

Perspective: the path to confirming and exploiting potential satiety-enhancing effects of sorghum-based foods for human diets

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REVIEW ARTICLE

Abstract

Consumer trends, particularly in populations burdened with high rates of obesity and overweight, indicate a growing demand for food products with specific satiety-enhancing effects to assist with appetite regulation and longer-term weight management. Sorghum whole grain, containing dietary fibre, slowly digestible starches and polyphenolic compounds, has been identified as a potential ingredient in the formulation of novel food products targeted for appetite control. Rigorous human clinical trials are necessary to build evidence for these purported effects, including studies that examine the underlying satiety-enhancing mechanisms. This paper provides perspectives on the path to confirming and exploiting potential satiety attributes of sorghum-based foods for human diets, highlighting research activities currently being undertaken by the Smart Foods Centre at the University of Wollongong, Australia, where preliminary clinical results from an acute satiety study with 40 healthy participants indicate that a breakfast cereal biscuit made from whole grain sorghum may increase short-term satiety to a greater extent than a wheat-based control.

Keywords: appetite, cereal foods, disease, innovation, weight

1. Introduction

Food, diet and health are interrelated and dietary intake impacts significantly on public health outcomes. Recent reviews of the evidence confirm that healthy dietary patterns are positively associated with indicators of health and wellbeing (NHMRC, 2013). These diets contain specific foods and food components to which potent positive effects on disease markers may be attributed. While food has been used historically to improve the health of people, modern food and nutrition research has focused on improving and innovating food itself, through a greater understanding of the links between food components, the whole diet and health. This approach has facilitated improvements in the quality (or functionality) of food products, enhancing their potential to benefit health and reduce the risk of disease when they are consumed regularly. Today such foods are commonly referred to as ‘functional foods’.

Global food mega-trends, particularly in the developed countries, indicate a strong and growing consumer

interest in ‘naturally functional’ food products, including those that promote greater feelings of fullness and satiety (Hetherington *et al.*, 2013; Mellentin, 2013). Food companies have responded by investing in innovative product development and reformulations that have resulted in novel satiety-enhancing food products. Diets containing foods with optimised satiety attributes could be beneficial for appetite regulation and longer-term weight management (Hetherington *et al.*, 2013).

2. The opportunity for more sorghum-based foods with satiety attributes in western diets

Food choice at breakfast represents an important opportunity to increase satiety in the morning and reduce energy intake at lunch and during the remainder of the day (Beck *et al.*, 2009). Consequently, developing breakfast products from whole grain cereals with inherent satiety-enhancing functional properties is a growing area of interest for researchers and food companies alike. Sorghum, a phytonutrient-rich, gluten free cereal

whole grain, has a reputation for being satiating (based on reports from traditional African farmers (Awika and Rooney, 2004)) and may be a viable high-value ingredient for such food applications. Traditionally, sorghum has been used in a variety of foods particularly in Africa, India and Central America, including breads, porridges, steamed and boiled products, beverages and snack foods (such as popped sorghum) (Anglani, 1998; Taylor and Duodu, 2015). In more recent years in Western cultures, sorghum's light colour (characteristic of some cultivars), neutral flavour and pleasing texture has made it suitable for use in non-traditional food products including breakfast cereals, baking mixes for bread, gluten-free bread, cakes/brownies, pancakes, bars and gluten-free beer (Taylor, 2012; <http://tinyurl.com/hldxb8n>). In a USA consumer survey, Vazquez-Araujo *et al.* (2012) identified several drivers for purchase intent of sorghum grain products including: local origin (domestically-grown grain), inherent health benefits (for example, antioxidants), and appealing sensory characteristics (such as crunchy texture in breakfast cereals). To date, most of the sorghum-based products that have been launched are marketed for their gluten-free attribute and to our knowledge none have exploited the potential satiety-enhancing effects of sorghum grain.

3. Sorghum's nutritional and functional attributes

In a previous extensive review, we noted that sorghum may confer similar health benefits to whole grains in general, but that it has the added value of being drought-adaptable and relatively cheap to grow (Stefoska-Needham *et al.*, 2015). Sorghum is high in starch (approximately 70%), and the starch granules are enmeshed in a strong protein matrix in the endosperm (Duodu *et al.*, 2003). Some cultivars have a higher fibre and polyphenolic content (Awika and Rooney, 2004; Barros *et al.*, 2012). Collectively, these attributes contribute to lower *in vitro* starch digestibility rates. Depending on processing conditions, the resultant lower starch digestibility has implications for the glycaemic index of foods and in turn for post-prandial satiety-related responses as measured by glucose, insulin and various gut peptides involved in appetite regulation. Researchers have formulated a variety of organoleptically-acceptable sorghum-based foods that deliver slowly digestible starches (flat bread, pasta, extruded snacks), identifying sorghum's potential as a viable food ingredient in the manufacture of new grain products (Khan *et al.*, 2013; Licata *et al.*, 2014; Yousif *et al.*, 2012). Specific indications for effects have come from animal studies (Shen *et al.*, 2015), but to date few human studies have been conducted. One of the few and most recent studies was a randomised-crossover study involving 10 adult males which showed the potential of sorghum-based foods (wholegrain sorghum muffins) to attenuate blood glucose and insulin responses compared to a wheat alternative ($P < 0.05$) (Poquette *et al.*, 2014).

4. Research directions: preliminary findings from an acute satiety study

The need to bridge the gap between *in-vitro*/animal research and human clinical trials is the clear next step. To this end, our laboratory embarked on testing the hypothesis that sorghum grain's chemical and nutritional composition, together with its functional properties, is beneficial to human health and may assist in the prevention of chronic disease. Focusing clinical research on body weight outcomes is important within this framework, with investigation of satiety-related mechanisms assisting in our understanding of potential drivers of clinical effects. Hence, we initially conducted a randomised, double-blinded, crossover feeding trial with 40 healthy subjects (20 males; 20 females; BMI range 20–31 kg/m²; aged 20–50 years) (Stefoska-Needham *et al.*, 2016). Subjects attended the University of Wollongong, Australia, on four occasions after a 12-hour overnight fast. At baseline on each visit, they consumed 50 grams of one of four treatment meals, in the form of flaked breakfast biscuits, with water. The biscuits were produced from three different sorghum varieties (white, red and brown – differing in polyphenolic content) or a wheat-based control. Subjective satiety was measured using visual analogue scales (VAS) (Flint *et al.*, 2000) at 8 time-points over 4 hours. Satiety-related gut hormones including GLP-1 were measured in a subset of 20 subjects. Prospective food intake was measured at an *ad-libitum* lunch and also during the remainder of the test day using weighed food records.

Subjects reported greater subjective satiety sensations after eating all sorghum breakfast biscuits compared to wheat biscuits (Stefoska-Needham *et al.*, 2016). Figure 1 shows VAS measurements in response to the following 4 questions asked in the VAS: How hungry do you feel at this moment? (Q1); How satisfied do you feel at this moment? (Q2); How full do you feel at this moment? (Q3); and, How much do you think you can eat at this moment? (Q4). Differences in VAS responses between the treatments were identified using repeated measures analysis of variance (RMANOVA). For each question, responses aligned with greater sensations of hunger and lower satisfaction after the wheat biscuit was consumed, and participants reported feeling that they could eat more food at a subsequent meal.

The gut peptide, GLP-1, is associated with increased satiety in humans (Drucker and Nauck, 2006) and was used as a biochemical marker of satiety in this study. Figure 2 shows that GLP-1 levels (incremental area under the curve, corrected for baseline) differed significantly between treatment responses over the 4 hours testing period, being significantly higher after all sorghum biscuits compared to wheat (Stefoska-Needham *et al.*, 2016). Overall, both subjective satiety sensations and post-prandial GLP-1 responses were significantly increased after intake of sorghum biscuits compared to wheat. Further analysis

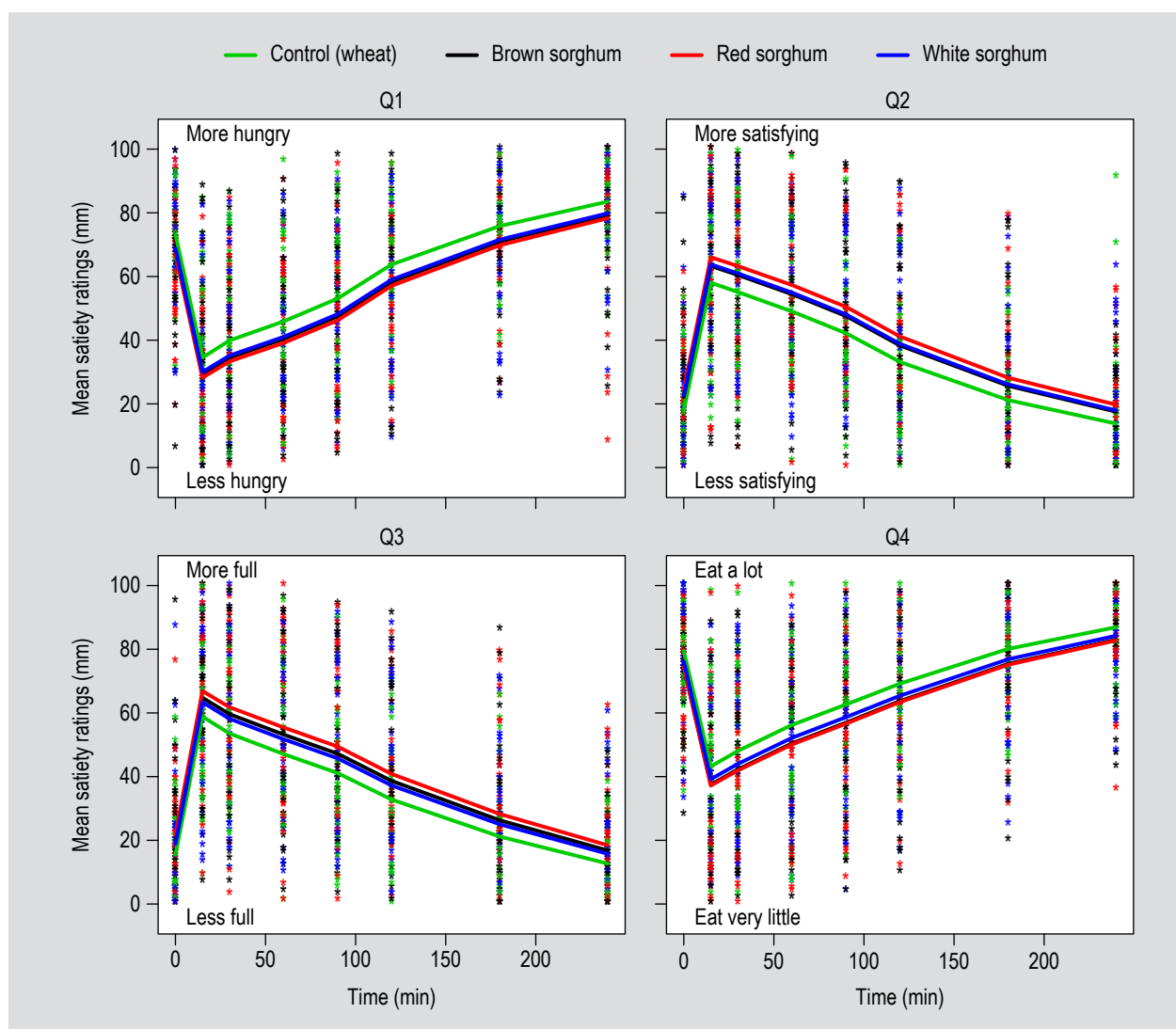


Figure 1. Repeated measures analysis of variance (RMANOVA) of mean satiety ratings (mm) for all 4 questions (Q1, Q2, Q3, Q4) after intake of different breakfast cereal biscuits at different time points over 4 h. Q1, Q4: increasing values on y-axis associated with greater hunger/lower satiety sensations. Q2, Q3: decreasing values on y-axis associated with greater satiety/lower hunger sensations.

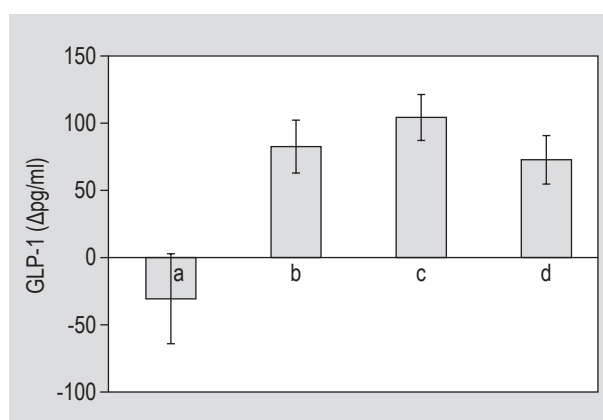


Figure 2. Concentration of the gut peptide GLP-1 (Δ pg/ml), measured as net incremental area under the curve, after eating different breakfast biscuits over time (a = wheat; b = white sorghum; c = red sorghum; d = brown sorghum).

of subsequent food intake data, together with a review of other appetite measures will enable a more complete interpretation of results. Polyphenol interactions effecting starch digestibility may be an underlying mechanism of action.

Exposing the mechanisms behind acute effects from sorghum intake in studies of this nature help to formulate hypotheses for the effects of chronic sorghum consumption in longer-term weight reduction trials that are considered the ‘gold-standard’ for evidence based practice. In these latter studies, the background diets of participants must be carefully scrutinised to ensure more precise attribution of effects to the dietary variable of interest. The comprehensive characterisation of physico-chemical properties of the test foods is an imperative, for valid interpretations of possible clinical effects. This may include identification of specific

polyphenolic or other antioxidant compounds, fibre types and other proximate determinations, as well as full details on the processing of the sorghum grain.

5. Concluding remarks

Clinical investigations conducted by our research group have explored the short-term effects of sorghum consumption. Preliminary results indicate that eating foods made from whole grain sorghum may have positive effects on subjective and biochemical measures of satiety, and therefore may assist in managing body weight in the longer-term. However, further interpretation of results is required to confirm this. In addition, evidence is needed from future randomised controlled trials that aim to directly examine specific effects on chronic disease biomarkers or health outcomes between a control and sorghum-intervention diet. The use of sorghum whole grain as an ingredient in the formulation of foods targeted for weight control through appetite regulation is promising and relevant in developed countries where obesity-related chronic diseases are prevalent and consumer demand for novel food products is high. From a food manufacturing perspective, these results will inform the development of novel sorghum grain food products that may be of assistance in appetite and weight regulation.

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