Carbohydrate engineering in sweet energy biscuits

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Summary

Biscuits containing sugar, rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) were characterized for composition and impact on blood glucose concentration with healthy volunteers. Products with added starch contained 1.7–2.2 % moisture, 23.8–24.4 % fat, 64.6–67.4 % carbohydrates where 19.4–19.5 % was sugar and 45.1–48.0 % starch, 1.1–3.6 % dietary fibre, 4.2–4.8 % protein and 0.5 % salt with 41.5–42.3 % digestible starch (SDS). The proportion of available carbohydrates as starch exceeded 55 % as recommended by the European Food Safety Authority (EFSA) for glycemic claims, where the SDS content exceeded the EFSA recommendation (40 %). For the wholewheat-based product with added starch, there was a progressive glucose response with a peak around 50–80 min, then a gradual return to baseline after approximately 4 h. For the white flour-based product with added starch, the peak was spread over 50–115 min with a flatter profile than for the wholewheat variant and still slightly above baseline at 5 h. The peak blood glucose concentrations for both the wholewheat and white flour-based products were approximately 6.4 $mmol \cdot l^{-1}$ and 6.7 $mmol \cdot l^{-1}$, respectively. The release of glucose over hours is relevant to general health, sport (endurance) and disease (hypoglycemia).

Keywords

blood glucose; starch; digestion; sweet; biscuit

Modern food products, including baked goods such as biscuits, contain in many cases high amounts of rapidly digestible starch (RDS). This provides a rapid increase in blood glucose concentration, which may repeat over many cycles with continued consumption. This is associated with a corresponding insulin response. In excess, this can cause health issues, e.g. obesity, diabetes (type II) and cardiovascular disease. The incorporation of slowly digestible starch (SDS) in food products, although difficult to achieve, provides for a healthier sustained blood glucose concentration and insulin response. This provides associated short- and long-term health benefits. This topic is of considerable interest to nutritionists and health providers due to the impact of lack of calorie control in modern diets and the considerable detrimental impact on health.

It is very difficult to make products such as baked goods, especially biscuits, that both taste good and provide a slow release of energy over many hours rather than a rapid and continued with further consumption 'yo-yo' of peaks and troughs of blood glucose with insulin response. It is a considerable challenge to obtain products that provide an attractive alternative to currently commercially available biscuits, which would have desirable health benefits in terms of appropriate glucose release profiles in the blood stream. The authors built on their considerable expertise in carbohydrate utilisation and attempted to prepare 'healthy biscuits' working out from the laboratory, through production trials into clinical trials to achieve this. These types of products provide health benefits for the general population, within the sports or endurance sectors and within areas of health where subjects are susceptible to hypoglycemia as a form of glycogen storage disease and insulin-induced hypoglycemia in diabetics.

Short dough products are relatively simple in composition with three main ingredients: flour, fat (butter traditionally, now more often with margarine) and sugar [1, 2]. Shortbread biscuits are an example of a short dough type product. The dough used in the preparation of these products represents a suspension of solid particles in

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a liquid phase comprising an emulsion of lipids within a relatively concentrated sugar solution [3]. Sometimes shortbread is referred to as a 'one-two-three' type biscuit, one part sugar, two parts butter (or margarine) and three parts flour (by weight). Within the ingredient selection, there is room for a great deal of variation in terms of type and composition of flour, fat and sugar used. As shortbread type biscuits are very simple to formulate and manufacture compared to many other types of biscuits, it might be assumed that they are relatively low value products. However, coupled with their desirable eating characteristics, the skilled packaging and storyline underpinning has made the products hugely popular in hospitality and domestic consumption worldwide.

In general, biscuits are consumed as snacks where energy is derived from the different nutrients, which include the carbohydrate sources starch and sugar, together with fat and protein. Amorphous starch will be digested as rapidly as glucose in the body, so that if the starch fraction is gelatinised, damaged or hydrolysed (as is the case of dextrins), it will, together with free sugar, impact on the blood glucose response rapidly and on the associated glycemic index (*GI*).

A typical shortbread biscuit's nutritional profile [4] is shown in Tab. 1. It is apparent that the product is rich in potentially digestible starch, sugar and fat making it a relatively energy-dense product. The glycemic characteristics of shortbread biscuits are presented in Tab. 2. The glycemic index (*GI*) of 64 puts the product into the medium *GI* range [5, 6]. Other types of plain sweet biscuits may have a lower *GI* [7]. Saccharose (table sugar) used in biscuit manufacture, including shortbread, does not just provide the sweetness but contributes to structure and mouthfeel, too [8, 9].

The extent of starch damage or gelatinisation in biscuits, reflecting the amorphous starch content, is associated with enhanced digestibility in vitro and in vivo [10, 11], as shown in Tab. 3 and Tab. 4. The SDS in plain biscuits may increase the sensations of fullness and satiety, leading to reduced energy intake [7]. Shortbread biscuits would appear to be a relatively good source of SDS (Tab. 4) where gelatinisation during processing is restricted [12].

The content of sugar and energy in cakes and biscuits is receiving attention from both public bodies and product manufacturers to identify how they might evolve, to reduce their energy provision in the diet [13]. There is interest in reducing the content of sugar and starch in the form of RDS within various food products [14, 15]. Baked goods, such as crackers or biscuits, could be formulated and manufactured to have a slow (e.g. four-hour) glucose release profile [16–19]. Elderly in the United Kingdom consume a number of snack types where shortbread biscuits are also popular [20].

Functional biscuits were developed that generated less glucose than 'standard' biscuits, although the ingredients were not declared, with the aim to reduce nutritional risk factors for coronary heart disease [21]. Similar approaches for controlling starch digestion rate and extent within food products, including snacks, for managing diabetic conditions were discussed in some detail by some authors [22–24]. Functional bars developed for sport nutrition, with controlled energy

Tab. 1. Typical shortbread biscuit composition [4].

Component	Proportion [%]
Water	3.5
Fat	29.0
Starch	46.5
Sugar	15.6
Protein	5.3
Fibre	1.3

Tab. 2. Typical shortbread biscuit glycemic characteristics [35].

Characteristic	Score
Glycemic index (glucose as reference)	64
Glycemic index (white bread as reference)	91
Glycemic load	10

Glzcemic characteristics is based on a serving size 25 g of which 16 g are carbohydrates.

Tab. 3. Content of starch and amorphous starch in various types of baked goods [11].

Product	Starch [$g \cdot kg^{-1}$]	Amorphous starch [$g \cdot kg^{-1}$]
Digestives	476	118
Shortbread	439	134
Rusks	510	271
Water biscuits	688	496
Oatcakes	521	637
Wholemeal bread	331	637
White bread	416	715
Crispbakes	631	713
Extruded crispbakes	653	905
Wafers	705	906

Starch content is expressed per kilogram of sample. Amorphous starch content is expressed per kilogram of starch.

Tab. 4. Glycemic index and other starch characteristics of some wheat-based products extracted from the literature [10, 36].

	Shortbread biscuits	White bread	Wholemeal bread	Water biscuits	Puffed wheat	Puffed crispbread
Glycemic index	64	–	77	78	80	81
Insulin Index	80	–	102	105	79	99
Starch hydrolysed in vitro [%]	58	–	76	74	105	97
Degree of gelatinisation [%]	0.4	–	60	1.5	54	50
Rapidly digestible starch (RDS) [%]	56	94	90	–	–	–
Slowly digestible starch (SDS) [%]	43	4	8	–	–	–
Resistant starch Type 1 (RS1) [%]	–	–	–	–	–	–
Resistant starch Type 2 (RS2) [%]	–	–	–	–	–	–
Resistant starch Type 3 (RS3) [%]	Traces	2	2	–	–	–

management properties, were discussed by other authors [25, 26].

There is limited information published in the literature on the relative digestibility of shortbread-type products. This is surprising in view of the products relatively high in SDS (Tab. 3, Tab. 4 for comparison). Possibly this nutritional benefit is overlooked in view of the relatively high sugar (saccharose) content, which tends to deflect energy focus from the slowly digestible carbohydrate fraction. This sugar content plus the RDS fraction are both contributing to the medium *GI* classification (Tab. 4).

This study was undertaken to understand how four different shortbread biscuit formats functioned when made with white or wholewheat (wholemeal) flour and for both flour types, with added maize starch. Specifically, the impact on product composition, proportion of starch fractions (RDS, SDS and resistant starch, RS) and for two products with starch addition, the impact on blood glucose response in human volunteers. The work represented an extension of previously reported work on savoury crackers, which contained no added sugar [19].

The objective of this work was to create SDS-rich sweet biscuits and test if judicious use of formulation and processing regimes would generate products rich in SDS, which were attractive to eat with associated health benefits. This represents a novel approach to manufacturing biscuits. The understanding of the chemistry of the ingredients, their interactions during processing and of processing steps allowed for the formation of sensorially desirable products, which have the capacity to release energy over many hours due to the control of starch molecular transformations during processing. This then provided a product (range) to avoid hypoglycemia during endurance and for clinical conditions such as glycogen storage disease and diabetes. The authors previously developed powder-based drink formats to manage hypoglycemia and these proved to be successful for the purpose. They also developed savoury products for this same purpose [19]. Sweet biscuit-type products are more universally accepted than savoury flavours as particular savoury flavours tend to be attractive to particular consumer groups. The overall novelty of the work described here is to make a desirable sweet, convenient, stable, long shelf life, ready-to-use product that confers the advantages of the drinks and savoury snacks [19] but in a more universal, sweet food format. This to support glucose homeostasis in health and disease.

The authors hypothesised that the product format used could control the rate and extent of digestion in humans over a number of hours (rather than within two hours reflecting glucose or sugar and RDS digestion rates. This hypothesis was evaluated using laboratory-based testing linked to in vivo data generated from human trials.

MATERIALS AND METHODS

Sweet energy biscuits were made 'in-house' by Glycologic Limited (Reading, United Kingdom) as shown in Tab. 5 using combinations of white or wholewheat biscuit flour, unsalted plant-based margarine and caster sugar (all from ASDA, Leeds, United Kingdom) and maize starch (Ingredion, Manchester, United Kingdom). The proximate composition of the products was determined by a United Kingdom Accreditation Service (UKAS) accredited laboratory (Premier Analytical Services, High Wycombe, United Kingdom). The sugar profile, RDS, SDS, RS and total starch (TS) content of the biscuit samples was determined by Englyst Carbohydrates (Southampton, United

Tab. 5. Nutritional data of sweet energy biscuits.

	White flour biscuits		Wholewheat flour biscuits	
	Without added starch	With added starch	Without added starch	With added starch
Moisture [%]	3.6	1.7	3.8	2.2
Energy [kJ]	2 185	2 128	2 144	2 089
Fat [%]	28.3	24.4	28.0	23.8
Saturated fat [%]	17.4	14.7	17.4	14.2
Mono-unsaturated fat [%]	6.5	5.9	6.4	5.8
Poly-unsaturated fat [%]	3.1	2.7	3.1	2.7
Carbohydrate [%]	61.8	67.4	57.6	64.6
Sugars [%]	23.6	19.4	24.2	19.5
Starch [%]	38.2	48.0	33.4	45.1
Dietary fibre [%]	< 0.5	1.1	3.5	3.6
Protein [%]	5.1	4.2	5.9	4.8
Salt [%]	0.6	0.5	0.6	0.5

Data generated by Premier Analytical Services (High Wycombe, United Kingdom) and Englyst Carbohydrates Limited (Southampton, United Kingdom).
Starch is calculated by difference from carbohydrates minus sugar content.

Kingdom). The company provides commercial testing for the Englyst-based classification of starches using the Englyst et al. [27] starch digestion classification system.

Blood glucose concentrations were determined in healthy adults pre- and post-consumption of the white and wholewheat biscuits with added maize starch, which contained the highest proportions of starch in total (Tab. 5). The trial was conducted in July 2023 at Viet My General Clinic, (Ho Chi Minh City, Vietnam). Ethical approvement was obtained from the hospital, who operated under globally recognised clinical conditions for all patient care and attention, with assigned code PN110723. Twenty healthy volunteers (ten male and ten female aged 20 to 67, in the weight range from 40 kg to 85 kg, as profiled in Tab. 6) were recruited and agreed to attend the clinic on two separate visits for the trial, having been informed verbally and in writing what was involved and had, thereupon, provided consent to take part in the trial. They were each assigned an individual code (Tab. 6). Average age and weight for the females was 33.6 ± 15.0 and 51.7 ± 13.5 kg and for males 35.1 ± 15.2 and 63.8 ± 8.5 kg, respectively, as shown in Tab. 6. These individuals showed a natural normal distribution, which matched the average weight for Vietnamese people (2021), where the average for women and men in the age group from 20 to over 85 is 53.2 ± 8.2 and 62.9 ± 10.0 ($P \leq 0.001$), respectively [28].

All of the volunteers fasted overnight before either of two visits to the clinic. On day one, the volunteers blood glucose concentrations were measured at time zero (07:00–09:00) using Roche Diagnostics Accu-Chek Active blood glucose monitoring systems (Roche Diagnostics, Basel, Switzerland) whereupon they ate 60 g white flour-based biscuits (within 2 min) with access to 150 ml warm bottled water as required. Blood glucose concentration measurements were continued after

Tab. 6. Participant profile.

Participant	Sex	Age	Weight [kg]
1	Male	38	75
2	Male	24	60
3	Female	31	42
4	Male	57	70
5	Male	27	61
6	Female	21	53
7	Female	20	40
8	Male	21	55
9	Male	28	52
10	Female	22	64
11	Female	31	45
12	Male	27	65
13	Male	26	55
14	Female	25	44
15	Female	51	46
16	Male	67	70
17	Female	61	85
18	Male	36	75
19	Female	23	50
20	Female	51	48
Average female		33.6 ± 15.0	51.7 ± 13.5
Average male		35.1 ± 15.2	63.8 ± 8.5

thirty minutes and then every fifteen minutes for five hours. On day two, no trials were conducted. On day three, this procedure was repeated for the wholewheat flour-based biscuits. Once again, blood glucose concentrations were determined after thirty minutes and then every fifteen minutes for five hours. The volunteers' data were tabulated and converted into graphical format, specifically, averages (for all participants combined) with associated error bars (Fig. 1). Areas under the curves were integrated using various approaches although cutting and weighing was found to be the preferred method.

RESULTS AND DISCUSSION

Composition

The composition and nutritional data for the four biscuits are reported in Tab. 5. As shown in the table, the wholewheat flour-based products were similar to the white flour-based products with respect to some nutrients although the overall dietary fibre and protein contents were higher, < 0.5–1.1 % versus 3.5–3.6 % and 4.2–5.1 % versus 4.8–5.9 %, respectively. The addition of maize starch to the white or wholewheat-flour based products had the impact of decreasing relatively the energy, moisture, fat, sugar, protein and salt content whilst increasing relatively the dietary fibre and starch content.

In terms of the starch fractions (Tab. 7), as anticipated, products made with white flour contained more carbohydrates than wholewheat flour (65.5–72.2 % and 60.2–68.2 %, respectively). Starch addition to both flour types increased the carbohydrates content from 60.2–65.5 % to 68.2–72.2 %. The total sugar (calculated as glucose plus fructose post saccharose inversion plus any free monosaccharides) content of the white and wholewheat flour products without maize starch addition was essentially the same (25.4–25.6 %), which was reduced relatively when starch was added (21.0–21.2 %).

When maize starch was added to the white flour base, the total starch content increased from 40.7 % to 52.3 %, with an associated increase in SDS from 15.2 % to 21.3 % equivalent to the increase from 37.8 % to 41.5 % for claim purposes. The wholewheat flour variant responded similarly where the total starch content increased from 35.1 % to 48.0 %, with an associated increase in SDS from 11.7 % to 19.9 % equivalent to the increase from 33.7 % to 42.3 % for claim purposes. The SDS figure in samples with starch addition fell above the 40% threshold as defined by the European Food Safety Authority (EFSA) [29] (Tab. 7). In terms of the available starch proportion of available carbohydrates, all samples exceeded 55 % as discussed in more detail below.

All of the biscuit variants (Tab. 5) had very desirable eating characteristics according to the volunteers who participated in the trial (data not shown).

The benefits of sustained energy release products in the diet have been gaining in interest

Tab. 7. Comparison of the in vitro derived starch fractions for biscuits with EFSA criteria for crackers and biscuits expressed as monomer equivalents.

	White flour biscuits		Wholewheat flour biscuits		EFSA [29]
	Without added starch	With added starch	Without added starch	With added starch	
Available carbohydrates [%]	65.5	72.2	60.2	68.2	–
Fructose [%]	12.8	10.6	12.9	10.7	–
Glucose [%]	12.6	10.4	12.7	10.5	–
Total sugar [%]	25.4	21.0	25.6	21.2	–
Total starch (TS) [%]	40.7	52.3	35.1	48.0	–
Rapidly digestible starch (RDS) [%]	25.0	30.0	22.9	27.1	–
Slowly digestible starch (SDS) [%]	15.2	21.3	11.7	19.9	–
Available starch (RDS + SDS) [%]	40.2	51.3	34.6	47.0	–
Resistant starch (RS) [%]	0.6	1.0	0.6	1.0	–
Available starch proportion* [%]	61.3	71.0	57.4	68.9	55.0
SDS fraction** [%]	37.8	41.5	33.7	42.3	40.0

Data from Englyst Carbohydrates Limited (Southampton, United Kingdom). Numbers are rounded from calculated fraction determinations.

* – available starch proportion of available carbohydrates for claim purposes, ** – slowly digestible starch fraction of available starch for claim purposes.

over recent years. The consumption of products high in SDS raises blood glucose concentration after a meal less compared to products low in SDS [30]. According to EFSA [29], in order to claim that glycemic responses as a consequence of consuming SDS, consumption of cereal products high in SDS raises blood glucose concentrations after a meal less than cereal products low in SDS, cereal products should contain at least 55 % of available carbohydrates as starch of which at least 40 % should be SDS. The target population is individuals who wish to reduce their post-prandial blood glucose responses.

Both *GI* and insulin index (*II*) of cereal products can be defined by rapidly and slowly available glucose contents where the latter reflects low-*GI* foods rich in slowly released (digested) carbohydrates with associated health benefits [31]. The available carbohydrates content of energy bars defines the blood glucose and (to a great extent) the insulin response [32].

It is evident that it is not just the amount of starch in a product which controls its capacity to be digested and release calories, as the body is very efficient at digesting food, but critically too, the amorphous to ordered (semi-crystalline) α-glucan content. This relative digestibility governed by starch structural damage (during ingredient production) and even more by gelatinisation (during product heating or cooking). Thus, there is a variable starch content with variable digestibility in many food products. Consideration of both aspects, which is relevant to the relative *GI* of a product, is important to understand calorie availability, which is ultimately derived from glucose. There are really four extremes of starch digestibility in this respect:

A – relatively high starch content with relatively low amorphous starch proportion and hence relatively high SDS content,

B – relatively high starch content with relatively high amorphous starch proportion and hence relatively low SDS content,

C – relatively low starch content with relatively low amorphous starch proportion and hence relatively low SDS content due to the low amount of starch in totality,

D – relatively low starch content with relatively high amorphous starch proportion and hence relatively low SDS content, amounting to even less than scenario C.

In terms of blood glucose increase approximately 40 min after ingestion, with which increase in insulin is associated, of the four scenarios above, they would appear with a magnitude of B > D > A > C. This is not a theoretical consideration but represents the reality of eating starch-containing foods as discussed previously [19].

The content of starch, as part of the carbohydrate fraction, presented on a food product label says nothing about the rate and extent to which it is digested with the associated physiological impact. Only the content is recorded on food labels, from which calories are derived and counted. Hence, only part of the nutritional consequence of eating starch in any given product is made available and thus to be understood by the consumer. This has an impart in terms of weight management, disease states (e.g. diabetes) and colonic health, where RS may function as a prebiotic.

SDS, RDS and RS classifications of starch are not commonly understood. The RS concept would potentially add to most confusion on food products if labelled as such as it would tend to function as dietary fibre and not as digestible starch. However, when fermented in the colon, it does (like non-starch polysaccharides) provide energy (8 368 $kJ \cdot kg^{-1}$ versus 15 690 $kJ \cdot kg^{-1}$ for starch digested in the small intestine).

There may be an argument that classification of starch digestibility does not matter in a balanced and calorie-controlled diet. However, the evidence is that SDS is a much healthier way to consume starch than RDS. This is against the backdrop of the shear amount of starch consumed by consumers throughout the world and calories derived thereof. In the United Kingdom, on average, people consume 54 kg of flour per person each year [33]. This amounts to approximately 37.8 kg starch in the case of wholewheat flour and 43.2 kg in the case of white flour. Other crops, such as potatoes, rice, cassava etc., will provide additional dietary starch.

Overall, the content of starch listed on a food product label does not reflect its digestibility in the body. It is the content plus the relative proportions of RDS, SDS, RS, which impact on *GI*, blood glucose concentration and impact on glucose homeostasis. Food labelling legislation has tried, over many decades, to improve consumer understanding of what food they are buying but this has created anomalies in some areas of nutrition even with an ingredients list presented on the pack. Starch is one such anomaly. In some countries, declaring *GI* scores has been allowed to help people understand part of the story with respect to digestibility of the available carbohydrates. Consumers may not, however, be always tuned into the limitations of this concept, including the appropriate amounts to be consumed, which are reflected in *GI*.

Shortbread biscuits have, even with its added sugar content, the opportunity to be developed into a range of products targeted at various markets where energy management in the diet is important, although it is actually important for all consumers. The unique composition of shortbread makes it a very interesting matrix containing carbohydrates, which can be tuned potentially to achieve various digestibility profiles.

Blood glucose response

The blood glucose response for the volunteers is shown in Fig. 1. For the wholewheat flour biscuits, there was a flat glucose response with a peak between 50 min and 80 min post consumption, followed by a gradual return to baseline after approximately 4 h. For samples based on white flour, the peak was spread between 50 min and 115 min with a flatter profile than for the wholewheat format. The released blood glucose concentration was still slightly above the baseline at 5 h. The peak blood glucose concentrations for the wholewheat- and white flour-based products were approximately 6.4 $mmol\cdot l^{-1}$ and approximately 6.7 $mmol\cdot l^{-1}$, respectively.

The profiles (Fig. 1) indicated that the products could release energy for a relatively long period of time apparently reflecting their relatively high SDS content of 19.9–21.3 % (Tab. 7). Glucose derived from the added saccharose will be absorbed within the peak regions of the profiles; that is within 120 min [19]. The relative areas under the curves for the two samples were 1 : 1.68 for the wholewheat flour-based compared to the white flour-based product, showing that more glucose was derived from the white flour-based format.

Relationship between starch fractions and blood glucose release property

The main compositional differences between the wholewheat- and white flour-based products were (Tab. 5, Tab. 7): dietary fibre (3.6 % and 1.1 %, respectively), protein (4.8 % and 4.2 %, respectively), starch (45.1 % and 48.0 %, respectively), available carbohydrates (68.2 % and 72.2 %, respectively), total starch (48.0 % and 52.3 %, respectively), RDS (27.1 % and 30.0 %, respectively) and SDS (19.9 % and 21.3 %, respectively).

In terms of relative availability of glucose from their matrices over time, there were major factors to consider:

1. composition,
2. structure,
3. impact of composition and structure on relative hydrophilic or hydrophobic aspects of the structure and associated relative ease of hydration,
4. impact of composition and structure on the accessibility to starch within the products for α-glucan-directed enzymes (probably α-amylase in particular) in the small intestine,
5. relative presence of any enzyme inhibitors with the ingredients or created during processing,
6. impact on 'wicking' caused by the bran in the wholewheat product,
7. impact of composition and structure on the rate of transit through the mouth-oesophagus, stomach and small intestine.

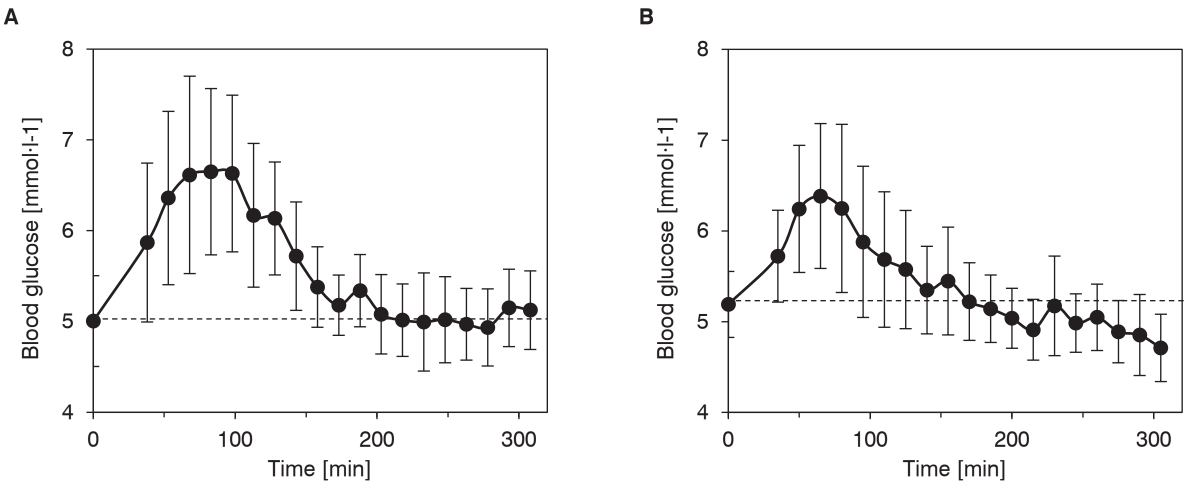

Fig. 1. Blood glucose profile of healthy volunteers (n = 20) after consumption of 60 g biscuits with added starch.

A – white flour biscuits, B – wholewheat flour biscuits.

Tab. 8. Impact of volunteer age and body weight on blood glucose parameters (peak amplitude and blood glucose concentration after 4 h).

	r	R^2	*P*-value	Significance at 0.01	Significance at 0.001
White flour biscuits					
Age versus blood glucose at peak height (83 min)	0.0539	0.0029	0.8213	*	*
Weight versus blood glucose at peak height (83 min)	0.0636	0.0040	0.7901	*	*
Age versus blood glucose at 233 min	0.4126	0.1703	0.0706	–	–
Weight versus blood glucose at 233 min	0.1036	0.0107	0.6637	*	*
Wholewheat flour biscuits					
Age versus blood glucose at peak height (65 min)	0.0313	0.0010	0.8958	*	*
Weight versus blood glucose at peak height (65 min)	0.2729	0.0745	0.2443	–	–
Age versus blood glucose at 230 min	0.2559	0.0655	0.2762	–	–
Weight versus blood glucose at 230 min	0.1862	0.0347	0.4319	–	–

The starch within bread will be more gelatinised than within shortbread biscuits and will also thus retrograde more to create more resistant starch post processing. Whitney and Simsek [34], however, reported some very interesting observations for bread. They prepared breads according to six formulations: two based on refined flours, two based on wholewheat flours and two based on wholewheat flours with added starch to make up for the lower starch content in the wholewheat products and match the starch content to the white flours. They conducted physico-chemical analysis together with in vitro hydrolysis studies to determine the 'estimated' *GI* (*eGI*). They found that the RDS, SDS, RS proportions and *eGI* of the refined flour breads were 40.6–40.8 %, 26.0–26.4 %, 1.7–1.9 % and 92.7–93.1 %, respectively, for the wholewheat breads 35.7–36.1 %, 17.3–17.6 %, 2.3–2.8 % and 83.4–84.7 %, respectively, and for the wholewheat product with starch added to become equivalent to white flour 35.6–36.3 %, 19.1–19.3 %, 2.2–3.0 % and 84.0–85.1 %, respectively. Hence, something quite profound was happening in the products made with wholewheat flour, which was beyond the amount of starch present or gelatinisation of starch during processing to control the capacity to be hydrolysed by simulated digestive processes. The authors concluded that the relatively low starch content in the wholewheat bread products did not in itself decrease *eGI*, with some other component or components of the wholewheat bread causing the decrease. They suggested that two factors were (i) an increase in starch damage of the white bread starch after baking compared to the wholewheat bread and (ii) a reduction of starch molecular weight after baking to a greater extent in white bread versus wholewheat bread. For the sweet energy biscuits discussed in this study, however, the starch will be far less modified than in bread due to its low water content [11]. So, the logical conclusion is that something or some aspect present in the wholewheat flour, significantly more than in the white flour, decreases the capacity of the digestive enzymes to hydrolyse the starch. This may be physical, chemical, biochemical and/or physiological.

Statistical interpretation

The peak height (amplitudes) of the blood glucose response versus participant age and weight for white flour- and wholewheat flour-based products are presented in Tab. 8. In addition, the blood glucose response at approximately 4 h (which is double the standard two-hour glycemic response period) are included, too. Although the graphical profiles almost 'flat-lined' with data spread around the trend line (reflected in low *r* and R^2 as a function of weight and age), these data indicate that for the white flour-based products there was:

- A significant *P*-value (significance at 1 % and 0.1 %) correlation (at 0.01 and 0.001) between participant age and body weight with peak blood glucose response (83 min post consumption) and for body weight (not age) linked blood glucose response at 4 h (actually 233 min) post consumption. This is not surprising when considering clinical nutrition products at least as they are most often consumed in amounts linked to body weight (and age).
- The wholewheat products, which contained less starch, showed significant correlation for age versus peak height blood glucose response (in this case 65 min post consumption) but not for

the other parameters (age versus peak height and body weight versus duration of blood glucose response, here 230 min represented the 4 h reading).

It is anticipated that larger scale trials will be conducted in the future with a broader age and body weight range of participants.

Comparison with other products

The authors compared the sustained release properties of crackers developed by themselves with biscuits generated by other groups elsewhere [19] and readers are referred to those publications for more insight. Commercial brands of sweet biscuits with sustained energy release claims have been marketed over the last two decades and have proven to be popular. Unlike the products developed for this study, which were focused towards sensory, nutrition and vegan in character advantages, commercial products on the market now are more complex in ingredient design, not 'natural' in terms of all ingredient choice, very sweet, tend to be fragile, not sensorially optimised, not vegan, potentially more expensive to manufacture and are limited with respect to their claim base (changed from the time of launch). One such product was profiled for composition and digestive properties in terms of blood glucose control previously [19].

CONCLUSIONS

This study demonstrated that by employing judicious control in recipe formulation underpinned by an understanding of carbohydrate chemistry, it is possible to produce sensorially desirable sweet energy biscuits which, due to their increased SDS content, can provide sustained blood glucose release into the blood stream for up to 4 h when made with wholewheat flour and in excess of 5 h when made with white flour. All products developed for this study exceeded 55 % available starch as a proportion of available carbohydrates for claim purposes and, similarly, the SDS content in products with added starch exceeded 40 %. Thus, these products fall within the EFSA claim that 'Consumption of cereal products high in slowly digestible starch raises blood glucose concentrations less after a meal than cereal products low in slowly digestible starch' [29]. The products provide a valuable option for helping to provide sustained energy release in the body in health and where the consumer may be susceptible to hypoglycemia, e.g. sport, endurance, glycogen storage disease or diabetes. In addition, applications to support cognition. The study is very timely to support human health and make a contribution to the health-promoting baked goods sector. This can be a key contributor to excess calorie consumption associated sharp transient increase and decrease in blood glucose concentrations, insulin secretion and deposition of fat with associated impacts on human health. The authors plan to expand the trial base in the future to larger groups including those requiring hypoglycemia support.

REFERENCES

1. Manley, D. – Pareyt, B. – Delcour, J. A.: Short dough biscuits. In: Manley D. (Ed.): Manley's technology of biscuits, crackers and cookies. 4th edition. Cambridge : Woodhead Publishing, 2011, pp. 331–346. DOI: 10.1533/9780857093646.3.331.
2. Baldino, N. – Gabriele, D. – Lupi, F. R. – de Cindio, B. – Cicerelli, L.: Modelling of baking behavior of semi-sweet short dough biscuits. Innovative Food Science and Emerging Technologies, *25*, 2014, pp. 40–52. DOI: 10.1016/j.ifset.2013.12.022.
3. Chevallier, S. – Colonna, P. – Buléon, A. – Della Valle, G.: Physicochemical behaviours of sugars, lipids and gluten in short dough and biscuit. Journal of Agricultural and Food Chemistry, *48*, 2000, pp. 1322–1326. DOI: 10.1021/jf990435+.
4. McCance and Widdowson's composition of foods integrated dataset 2021. London : Public Health England, 2021. <https://assets.publishing.service.gov.uk/media/60538e66d3bf7f03249bac58/McCance_and_Widdowsons_Composition_of_Foods_integrated_dataset_2021.pdf>
5. Qi, X. – Tester, R. F.: Fructose, galactose and glucose – In health and disease. Clinical Nutrition ESPEN, *33*, 2019, pp. 18–28. DOI: 10.1016/j.clnesp.2019.07.004.
6. Qi, X. – Tester, R. F.: Lactose, maltose, and sucrose in health and disease. Molecular Nutrition and Food Research, *64*, 2020, article e1901082. DOI: 10.1002/mnfr.201901082.
7. Garsetti, M. – Vinoy, S. – Lang, V. – Holt, S. – Loyer, S. – Brand-Miller, J. C.: The glycemic and insulinemic index of plain sweet biscuits: Relationships to in vitro starch digestibility. Journal of the American College of Nutrition, *24*, 2005, pp. 441–447. DOI: 10.1080/07315724.2005.10719489.
8. Laguna, L. – Vallons, K. J. R. – Jurgens, A. – Sanz, T.: Understanding the effect of sugar and sugar replacement in short dough biscuits. Food and Bioprocess Technology, *6*, 2013, pp. 3143–3154. DOI: 10.1007/s11947-012-0968-5.
9. van der Sman, R. G. M. – Renzetti, S.: Understanding functionality of sucrose in biscuits for reformulation purposes. Critical Reviews in Food Science and Nutrition, *59*, 2019, pp. 2225–2239. DOI: 10.1080/10408398.2018.1442315.

10. Ross, S. W. – Brand, J. C. – Thorburn, A. W. – Truswell, A. S.: Glycaemic index of processed wheat products. American Journal of Clinical Nutrition, *46*, 1987, pp. 631–635. DOI: 10.1093/ajcn/46.4.631.
11. Karkalas, J. – Tester, R. F. – Morrison, W. R.: Properties of damaged starch granules. I. Comparison of a micro-method for the enzymic determination of damaged starch with the standard AACC and Farrand methods. Journal of Cereal Science, *16*, 1992, pp. 237–251. DOI: 10.1016/S0733-5210(09)80087-8.
12. Tester, R. F. – Sommerville, M. D.: The effects of non-starch polysaccharides on the extent of gelatinisation, swelling and α-amylase hydrolysis of maize and wheat starches. Food Hydrocolloids, *17*, 2003, pp. 41–54. DOI: 10.1016/S0268-005X(02)00032-2.
13. Hashem, K. H. – He, F. J. – Alderton, S. A. – MacGregor, G. A.: Cross-sectional survey of the amount of sugar and energy in cakes and biscuits on sale in the UK for the evaluation of the sugar-reduction programme. BMJ Open, *8*, 2018, article e019075. DOI: 10.1136/bmjopen-2017-019075.
14. Azeredo, H. M. C. – Tonon, R. V. – McClements, D. J.: Designing healthier foods: Reducing the content or digestibility of key nutrients. Trends in Food Science and Technology, *118* (Part A), 2021, pp. 459–470. DOI: 10.1016/j.tifs.2021.10.023.
15. Di Cairano, M. – Caruso, M. C. – Galgano, F. – Favati, F. – Ekere, N. – Tchuenbou-Magaia, F.: Effect of sucrose replacement and resistant starch addition on textural properties of gluten-free doughs and biscuits. European Food Research and Technology, *247*, 2021, pp. 707–718. DOI: 10.1007/s00217-020-03659-w.
16. Lehmann, U. – Robin, F.: Slowly digestible starch – its structure and health implications: a review. Trends in Food Science and Technology, *18*, 2007, pp. 346–355. DOI: 10.1016/j.tifs.2007.02.009.
17. Péronnet, F. – Meynier, A. – Sauvinet, V. – Normand, S. – Bourdon, E. – Mignault, D. – St-Pierre, D. H. – Laville, M. – Rabasa-Lhoret, R. – Vinoy, S.: Plasma glucose kinetics and response of insulin and GIP following a cereal breakfast in female subjects: effect of starch digestibility. European Journal of Clinical Nutrition, *69*, 2015, pp. 740–745. DOI: 10.1038/ejcn.2015.50.
18. Vinoy, S. – Laville, M. – Feskens, E. J. M.: Slow-release carbohydrates: growing evidence on metabolic responses and public health interest. Summary of the symposium held at the 12th European Nutrition Conference (FENS 2015). Food and Nutrition Research, *60*, 2016, article 31662. DOI: 10.3402/fnr.v60.31662.
19. Qi, X. – Ta, M. N. – Tester, R. F.: Savoury cracker development for blood glucose control and management. Bioactive Carbohydrates and Dietary Fibre, *24*, 2020, article 100249. DOI: 10.1016/j.bcdf.2020.100249.
20. Butt, N.: Snack choices in older people. Clinical Nutrition, *37*, 2018, pp. S235–S236. DOI: 10.1016/j.clnu.2018.06.1838.
21. Boobier, W. J. – Baker, J. S. – Hullen, D. – Graham, M. R. – Davies, B.: Functional biscuits and coronary heart disease risk factors. British Food Journal, *109*, 2007, pp. 260–267. DOI: 10.1108/00070700710732574.
22. Kaufman, F. R. – Devgan, S.: Use of uncooked corn starch to avert nocturnal hypoglycaemia in children and adolescents with Type 1 diabetes. Journal of Diabetes and its Complications, *10*, 1996, pp. 84–87. DOI: 10.1016/1056-8727(94)00079-4.
23. Vinoy, S. – Normand, S. – Meynier, A. – Sothier, M. – Louche-Pelissier, C. – Peyrat, J. – Maitrepierre, C. – Nazare, J.-A. – Brand-Miller, J. – Laville, M.: Cereal processing influences postprandial glucose metabolism as well as the GI effect. Journal of the American College of Nutrition, *32*, 2013, pp. 79–91. DOI: 10.1080/07315724.2013.789336.
24. Russell, W. R. – Baka, A. – Bjorck, I. – Delzenne, N. – Gao, D. – Griffiths, H. R. – Hadjilucas, E. – Juvonen, K. – Lahtinen, S. – Lansink, M. – Van Loon, L. – Mykkanen, H. – Ostman, E. – Riccardi, G. – Vinoy, S. – Weickert, M. O.: Impact of diet composition on blood glucose regulation. Critical Reviews in Food Science and Nutrition, *56*, 2016, pp. 541–590. DOI: 10.1080/10408398.2013.792772.
25. Kaviani, M. – Chilibeck, P. D. – Jochim, J. – Gordon, J. – Zello, G. A.: The glycaemic index of sport nutrition bars affects performance and metabolism during cycling and next-day recovery. Journal of Human Kinetics, *66*, 2019, pp. 69–79. DOI: 10.2478/hukin-2018-0050.
26. Kaviani, M. – Chilibeck, P. D. – Gall, S. – Jochim, J. – Zello, G. A.: The effects of low- and high-glycemic index sport nutrition bars on metabolism and performance in recreational soccer players. Nutrients, *12*, 2020, article 982. DOI: 10.3390/nu12040982.
27. Englyst, K. N. – Englyst, H. N. – Hudson, G. J. – Cole, T. J. – Cummings, J. H.: Rapidly available glucose in foods: An in vitro measurement that reflects the glycemic response. American Journal of Clinical Nutrition, *69*, 1999, pp. 448–454. DOI: 10.1093/ajcn/69.3.448.
28. Nguyen, H. G. – Le, N. V. – Nguyen-Duong, K. H. – Ho-Pham, L. T. – Nguyen, T. V.: Reference values of body composition parameters for Vietnamese men and women. European Journal of Clinical Nutrition, *75*, 2021, pp. 1283–1290. DOI: 10.1038/s41430-020-00840-y.
29. Scientific opinion on the substantiation of a health claim related to “slowly digestible starch in starch-containing foods” and “reduction of post-prandial glycaemic responses” pursuant to Article 13(5) of Regulation (EC) No 1924/2006. EFSA Journal, *9*, 2011, article 2292. DOI: 10.2903/j.efsa.2011.2292.
30. Vinoy, S. – Meynier, A. – Conrad, M. – Goux, A.: Authorised EU health claim for slowly digestible starch. In: Sadler M. J. (Ed.): Foods, nutrients and food ingredients with authorised EU health claims: Volume 2. Cambridge : Woodhead Publishing, 2015, pp. 49–74. ISBN: 9781782423829. DOI: 10.1016/B978-1-78242-382-9.00003-7.
31. Englyst, K. N. – Vinoy, S. – Englyst, H. N. – Lang, V.: Glycaemic index of cereal products explained by

their content of rapidly and slowly available glucose. British Journal of Nutrition, *89*, 2003, pp. 329–339. DOI: 10.1079/BJN2002786.
32. Hertzler, S. R. – Kim, Y.: Glycaemic and insulinaemic responses to energy bars of differing macronutrient composition in healthy adults. Medical Science Monitor, *9*, 2003, CR84–CR90. ISSN: 1643-3750. <http://www.MedSciMonit.com/pub/vol_9/no_2/3230.pdf>
33. Flour and bread consumption. In: UK Flour Millers [online]. London : UK Flour Millers, 2023 [cited 23 February 2024]. <https://www.ukflourmillers.org/flourbreadconsumption>
34. Whitney, K. – Simsek, S.: Reduced gelatinisation, hydrolysis and digestibility in whole wheat bread in comparison to white bread. Cereal Chemistry, *94*, 2017, pp. 991–1000. DOI: 10.1094/CCHEM-05-17-0116-R.
35. Foster-Powell, K. – Holt, S. H. A. – Brand-Miller, J. C.: International table of glycaemic index and glycaemic load values: 2002. American Journal of Clinical Nutrition, *76*, 2002, pp. 5–56. DOI: 10.1093/ajcn/76.1.5.
36. Eastwood, M.: Principles of human nutrition. New York : Springer, 1997. ISBN: 9780412576508. DOI: 10.1007/978-1-4899-3025-5.

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