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In vitro measurements of intragastric rheological properties and their relationships with the potential satiating capacity of cheese pies with konjac glucomannan

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ABSTRACT

Konjac glucomannan (KGM) is consistently associated with creating a sense of fullness while slowing down physiological processes associated with food digestion and nutrient absorption. Formulating food with KGM is difficult because it develops very high viscosity in aqueous solution. In the present study, cheese pies containing increasing amounts of KGM were prepared in such a way that the gum was not fully hydrated. The aim was to achieve formulations with high doses of KGM and to delay development of the gum's rheological properties until it reaches the gastric tract. The pies and the gum alone were then submitted to oral plus gastric *in vitro* digestion and their rheological properties were measured and compared. The viscoelastic properties increased as the KGM content of the pies rose. In addition, the digested pies were more effective at forming solid-like structures than the digested gum alone at the same concentration. The instrumental texture measurements of the pies indicated that higher KGM levels produced harder and more cohesive pies. These texture attributes would potentially enhance the expected satiating capacity of the pies. When 118 consumers with no information about the pies' composition or the health benefits of KGM performed a hedonic sensory test, their liking for the pies decreased in line with the increases in KGM level in high-KGM formulations.

1. Introduction

Konjac glucomannan (KGM) is a very well-known water-soluble type of fibre composed of a straight chain of β-1 → 4 D-mannose and D-glucose units in a ratio of 1.6:1, with a small amount of branching (8%) through β-(1 → 6)-glucosyl linkages. It is derived from the tuberous roots of the konjac plant (*Amorphophallus konjac* K. Koch), native to Asian countries such as China, Japan and Thailand. Konjac flour, extracted from the corm, has a long history of food use in Asia and is used in Far Eastern cuisine to make noodles, tofu and snacks (Chua, Baldwin, Hocking, & Chan, 2010). KGM is the main constituent of konjac flour (50–98 g/100 g content) (Fang & Wu, 2004). To date, the most common KGM purification methods involve ethanol extraction, due to its simplicity and efficiency (Takigami, 2000). This method could be notably improved using hydration followed by precipitation and freeze-drying (Chua et al., 2012).

KGM is non-digestible in the human small intestine. It has a high molecular weight (200–2000 kDa) and high viscosity in a water solution. As a food additive, it is used as an emulsifier, thickener, meat binder, etc. in a number of food applications. Examples include a gel property enhancer in low-quality surimi (Iglesias-Otero, Borderías, & Tovar, 2010; Liu, Wang, & Ding, 2013), egg white gel (Liu, Zhu, et al., 2013) and noodles (Zhou et al., 2013) and a fat replacer in meat products (Jimenez-Colmenero, Triki, Herrero, Rodríguez-Salas, & Ruiz-Capillas, 2013; Ruiz-Capillas, Triki, Herrero, Rodriguez-Salas, & Jiménez-Colmenero, 2012) and in mayonnaise (Li, Wang, Jin, Zhou, & Li, 2014).

KGM is also consumed in capsules or in powder form as dietary fibre supplement (Keithley & Swanson, 2005). A number of effects of this substance on human health have been reported. KGM affects total cholesterol and fasting blood glucose beneficially (Guardamagna, Abello, Cagliero, & Visioli, 2013; Sood, Baker, & Coleman, 2008). Although its therapeutic uses need further

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investigation, glucomannan could be a candidate for treating a range of physiological disorders such as diverticulitis, Crohn's disease or ulcerative colitis (Tester & Al-Ghazzewi, 2013).

The present study focuses on the properties of KGM as a satiating agent. In its Scientific Opinion on the substantiation of health claims related to KGM and reduction of body weight (EFSA, 2010), the Panel on Dietetic Products, Nutrition and Allergies of the European Food Safety Authority "noted that glucomannan forms a viscous, gel-like mass in the stomach when hydrated, and that this 'mass effect' could delay gastric emptying and induce satiety leading to a decrease in subsequent energy intake". It considered that reduction of body weight is a beneficial physiological effect for overweight individuals and concluded that "a cause and effect relationship has been established between the consumption of glucomannan and the reduction of body weight in the context of an energy-restricted diet." According to Vuksan et al. (2009), KGM, like other viscous fibres, has volumetric effects, creating a sense of fullness while slowing down physiological processes associated with food digestion and nutrient absorption. Several studies have concluded that when administered in capsules, a daily base dose of KGM can promote increased weight loss and satiety (McCarty, 2002).

According to Keithley and Swanson (2005), KGM may promote satiety via several mechanisms: increased mastication effort, postulated to induce cephalic- and gastric-phase signals that induce satiety; delayed gastric emptying; slowed small-bowel transit time; slowed absorption of food in the small intestine leading to attenuated postprandial insulin surges; and accelerated delivery of food to the terminal ileum, where satiety signals are transmitted. A number of intervention studies in which KGM was supplied found increased satiety and weight reduction (Lyon & Reichert, 2010; Salas-Salvadó et al., 2008). Sukkar et al. (2013) found that a mixture of dairy proteins and glucomannan reduced eating desire. They concluded that this effect was related, besides other hormonal factors, to the presence of KGM, which forms a "net" after gelling in the acid milieu of the stomach. The viscosity of a newly-made KGM solution develops gradually over long periods of time and reaches a peak depending on particular characteristics like the degree of acetylation (Du, Li, Chen, & Li, 2012) or geographical origin (Fang & Wu, 2004).

Some KGM-based products (made almost exclusively of KGM) such as noodles and other pasta-like items are currently on the market. They are essentially designed as weight-control food products because they contain very few calories. However, references in the literature to real solid foods with KGM added to enhance their satiating capacity are scarce. In the present work a cheese pie was used as a vehicle to add KGM. This cheese pie is a refrigerated dairy dessert with a soft, gel-like texture. It could be eaten as a snack between meals. Its high protein content gives it a high satiating capacity *per se* and offers a good basis for adding ingredients/additives that could enhance this property.

The hypothesis of the present study was that adding KGM to the cheese pie in such a way that gum hydration would be not favoured during pie processing and baking but would take place in the intragastric digestion phase would increase the viscosity of the digesta and deliver its satiating capacity properties *in situ*.

Dikeman and Fahey (2006) reviewed the literature on the viscosity measurements of fluid digesta from the stomach of monogastric animals. They concluded that this was a complex and difficult task. In their opinion, viscosity in the gastrointestinal tract of animals has not been measured adequately since shear rate may vary considerably with sampling location, individual animal, meal composition, and gut motility. In addition, many papers have reported apparent digesta viscosity values measured at a single shear rate values, which is not correct since the material would normally exhibit pseudoplastic behaviour. *In vitro* methods simulating digestion processes are widely used to study the gastrointestinal behaviour of food. Although human nutritional studies are still considered the "gold standard" for addressing diet-related questions, *in vitro* methods have the advantage of being more rapid, less expensive and less labour intensive and of not being subject to ethical restrictions (Minekus et al., 2014). *In vitro* methods try to mimic *in vivo* physiological conditions, taking into account the presence of digestive enzymes and their concentrations, pH, digestion time and salt concentrations, among other factors. Static models of human digestion have been used to address such diverse scientific subjects as digestibility and bioaccessibility and, to a much lesser extent, to assess viscosity development or gelation in the gastric tract. Other approaches have taken into consideration the development of viscosity over time (enabling hydrocolloid hydration). For instance, Vuksan et al. (2009) measured the viscosity of three preload drinks containing three different hydrocolloids, including glucomannan, at 15 min intervals over 90 min, to estimate their hydration time. However, they only reported single measurements at a single shear rate and did not consider any behaviour change due to shear strain or any effect of the gastric enzymes.

The present study aimed to assess the effect of adding increasing amounts of konjac glucomannan (KGM) on the rheological behaviour of cheese pies digested orally plus gastrically *in vitro*. The effects of the KGM ingredient alone and a KGM commercial product were also compared. In addition, the instrumental texture of the KGM cheese pies and consumer liking for them were assessed and compared with those of a control recipe.

2. Materials and methods

2.1. Cheese pie formulations

A control cheese pie sample (B) was prepared with full-fat fresh cheese (starter-free, pasteurized, protein content 10.9 g/100 g, moisture 72 g/100 g and 14 g fat/100 g, as declared by the supplier, Hacendado, Spain), native maize starch (Maizena®, Barcelona, Spain), pasteurized liquid whole egg (Ovocity, Valencia, Spain), sucrose (Acor, Valladolid, Spain) and skimmed milk powder (Central Lechera Asturiana, Siero, Spain) (Table 1). Four cheese pie samples were formulated with different amounts of KGM (konjac glucomannan 90.5 g/100 g, Trades S.A, Barcelona, Spain) (Table 1). During the mixing process, it was observed that the viscosity of the

Table 1
Cheese pie samples with increasing amounts of konjac glucomannan (KGM): composition and total protein, fat and calorie contents.

Ingredient	Sample				
	B	K1	K2	K3	K4
Full-fat fresh cheese	55.00	0	0	0	0
Low-fat fresh cheese	0	57.46	57.03	56.59	56.16
Whole egg	20.00	20.90	20.74	20.58	20.42
Sugar	10.00	10.45	10.37	10.29	10.21
Skimmed milk	10.00	10.45	10.37	10.29	10.21
Corn starch	5.00	0	0	0	0
KGM	0	0.75	1.50	2.25	3.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Protein content (g/100 g)	9.21	10.41	10.33	10.25	10.17
Fat content (g/100 g)	9.84	2.35	2.33	2.32	2.30
Carbohydrates (g/100 g)	17.50	14.29	14.21	14.08	13.97
of which sugars	9.98	10.43	10.38	10.27	10.19
Calorie content (cal/100 g)	196.70	120.61	119.79	118.79	117.86

B: control sample without KGM; K1, K2, K3, and K4: samples containing 0.75, 1.5, 2.25, and 3 g of KGM/100 g, respectively.