.9	b	82.9	d	79.6	d

Mean of three replicates. Values followed by different letters in each column are significantly different ($p \leq 0.05$).

C∞, equilibrium concentration; k, kinetic constant; AUC 180, area under curve; H_{90} percentage of total starch hydrolyzed at 90 minutes; HI, hydrolysis index; eGI, estimated glycemic index.

Figure 1.

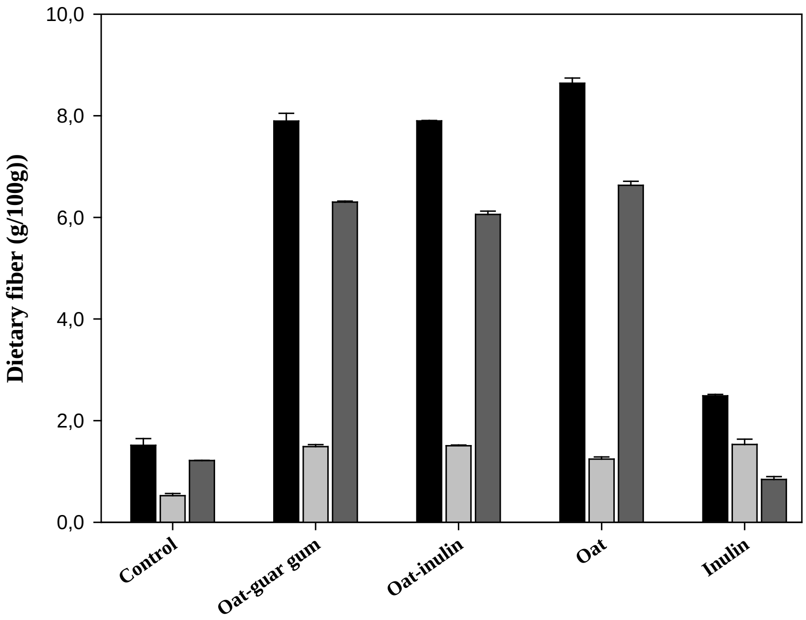

Figure 2.