Soluble fibres as sucrose replacers: effects on physical and sensory properties of sugar-reduced short-dough biscuits

Article

Published Version

Rodriguez Garcia, J. ORCID: https://orcid.org/0000-0002-4986-3144, Ding, R., Nguyen, T. H. T., Grasso, S., Chatzifragkou, A. ORCID: https://orcid.org/0000-0002-9255-7871 and Methven, L. (2022) Soluble fibres as sucrose replacers: effects on physical and sensory properties of sugar-reduced short-dough biscuits. LWT - Food Science and Technology, 167. 113837. ISSN 0023-6438 doi: 10.1016/j.lwt.2022.113837 Available at https://centaur.reading.ac.uk/106563/

To link to this article DOI: http://dx.doi.org/10.1016/j.lwt.2022.113837

Publisher: Elsevier

LWT - Food Science and Technology 167 (2022) 113837

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Soluble fibres as sucrose replacers: Effects on physical and sensory properties of sugar-reduced short-dough biscuits

Julia Rodriguez-Garcia *, Rui Ding, Thao H.T. Nguyen, Simona Grasso, Afroditi Chatzifragkou, Lisa Methven

Department of Food and Nutritional Sciences, University of Reading, Whiteknights, Reading, Berkshire, RG6 6AP, UK

ARTICLE INFO

Keywords:
Sugar replacement
Short-dough biscuit
Dextrin
Inulin
Texture

ABSTRACT

Four different soluble fibres were evaluated as sugar replacers in short dough biscuits: two resistant dextrins (Nutriose® FM06 and Promitor® SGF 70R) and two inulin-derived fibres (Orafti® HSI and Fibruline™ Instant). The degree of polymerisation of the fibres was analysed, and dough viscoelastic properties were assessed. Weight loss during baking, dimensions, textural properties, surface colour and sensory profile were evaluated. Higher degree of polymerisation fibres (e.g. Fibruline) limited water availability for syrup formation, restricting dough expansion and resulting in smaller, more compact, and harder biscuits than control. Biscuits with inulin derived fibres with a lower degree of polymerisation (e.g. Orafti) showed similar dimensions to control biscuits. In general, sucrose reduction gave place to biscuits with lower resistance to penetration and fracture strength due to less sugar recrystallisation in the final biscuit. In contrast, when dextrin-type fibres were used the rheological behaviour of the dough, spreading during baking, and resistance to penetration were similar to the control as the fibres showed an *anti*-plasticising effect similar to sucrose. However, all reduced sugar biscuits were significantly firmer and crunchier in sensory profile suggesting further optimisation is needed, potentially by modification of the fibre structure or baking method.

1. Introduction

Biscuits are affordable, energy-dense, convenient and highly palatable products, what makes them an ideal snack for the modern lifestyle. Biscuits are cereal based products baked to a moisture content below 5% and flour, sugar, and fat are the three major ingredients used in biscuit manufacturing (Manley, 2011). The main sources of sugar in the UK diet are soft drinks, table sugar, confectionery, biscuits, and other bakery products. Consumption of free sugars by all population groups exceeds government recommendation, contributing between 12 and 15% of energy, rather than providing no more than 5% of total energy intake (Public Health England, 2015, 2020). Overconsumption of food and drinks high in sugar is linked to a global rise in health issues including obesity, type 2 diabetes, and coronary heart disease (World Health Organization, 2003), which have direct economic and quality-of-life consequences. Research shows that marketing influences food preference, choice and purchase increasing the amount of sugar purchased (Public Health England, 2015). Therefore, the UK Government implemented a broad, structured programme of parallel measures to reduce sugar content in food and drinks and support people in making healthier choices through information and education (Deparment of Health and Social Care, 2020; Public Health England, 2015). The bakery industry, along with the soft drink industry is working towards reduction of 20% of sugar in their products.

Sucrose is the most common sugar used in biscuit formulation; it is added as a crystalline solid and it partially dissolves during dough mixing, resting, and baking. The concentrated sugar solution decreases the mobility of the system, retarding the kinetics of gluten development during mixing and increasing starch gelatinisation temperature during baking (Kweon, Slade, Levine, Martin, & Souza, 2009; Manley, Pareyt, & Delcour, 2011). The syrup formed also affects dough consistency and machinability (Curley & Hoseney, 1984), and controls gluten mobility (cross-linking) and thus dough spreading and setting during baking (Manley et al., 2011; Pareyt, Brijs, & Delcour, 2009). Sugars also take part in flavour and colour development during baking, through caramelisation and Maillard type reactions (Manley et al., 2011; Pareyt & Delcour, 2008a). Sucrose recrystallisation during heating creates surface cracks and sugar crystals are partially responsible for the hard and crisp

* Corresponding author.
E-mail address: j.rodriguezgarcia@reading.ac.uk (J. Rodriguez-Garcia).

https://doi.org/10.1016/j.lwt.2022.113837
Received 9 June 2022; Received in revised form 19 July 2022; Accepted 1 August 2022
Available online 10 August 2022

texture of biscuits (Pareyt & Delcour, 2008a). Reduction of sucrose is therefore very challenging due to its multifunctional role. The combination of high intensity sweeteners with fibres or polyols has been suggested as an strategy to achieve both the development of sweetness and flavour and the formation of the biscuit structure (Struck, Jaros, Brennan, & Rohm, 2014). Research has been done to investigate the effect of commercial soluble fibres and polyols in dough and biscuit properties; Laguna, Primo-Martín, Salvador, and Sanz (2013a) observed that sucrose reduced biscuits with a native inulin were closer to the control than biscuits with erythritol. These authors found that when using inulin to replace sucrose, softer and less crispy biscuits were obtained, but biscuits with 25% sucrose replacement by inulin had similar consumer acceptability to the control. Other authors have investigated the functionality of Raftilose, a commercial oligofructose, as sugar replacer (Gallagher, O'Brien, Scannell, & Arendt, 2003; Handa, Goomer, & Siddhu, 2012). These authors found that due to the higher solubility and water binding properties of the oligosaccharide in comparison to sucrose, doughs with Raftilose could flow and spread more during baking giving place to biscuits with lower height and hardness. These biscuits were also very well rated by panellists due to their softer eating characteristics. Although these results are promising in terms of achieving a significant sugar reduction and improvement of the biscuit nutritional profile, further understanding on the functionality of soluble fibres as sucrose alternatives is needed. It is hypothesised that soluble fibres could have a similar or greater antiplasticising effect than sucrose depending on their degree of polymerisation and solubility, that could mitigate some of the negative consequences of sucrose reduction, such as excessive gluten development and starch gelatinisation. The objective of this study is to compare the functionality of four soluble fibres, two inulin and two dextrose with different chemical structures as potential sucrose replacers in short dough biscuits by evaluating their effect on dough rheology, biscuit dimensions, texture, colour and sensory profile.

2. Materials and methods

2.1. Ingredients

The ingredients used in the preparation of short dough biscuits were soft wheat flour (Sainsbury's Plain Flour composition, Sainsburys, London, UK; protein 9.7%, dietary fibre 3.5%, fat 0.98%, salt 0.03%), unsalted butter (Sainsbury's British unsalted butter, Sainsburys, London, UK; 82.9% fat), granulated sugar(Sainsbury's white granulated sugar, Sainsburys, London, UK), salt (Sainsbury's table salt, Sainsburys, London, UK), sodium bicarbonate (Dr. Oetker, Leeds, UK), and skimmed milk powder (Sainsbury's Skimmed Milk Powder, Sainsburys, London, UK; <0.5% fat), ammonium hydrogen carbonate (APC Pure, Hyde, UK). The following soluble fibres were used as sugar replacers: a resistant dextrin Nutriose® FM06 (Roquette, France); resistant maltodextrin Promitor® SGF 70R (Tate & Lyle, London, UK); a highly-soluble inulin powder Orafti® HSI (Beneo GmbH, Mannheim, Germany); and a soluble inulin Fibruline® Instant (Cosucra, Pecq, Belgium), donated by Caldic Ltd. (Chesterfield, UK). Further specifications provided by the suppliers about the soluble fibres is presented in Table 1.

2.2. Degree of polymerisation (DP) of soluble fibres

The soluble fibres used as sugar replacers were analysed for their degree of polymerisation (DP) (Table 1) by High Performance Liquid Chromatography (HPLC), in an Agilent Infinity 1200 system (Agilent Technologies LDA, UK), equipped with a RI detector. Samples were prepared by mixing soluble fibres powders with ultra-purified water to make up aqueous solutions with standardised concentrations of 5 mg soluble fibre per mL of water. Separation was carried out in an Aminex HPX-42A column (300 × 7.8 mm, 25 μm particle size) (Biorad, UK), heated at 80 °C. Isocratic analysis was performed using ultra-purified water as eluent at a flow of 0.5 mL/min and an injection volume of 20 μL. OpenLab Chemstation software (Agilent Technologies LDA, UK) was used to interpret the chromatograms. The relative percentage of DP was calculated based on the ratio of each peak area to the total sum of integrated peak areas for each sample. Retention times for various DP were defined based on known concentrations of external standard maltooligosaccharide solutions (DP 2–8) (Megazyme Ltd, Ireland).

2.3. Dough and biscuit preparation

Five dough (D) formulations were developed according to Laguna, Primo-Martín, Salvador, and Sanz (2013b) in order to obtain the correspondent biscuits (B): a control formulation with no sugar replacement, and four formulations in which 30% of sugar was reduced by replacing sucrose with different soluble fibres (Table 2). Predictive values of Total solvent (TS) were calculated by summing up the grams of all sugars and water in the recipe per 100 g of flour. Then, the sugar

Table 1
Nutritional and chemical properties of the four sugar-replacers according to the products' specifications provided by suppliers and degree of polymerisation results from the experimental analysis carried out.

	Nutriose® FM06	Promitor® SGF 70R	Orafti® HSI	Fibruline™ Instant
Origin	Maize	Maize	Chicory	Chicory
Definition	Soluble fibre/Resistant dextrin	Soluble fibre/Resistant maltodextrin	High soluble inulin	Soluble inulin fibre
Production process	Partially hydrolysed starch	Enzymatic hydrolysis of maize starch	Enzymatically hydrolysed inulin	Extracted from chicory roots by a natural process
Average Degree of Polymerisation	~17	10	–	~10
Fibre (%)	82–88	≥70	85	88
Mono and Disaccharides (%)	≤0.5	≤10	≤12	≤10
Dextrose equivalent	5	19	–	–
Reducing sugars (%)	≤10	<10	–	<10
Bulk density (g/L)	400	–	730	550
Solubility *(g/L)	'Completely'	–	>200	~100
Degree of Polymerisation (DP)	Relative percentage (%)			
DP 6 or greater	99.6 (0.3)	74.9 (0.6)	54.5 (1.2)	52.6 (0.3)
DP 5	n.d.	1.5 (0.2)	n.d.	n.d.
DP 4	n.d.	2.8 (0.2)	n.d.	n.d.
DP 3	Traces (<0.3)	4.9 (0.3)	n.d.	n.d.
DP 2	Traces (<0.1)	7.7 (0.4)	n.d.	n.d.
DP 1	n.d.	8.2 (0.2)	45.5 (0.8)	47.4 (0.1)

*Solubility in water: Nutriose value is at 20, °C Orafti value is as 25 °C.
n.d.: not detected.

Table 2
Short dough biscuits formulations (% flour basis). Control sample (full sugar dough biscuit); Nutriose sample (30% sugar reduced dough biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced dough biscuit with Promitor® 70R); Orafti sample (30% sugar reduced dough biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced dough biscuit with Fibruline™ Instant).

Ingredients	Control	Nutriose	Promitor	Orafti	Fibruline
Flour	100	100	100	100	100
Butter	32.15	32.15	32.15	32.15	32.15
Sucrose	29.45	20.18	19.11	22.94	19.19
Nutriose® FM06	0	9.27	0	0	0
Promitor® 70R	0	0	10.34	0	0
Orafti® HSI	0	0	0	10.72	0
Fibruline™ Instant	0	0	0	0	10.26
Skimmed milk powder	1.75	1.75	1.75	1.75	1.75
Water	11	11	11	11	11
Salt	1.05	1.05	1.05	1.05	1.05
Sodium bicarbonate	0.35	0.35	0.35	0.35	0.35
Ammonium hydrogen carbonate	0.20	0.20	0.2	0.2	0.2
TS	42	33	32	32	32
%S	74	66	66	66	66

TS (Total solvent) is the amount of total syrup, which is the sum of all sugars in grams and water in grams/100 g flour; TS controls the lateral creep of biscuit products during baking. %S (Sugar concentration) is the concentration of the syrup created by the sugars and water; %S is calculated as grams sugars divided by the sum of grams sugars plus grams water (Kweon et al., 2014).

concentration (%S) was also calculated as the grams of total sugars (per 100g of flour) divided by TS (Kweon, Slade, Levine, & Gannon, 2014).

Sucrose and/or soluble fibres, butter (at 20 °C), leavening agents and milk powder (predissolved in water) were mixed (Kenwood Chef XL, UK) with a K-beater at minimum speed for 30s. The dough was scraped from the sides of the bowl and then mixed for 3 min at speed 4. The flour was added, and then mixed at minimum speed for 60 s. The dough rested for 10 min in a polyethylene bag (20 °C), and then sheeted to 10 mm thickness with a sheeting machine (Rondo STM-503 table-top reversible sheeter; Burgdorf, Switzerland). Dough pieces were cut (50 × 30 cm) and placed on parchment paper on a perforated tray (25 biscuits per tray), and baked in a deck oven (Polin Stratos, Italy) for 17 min at 175 °C (top heat at 70% and bottom heat at 30%). The biscuits were left to cool down at room temperature for 20 min and then they were packed in heat-sealed polyethylene bags and stored on cupboard boxes at 18 °C. The resulting products were named as follows: control sample (full sugar dough/biscuit); Nutriose sample (30% sugar reduced dough/biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced dough/biscuit with Promitor® 70R); Orafti sample (30% sugar reduced dough/biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced dough/biscuit with Fibruline™ Instant). Three batches of each formulation were made on three different days.

2.4. Biscuit dough rheological measurements

Rheological properties of doughs were evaluated using an oscillatory rheometer (MCR 302, Anton Paar Ltd., UK) following the method described by Tsatsaragkou, Methven, Chatzifragkou, and Rodriguez-Garcia (2021) with some modifications. The viscoelastic properties of the doughs were measured using 50 mm diameter serrated parallel plates (profile 1 mm × 0.5 mm) with a 3 mm gap. After loading the sample, a rest time of 15 min was set to allow the sample to relax and reach the measurement temperature (25 °C). Oscillatory frequency sweeps between 0.1 and 100 Hz (0.63–628 rad/s) were performed at constant stress amplitude within the LVE region (0.0001%). Dynamic rheological properties of samples were recorded by monitoring the shear storage modulus (G′) and the shear loss modulus (G″). The loss factor was also calculated (tan δ = G″/G′). Microsoft Excel (Microsoft 365, Microsoft, Washington, US) was used for curve fitting for G' = f (Frequency). Oscillatory measurements were carried out in two dough pieces per batch of each formulation.

2.5. Characteristics of the biscuits

2.5.1. Weight loss during baking

Percent weight loss (WL%) of biscuits during baking was calculated (Rodriguez-Garcia, Laguna, Puig, Salvador, & Hernando, 2013):

$$WL\ (\%) = (W_{dough}\text{-}W_{biscuit} / W_{dough}) \times 100 \quad (1)$$

Where *W* denotes weight (g). Measurements were taken from 10 dough pieces and biscuits. This measurement was done in each of the three batches per formulation.

2.5.2. Water activity and moisture

Moisture content was measured using a Sartorius M-Pact Series balance (Sartorius Lab Instruments, Germany) at 105 °C until constant weight. Water activity (a_w) was measured using a HygroLab balance (Rotronic instruments, UK). For these measurements 10 biscuits of each batch were crumbed and each analysis was carried out in triplicate.

2.5.3. Biscuit dimensions

The biscuits length and width was measured using an electronic caliper (RS PRO 150 mm Digital Caliper, RS PRO professional, Singapore) by placing 10 biscuits side-by-side; biscuits height was measured by stacking 10 biscuits (Rodriguez-Garcia et al., 2013). These measurements were done once per formulation batch.

2.5.4. Texture analyses

The texture of the biscuits was measured using a TAXT-Plus Texture Analyzer (Stable Micro System, UK) and analysed following the methodology described by (Laguna, Vallons, Jurgens, & Sanz, 2013) with some modifications:

A three-point bending probe (A/3 PB) was used to fracture the biscuits. The experimental conditions were test speed 1 mm/s; distance between supports, 20 mm; probe travel distance 6.5 mm; and trigger force 0.2 N. The parameters measured were the force at break (N), and the distance at break (mm) as the fracture strength and the fracturability, respectively.

A cylinder probe (2 mm diameter) was used to penetrate the biscuits in the centre, at a test speed of 0.5 mm/s, to a distance of 60% of the total height of the sample. The parameters studied were the area under the curve as the resistance to penetration and the number of peaks as an index of crunchiness. All the analyses were performed on 10 biscuits of each batch.

2.5.5. Colour measurements

Colour measurements of the biscuit surface were carried out using a Chroma Meter CR-400 colorimeter (Kinolta Minolta, Warrington, UK). Three biscuits per batch were analysed. Results were expressed using the CIELAB system (illuminant C and 10° viewing angle). The parameters measured were L* (L* = 0 [black], L* = 100 [white]), a* ((–a* = greenness and +a* = red) and b* ((–b* = blueness and +b* = yellow). The total colour difference (ΔE*) between the control sample and each of the biscuit samples containing different soluble fibres as sugar replacers was calculated as follows (Francis & Clydesdale, 1975):

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2} \quad (2)$$

The values used to determine whether the total colour difference was visually obvious were the following (Bodart, de Peñaranda, Deneyer, & Flamant, 2008):

ΔE* < 1 colour differences are not obvious for the human eye,
1 < ΔE* < 3 minor colour differences could be appreciated by the human eye depending of the hue, and Chroma

$\Delta E^* > 3$ colour differences are obvious for the human eye.

2.6. Sensory profiling

A trained sensory panel (n = 8) with more than 2 years of experience, developed a consensus descriptive vocabulary of the sensory attributes including appearance, aroma, taste, mouthfeel and after-effects over 2 training sessions, using reference standards to assist in defining attributes where required (Supplementary Table S1). Whole biscuits were presented to panellists at each tasting on a 3-digit coded ceramic plates. Scoring sessions were carried out twice, in these sessions samples were presented in a balanced monadic sequential and sample attributes were scored on visual analogue unstructured scales (0–100) with anchored extremes using Compusense cloud software (Compusense Inc., Canada). In order to minimize carryover effects, a 2 min interval was allowed between each sample. Panellists were asked to cleanse their palate between tastings with filtered warm water. All assessments were carried out in isolated sensory booths under artificial daylight and with the room temperature controlled at 23 °C. Our trained employed sensory panel provide consent to taste and rate food as their job, they only provide separate written consent to a specific study where they are tasting none-standard, none-commercial or novel food ingredients.

2.7. Statistical analysis

One-way Analysis of Variance (ANOVA) was performed using XLSTAT software package (version 2019.3.1, Addinsoft, France). Multiple pairwise comparisons using Tukey's HSD test were used to evaluate mean value's differences ($p < 0.05$).

Sensory data analysis was performed using Senpaq version 5.01 (QI Statistics, UK) using two-way ANOVA with sample fitted as a fixed effect, panellists as a random effect and both main effects tested against the sample by panellist interaction. Least significant differences were computed by Fisher's post hoc test ($p < 0.05$). Principle component analysis (PCA) was based upon the covariance matrix.

3. Results and discussion

3.1. Viscoelastic properties of biscuit doughs

All dough samples showed a weak gel-like behaviour where the elastic behaviour (G' modulus) was higher than the viscous behaviour (G'' modulus), and a slight frequency dependence was observed (Fig. 1). In order to quantify this dependence a power-law equation has been used to describe the evolution of the storage modulus with frequency:

$$G' = G'_1 \nu^{n'} \quad (3)$$

G'_1 corresponded to the values of storage modulus for $\nu = 1$ Hz. The power law index, n', was related to the slope of the lines, indicating the magnitude of frequency dependence. The results obtained are shown in Table 3. All dough samples showed similar moduli values at low frequencies (1 Hz; Table 3); however, at higher frequencies, the control dough showed a greater increase in moduli values (Fig. 1). The spectra from Orafti and Fibruline showed a significantly smaller n' in comparison to other doughs (Table 3).. These results indicated that both types of inulin derived fibres gave place to a more developed and complex dough microstructure than dextrin derived fibres and sucrose.

Considerable differences in the evolution of tanδ with frequency were observed among samples (Fig. 2); control dough showed a much higher frequency dependence than the other doughs, showing a more viscous behaviour at higher frequencies. In contrast, Orafti and Fribuline doughs presented a more elastic behaviour and a lower frequency dependence through the whole range of frequencies; thus, the replacement of sucrose by inulin derived fibres conferred structural stabilisation. These results could be explained by the fact that inulin is more hygroscopic than sucrose and is able to immobilise water, imparting physical stability in the matrix (Franck, 2002). In fact, long chain inulin molecules are more functional in immobilising water when forming a network (Franck, 2002; Handa et al., 2012), and this could explain why Fibruline dough showed the most elastic nature among all the samples as Fibruline® Instant had higher proportion of longer fructans than Orafti® HIS (Tsatsaragkou et al., 2021). Pareyt, Brijs, and Delcour (2009) reported that when sucrose levels are decreased, dough elasticity increased linearly. Similar results have been previously reported when reformulating biscuit dough with ingredients that increase the immobilisation of water. Tarancón, Hernández, Salvador, and Sanz (2015) observed that when replacing shortening by cellulose emulsions with glycerol, a more elastic and stable short dough was produced due to the increase in hydrogen bonds between glycerol, water and cellulose. In contrast, Nutriose® FM06 and Promitor® SGF 70R, are resistant dextrins, that produced sugar-reduced doughs similar to (full sugar doughs (control) (Fig. 1). These dextrins had higher solubility than the inulin derived fibres (Table 1), and may have become part of the liquid phase of the dough rather than of the continuous network structure. The latter and could impair the development and strength of the structure through a similar antiplasticiser effect as that of sucrose. Laguna et al. (2013) also reported that when using ingredients with similar hygroscopicity,

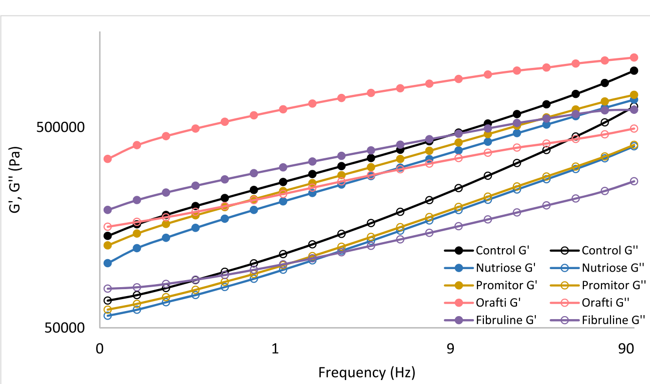

Fig. 1. Dynamic moduli of the doughs as a function of frequency. Control sample (full sugar dough biscuit); Nutriose sample (30% sugar reduced dough biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced dough biscuit with Promitor® 70R); Orafti sample (30% sugar reduced dough biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced dough biscuit with Fibruline™ Instant).

Table 3
Mean values of the parameters obtained when fitting storage modulus as a function of frequency to a power-law (eq. (3) $G' = G'_1 \cdot \nu^{n'}$). Weight loss, moisture, and water activity of the five biscuit samples. Control sample (full sugar sample); Nutriose sample (30% sugar reduced sample with Nutriose® FM06); Promitor sample (30% sugar reduced sample with Promitor® 70R); Orafti sample (30% sugar reduced sample with Orafti® HSI); Fibruline sample (30% sugar reduced sample with Fibruline™ Instant).

Doughs/ Biscuits	G'_1 (Pa)	n'	Weight loss (%)	Moisture (%)	a_w
Control	266355.00^{ab}	0.26^a	15.17^a	2.98^a	0.22^a
	(42407.45)	(0.01)	(0.25)	(0.11)	(0.02)
Nutriose	209086.17^b	0.26^a	15.73^a	2.88^a	0.19^a
	(72984.87)	(0.03)	(0.16)	(0.23)	(0.03)
Promitor	238256.67^{ab}	0.24^a	15.52^a	3.15^a	0.23^a
	(52115.03)	(0.02)	(0.38)	(0.37)	(0.04)
Orafti	520721.83^a	0.15^b	15.25^a	2.85^a	0.21^a
	(287143.51)	(0.03)	(0.62)	(0.22)	(0.02)
Fibruline	308451.17^{ab}	0.15^b	15.13^a	3.07^a	0.22^a
	(215112.40)	(0.04)	(0.12)	(0.36)	(0.03)

Values in parenthesis are the standard deviations. Means in the same column without a common letter are significantly different ($p < 0.05$) according to the Tukey's HSD Test).

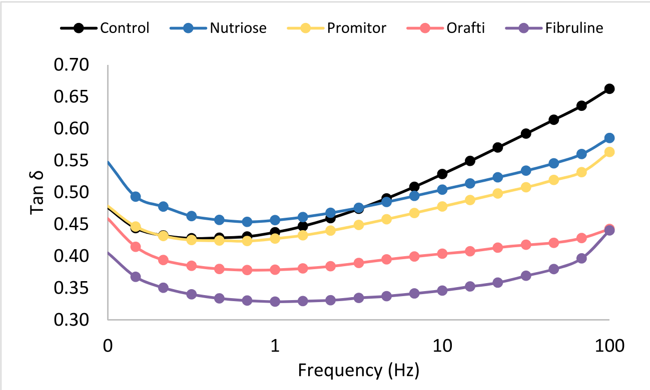

Fig. 2. Frequency dependence of the tanδ of the biscuit doughs. Control sample (full sugar dough biscuit); Nutriose sample (30% sugar reduced dough biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced dough biscuit with Promitor® 70R); Orafti sample (30% sugar reduced dough biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced dough biscuit with Fibruline™ Instant).

molecular weight and solubility as sucrose (e.g. maltitol), a dough viscoelastic behaviour similar to the control (100% sucrose) was observed. In formulations with higher concentration of sugar solutions the kinetics of gluten hydration and development during mixing are retarded due a decrease in the system mobility in comparison to formulations where water alone is used (Kweon et al., 2009; Kweon, Slade, & Levine, 2016). These phenomena could explain the higher viscous behaviour of control and dextrose doughs.

3.2. *Weight loss during baking (WL), moisture content and water activity of biscuits*

No significant differences in WL, moisture content and water activity were found among biscuit samples (Table 3). Water retention during baking has been related to the degree of development of water-holding networks, mainly gluten development during mixing and gelatinised/pasted-starch during baking (Kweon et al., 2009, 2016; Kweon, Slade, & Levine, 2010). As discussed in the previous section (3.1.) reduction of sucrose and replacement of sugar by soluble inulin fibres, resulted in the formation of inulin-water-holding networks during mixing, that gave place to a dough with a firmer structure (Fig. 1) and similar water retention as the control. It could be possible that the effect of sugar reduction (lower *anti*-plasticising effect) in the dough was compensated by the effect of the inulin three-dimensional network on holding water during baking. Other authors also found that when incorporating soluble fibres (Nutriose FM10 and inulin) in short dough cookies, no differences in water retention were observed (Mancebo, Rodríguez, Martínez, & Gómez, 2018). When replacing sucrose with dextrin type soluble fibres, small changes in the dough viscoelastic behaviour were observed (Fig. 2), but no significant changes were observed in dough water evaporation rate during baking. These results could be related with the lower solubility of these fibres in comparison to sucrose (Table 1); when reducing sugar concentration and replacing sucrose with soluble fibres, the dough had lower S% values during mixing (Table 1), thus the samples presented firmer structures than could inhibit water evaporation during baking resulting in lower water loss values than expected for a sugar reduced formulation. Kweon et al. (2016) found that when sucrose was replaced by isomaltulose at the same concentration, the S% was lower during mixing, and the resulting dough was firmer, could not expand during baking and evaporation was limited.

3.3. *Biscuit dimensions*

The quality of the final biscuits can be defined by two main characteristics: their size (width and height) and how do they bite (structure) (Pareyt & Delcour, 2008b). In general, sugar reduced samples showed similar diameter (width and length) to control (Table 4). However, Fibruline biscuit showed smaller width, and significantly smaller ($p < 0.05$) length and height than control biscuit. The biscuit spread during baking takes place mainly due to two reasons: i) an expansion of the dough by leavening, and ii) a gravitational flow due to an apparent decrease in viscosity as sugar solubilises and causes an increase in the volume of the dissolved phase or total solvent (TS) (Kweon et al., 2014; Pareyt & Delcour, 2008a). The end point of the spread during baking has related to the role of flour proteins (Manley et al., 2011; Pareyt & Delcour, 2008a); however, when using the same soft flour and fat content, the main factors affecting dough spreadability rate and duration will be related to the rate of sugar dissolution which depends on sugar solubility, particle size, and chemical properties (Kweon et al., 2014). Fibruline™ Instant had higher proportion of long fructans (32.7% of long fructans (DP > 11); 21.4% of fructooligosaccharides (FOS)) (Tsatsaragkou et al., 2021) and a lower solubility value in comparison to Orafti® HSI (Table 1). These characteristics mean that more water was immobilised in the dough by long polymer chains, leaving less water available for solubilisation of sucrose and FOS, constraining TS and S% to lower values than the predicted ones, thus limiting the flow and spread of the structure during baking, giving place to smaller biscuits (width and length). Previous literature suggests that less soluble sugars will allow for more gluten development and thus an expansion in biscuit height (Handa et al., 2012). However, Fibruline doughs although having greater elastic behaviour (Fig. 2) than other dough samples, did not give place to biscuits with higher heights. It is likely that dough microstructure was defined by the combination of long chain fructans interacting with water, rather than an elastic gluten network that could retain the spring of the dough during baking. The effect of replacing sucrose by soluble fibres (higher anti-plasticity) was greater on biscuit dimension than the effect of sugar reduction (higher plasticity). On the other hand, Orafti® HSI had better solubility than Fibruline™ Instant (Table 1) as it contained higher percentages of FOS (37.24% of FOS and 17.5% of long fructans (DP > 11) vs 21.4% of FOS and 32.7% of long fructans, respectively) (Tsatsaragkou et al., 2021). Similarly, Promitor® 70R contained higher proportion of smaller dextrins of DP 1–5 of 25% compared to Nutriose ® FM06 (less than 0.5%) (Table 1). Therefore, these two soluble fibres could contribute more to the increase in TS and S% during baking, promoting the spread of the structure, in a similar proportion as sucrose did. Handa et al. (2012) stated that soluble FOS contributed to the spread ratio of biscuit dough as they maintained their dissolved nature longer during baking, which could facilitate the flow of the dough.

3.4. *Biscuit texture*

The puncture test provides information about the microstructure of the biscuits. Fig. 3 shows biscuit penetration curve profiles, where a

Table 4
Dimensions of the biscuits. Control sample (full sugar biscuit); Nutriose sample (30% sugar reduced biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced biscuit with Promitor® 70R); Orafti sample (30% sugar reduced biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced biscuit with Fibruline™ Instant).

Biscuits	Width (mm)	Length (mm)	Height (mm)
Control	35.80^{ab} (0.97)	54.63^{a} (0.97)	14.77^{a} (0.17)
Nutriose	36.07^{ab} (0.52)	55.90^{a} (1.44)	13.63^{b} (0.25)
Promitor	36.07^{ab} (1.01)	55.87^{a} (1.03)	14.53^{a} (0.17)
Orafti	36.80^{a} (0.42)	56.10^{a} (0.91)	14.40^{a} (0.14)
Fibruline	34.27^{b} (1.30)	50.33^{b} (1.30)	13.64^{b} (0.16)

Values in parenthesis are the standard deviations. Means in the same column without a common letter are significantly different ($p < 0.05$) according to the Tukey's HSD Test).

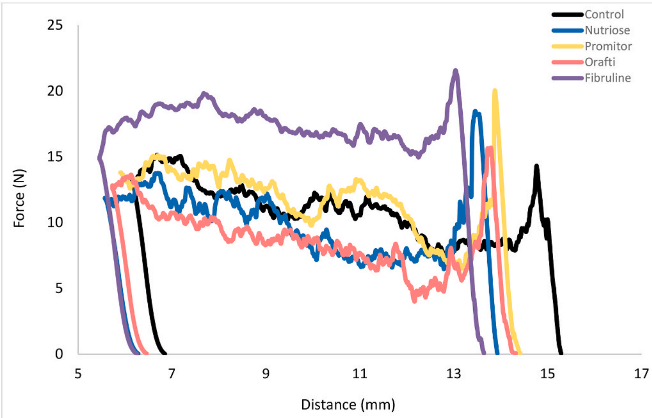

Fig. 3. Penetration representative curve profiles of biscuits. Control sample (full sugar biscuit); Nutriose sample (30% sugar reduced biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced biscuit with Promitor® 70R); Orafti sample (30% sugar reduced biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced biscuit with Fibruline™ Instant).

series of peaks can be observed giving place to an irregular profile. These peaks are the evidence of local fractures of structures or layers when the probe penetrated them (Laguna et al., 2013). Control biscuit showed the highest number of peaks, followed by Orafti and Promitor biscuits ($p > 0.05$). Nutriose biscuit had significantly lower number of peaks ($p < 0.05$) in comparison to control biscuit, but similar to Promitor biscuit. However, Fibruline biscuit presented the lowest ($p < 0.05$) number of peaks, reflecting a more compact structure with less cells and layers. . When comparing the resistance to penetration (area under the curve), Fibruline showed the highest ($p < 0.05$) values among all biscuits (Fig. 3); these results could be related to the compact structure (less peaks) that these biscuits presented. In agreement with these instrumental results were our empirical observations on dough machineability as Fibruline dough was less pliable and harder during sheeting operation. In comparison, Orafti biscuits showed the lowest resistance to penetration ($p < 0.05$).

Biscuit fracture strength is the maximum force applied to bend and fracture the biscuit. The fracturability of the sample was calculated as the distance at the point of break, which defines its resistance to bend, its fragility (Laguna et al., 2013). Control and Fibruline biscuit exhibited the highest ($p < 0.05$) force needed to fracture, while all the other sugar reduced samples showed a decrease fracture strength (Fig. 4). These

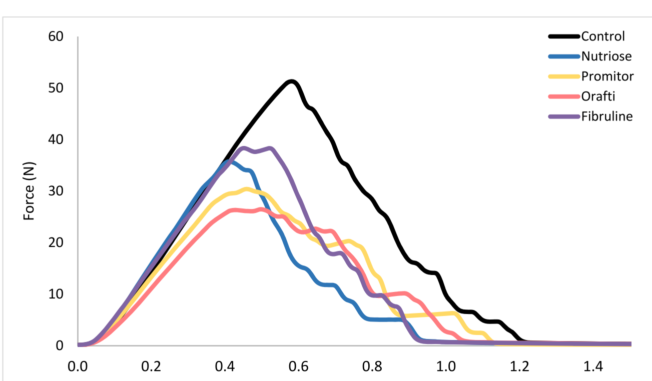

Fig. 4. Biscuit breaking strength and fracturability curve profiles obtained from the 3 point bending test. Control sample (full sugar biscuit); Nutriose sample (30% sugar reduced biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced biscuit with Promitor® 70R); Orafti sample (30% sugar reduced biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced biscuit with Fibruline™ Instant).

results could be explained by the link between biscuit hardness and sugar recrystallisation during cooling (Handa et al., 2012; Pareyt and Delcour, 2008a, 2008b). Moreover, although Fibruline™ Instant is a soluble fibre, the high proportion of long fructans (32.7% DP > 11), and thus insoluble molecules, may have contributed to the formation of a network that gave place to greater dough (Figs. 1 and 2) and biscuit strength. In fact, Franck (2002) described that when inulin is mixed with water, a tri-dimensional network of insoluble sub-micro crystalline particles is formed. After baking, the network of crystalline particles could have provided higher fracture strength to the biscuit structure. The remaining sugar reduced biscuits (Nutriose, Promitor and Orafti) showed lower ($p < 0.05$) fracture strength than control biscuits. When replacing sucrose with ingredients with higher solubility, their anti-plasticising effect limited the development, if any at all, of gluten and starch gelatinisation; this in conjunction to the lack of crystallinity of these fibres gave place to biscuits with lower fracture strength than Fibruline and control biscuits. Other authors also found that when sugar was reduced biscuit hardness and fracture strength decreased (Pareyt, Talhaoui, et al., 2009). Handa et al. (2012) reported that when replacing sucrose with FOS at 40%, 60% and 80%, a reduction in biscuit hardness was observed in comparison to control biscuit.

Moreover, all sugar reduced samples showed lower resistance to fracture than control biscuit, and a more gradual decrease in breaking force after the fracture. These results agree with Baltsavias, Jurgens, and van Vliet (1999), observations when decreasing sucrose in short dough biscuits; the authors explained that smoother drop in stress after fracture was due to a slower crack propagation caused by more energy dissipation due to plastic deformation. In contrast, other authors observed an increase in fracture strength when adding fibres, soluble (Nutriose or inulin) or insoluble (bamboo fibres), to cookies (Mancebo et al., 2018). The reason for the different results could be related to the fact that the authors added 15% of soluble fibres on top of their formulation, without replacing any other ingredient.

3.5. Biscuit colour

Browning of baked products is the result of a series of complex chemical reactions such as caramelisation and Maillard (Chevallier, Della Valle, Colonna, Broyart, & Trystram, 2002). No significant differences were found between the control biscuit and the sugar-reduced samples for surface colour parameters L*, a* and b*; except for Orafti biscuits that presented significantly lower lightness values (L*) in comparison to control (Table 5). Moreover, Orafti biscuit also presented significantly higher ($p < 0.05$) redness (a*) value in comparison with the other sugar-reduced biscuits and a total colour difference (ΔE*) higher than 3, meaning that the control and Orafti biscuits were obviously different to the human eye. Addition of inulin and oligofructose in bakery products have shown contradicting results in literature in terms of colour differences. Some authors observed a decrease in L* and an increase in a*, as it was observed for Orafti biscuits, associated with the

Table 5
Colour parameters for the five biscuits samples. Control sample (full sugar biscuit); Nutriose sample (30% sugar reduced biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced biscuit with Promitor® 70R); Orafti sample (30% sugar reduced biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced biscuit with Fibruline™ Instant).

Biscuit	L*	a*	b*	ΔE*
Control	61.96^{a} (1.55)	10.26^{ab} (0.62)	34.98^{a} (1.82)	0
Nutriose	63.35^{a} (2.21)	8.80^{b} (1.32)	35.25^{a} (1.78)	2.0
Promitor	60.50^{ab} (1.39)	10.11^{b} (0.90)	34.49^{a} (1.99)	1.5
Orafti	58.34^{b} (3.02)	11.77^{a} (1.09)	35.71^{a} (1.59)	4.0
Fibruline	62.0^{a} (3.18)	9.26^{b} (1.53)	34.53^{a} (2.07)	1.1

Values in parenthesis are the standard deviations. Means in the same column without a common letter are significantly different ($p < 0.05$) according to the Tukey's HSD Test).

increase on soluble fibres, and specifically inulin type-of fibres due to the hydrolysis of low molecular fructans to fructose, a reducing sugar that is involve in Maillard reaction (Mancebo et al., 2018; Peressini & Sensidoni, 2009; Rodriguez-Garcia, Puig, Salvador, & Hernando, 2012). However, other studies where oligofructose or inulin have been added in biscuits have shown no colour differences with the control sample (Gallagher et al., 2003; Tsatsaragkou et al., 2021). The differences in results could be due to the shorter baking process applied in the works referenced above.

3.6. Sensory profiling of biscuits

The mean results from the sensory profiling of biscuits are given in Table 6. Out of 40 descriptors, 22 were found to be significantly different between samples. Differences were discovered in 5 appearance attributes. The sugar-reduced biscuits scored significantly higher for surface and base colour than the control. These results suggest that the sampling method for colourimetry might not have been sensitive or representative enough to detect certain attributes. In addition to increased darkness in the colour of the sugar-reduced biscuits, which aligned with the suggestion that additional reducing sugars from the fibres facilitated Maillard reaction, panellists detected dark speckles on the surface and inside the crumbs. These were likely to be poorly dispersed fibre particles, and this would have led to some unwanted sample variability.

Half of the aroma descriptors (n = 3) were significantly different among biscuits. Where all fibre samples had significantly more baked aroma than the control, this was significantly higher for both inulin type fibres (Orafti and Fibruline) which were both additionally rated substantially higher for burnt aroma. Baked and burnt aroma ratings were related to increased Maillard reaction. The findings for baked and burnt attributes were progressed through to the same difference in oral flavour.

There was no significant difference between the sweetness of the control and the sugar reduced samples. A previous study has shown that different sugar levels in shortbreads were distinguishable (James, Laing, Oram, & Hutchinson, 1999). Inulin-type fibres were slightly sweet, but dextrin-type fibres had a neutral taste; thus in the current study it is perhaps the increase in baked flavour that has partly compensated for

Table 6
Mean sensory scores for the five biscuit samples. Control sample (full sugar biscuit); Nutriose sample (30% sugar reduced biscuit with Nutriose® FM06); Promitor sample (30% sugar reduced biscuit with Promitor® 70R); Orafti sample (30% sugar reduced biscuit with Orafti® HSI); Fibruline sample (30% sugar reduced biscuit with Fibruline™ Instant).

	Control		Nutriose		Promitor		Orafti		Fibruline		Significance of Sample (p value)
Appearance											
Surface colour	39.0	c	57.1	b	69.2	a	62.1	ab	60.1	b	<.0001
Base colour	54.1	c	67.2	b	82.2	a	79.2	a	78.1	a	<.0001
Smoothness of surface	67.5	a	59.7	b	54.6	bc	62.1	ab	47.4	c	0.0001
Evenness of colour	74.4	a	59.8	bc	49.2	c	62.1	b	51.4	bc	0.0004
Smoothness of sides	26.0	b	37.0	a	30.6	ab	32.8	ab	29.2	ab	0.24
Brown spots in crumb	3.5	b	21.6	a	24.6	a	27.9	a	29.5	a	0.0001
Aroma											
Sweet	39.9	a	39.1	a	36.8	a	34.8	a	39.4	a	0.68
Burnt	0.5	c	4.0	c	25.4	ab	31.8	a	15.8	b	<.0001
Buttery	34.1	a	32.0	ab	25.1	bc	22.2	c	27.1	abc	0.034
Floury	14.7	a	11.2	a	9.3	a	9.9	a	11.0	a	0.33
Cabbage	0.0	a	2.8	a	3.3	a	3.3	a	3.3	a	0.32
Baked	38.0	c	43.7	bc	55.2	a	56.5	a	48.5	b	<.0001
Mouthfeel on First Bite											
Firmness of Bite	46.9	c	68.2	ab	70.8	a	61.6	b	68.8	ab	<.0001
Mouthfeel on Second Bite											
Density of Mouthfeel	53.3	b	55.8	ab	54.6	ab	50.3	b	62.3	a	0.067
Flavour on Third Bite											
Sweet	33.4	ab	35.4	ab	33.4	ab	29.9	b	37.1	a	0.34
Salty	6.0	c	8.8	ab	11.1	a	8.4	bc	9.9	ab	0.003
Bitter	1.2	c	6.8	b	16.8	a	20.4	a	10.5	b	<.0001
Burnt	0.0	d	5.9	cd	27.6	ab	35.8	a	15.6	bc	<.0001
Buttery	27.5	a	27.1	a	25.0	a	21.1	a	27.0	a	0.60
Floury	29.1	a	17.9	bc	15.8	c	16.5	c	22.7	b	0.0001
Baked	31.4	c	47.5	b	55.5	ab	59.1	a	51.9	ab	<.0001
Metallic	0.0	a	0.8	a	0.7	a	0.6	a	0.0	a	0.73
Caramel	2.9	b	7.5	a	6.8	ab	5.5	ab	8.3	a	0.076
Mouthfeel on Fourth Bite											
Crumbly	54.8	a	50.7	ab	51.3	ab	54.3	a	46.3	b	0.064
Crunchy	45.5	c	69.6	a	70.5	a	70.4	a	60.5	b	<.0001
Pasting	40.4	a	26.1	b	31.1	b	29.8	b	33.0	ab	0.014
Dry	38.9	b	41.2	ab	45.9	a	42.6	ab	39.6	b	0.19
Floury	30.1	a	15.1	b	21.3	b	17.7	b	22.8	ab	0.008
Granular	12.4	c	29.3	a	27.2	ab	27.1	ab	21.7	b	0.0003
Rate of clearance	40.4	c	50.5	a	46.6	abc	48.6	ab	42.9	bc	0.015
After Effects											
Sweet	22.9	a	25.5	a	26.5	a	23.8	a	27.1	a	0.41
Salty	5.3	b	8.4	a	8.4	a	8.2	a	9.5	a	0.002
Bitter	1.0	c	6.2	b	9.7	b	16.2	a	8.0	b	<.0001
Burnt	0.0	c	2.7	bc	12.6	a	15.9	a	6.4	b	<.0001
Sour	0.5	a	1.4	a	1.7	a	0.4	a	1.0	a	0.60
Liquorice	0.0	a	0.8	a	1.1	a	0.0	a	0.7	a	0.42
Salivating	26.9	a	23.9	a	28.8	a	27.5	a	28.3	a	0.63
Drying	27.7	a	29.4	a	31.8	a	31.0	a	29.1	a	0.65
Numbing	1.8	a	4.3	a	5.3	a	3.6	a	2.7	a	0.39
ToothPacking	39.9	a	41.5	a	43.4	a	43.2	a	41.8	a	0.78

Values with the same superscript letter in the row did not differ significantly ($p < 0.05$).

the sugar reduction and enhanced the sweetness. All sugar-reduced samples scored higher for bitter taste than the control, with Orafti and Fibruline scoring significantly higher than the dextrin samples.

The sugar-reduced samples did not match mouthfeel of the full sugar control biscuit, they were all significantly firmer (harder to bite into) and crunchier. The Orafti inulin sample had the lowest mean score for firmness of bite of the fibre containing samples, it was significantly lower than the Promitor sample which is in line with the instrumental data obtained from the biscuit penetration test. The control was similar to most sugar-reduced samples for crumbliness, which is associated with fracturability, with only the Fibruline sample being significantly lower. In fact, Fibruline biscuit showed the highest fracture strength among sugar-reduced samples in the instrumental analysis. All sugar reduced samples had a significantly less floury and more granular mouthfeel, probably due to a combination of harder texture and increased content on fibre particles.

The were some significant differences in after-effects post swallow. Salty, bitter and burnt aftertastes were significantly higher in the sugar-reduced formulations, consistent with the in-mouth results. No difference in sweet aftertaste was observed among samples. Further evaluations with consumers will be needed in order to ascertain liking and acceptability of the sugar reduced biscuit samples.

4. Conclusion

The solubility and the degree of polymerisation profile of fibres defined their interaction with water, and consequently their effectiveness as plasticisers or as water-holding network building blocks. Inulin derived fibres with higher degree of polymerisation, such as such as Fibruline™ Instant, immobilised water in a three-dimensional network, and gave place to sugar reduced doughs with greater structural stability and elasticity, that showed a restricted dough expansion. The lower spreadability resulted in more compact biscuit with higher resistance to penetration and fracture strength. However, when reducing sugar content and replacing sucrose with fibres with higher solubilities and lower degree of polymerisation, the antiplasticising effect of the soluble sugars dominated the effect on dough and biscuit properties over the plasticising effect of the reduction of sugar in the dough. Thus, in general dextrose-type fibres produced doughs with similar structure and dimensions, and biscuits with similar texture to control biscuits. The higher presence of low molecular fructans, in Orfati samples, gave place to significant differences in biscuit surface colour, as fructans took part in Maillard reaction decreasing the lightness and increasing the redness of the samples. Although no differences in sweetness were perceived among biscuits, Orafti sample was most associated with bitter, baked, and burnt tastes and aftertastes in comparison to the Nutriose and Fibruline samples. These results indicated that the baking time and/or temperature could have been too high for the sugar reduced biscuits and that different formulations might require different optimal baking conditions to remove the effects of burning on the organoleptic properties of the samples.

Funding

This research was funded by EIT Food [Project SuReChoc-19105]. This EIT Food activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under Horizon 2020, the EU Framework Programme for Research and Innovation. EIT Food is Europe's leading agri-food innovation initiative, with the aim to create a sustainable and future-proof food sector. The initiative is made up of a consortium of key industry players, start-ups, research centres and universities from across Europe. EIT Food aims to collaborate closely with consumers to develop new knowledge and technology-based products and services that will ultimately deliver a healthier and more sustainable lifestyle for all European citizens.

CRediT authorship contribution statement

Julia Rodriguez-Garcia: Conceptualization, Methodology, Validation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Rui Ding:** Methodology, Validation, Formal analysis, Investigation. **Thao H.T. Nguyen:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Simona Grasso:** Conceptualization, Methodology, Formal analysis, Investigation, Supervision, Writing – review & editing. **Afroditi Chatzifragkou:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing. **Lisa Methven:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

None.

Data availability

The data presented in this paper are openly available in the University of Reading Research Data Archive at https://doi.org/10.17864/1947.000384

Acknowledgments

This research was carried out as an EIT Food project in collaboration with DouxMatok Limited and Strauss Group. The authors would like to thank Meytar Inbar (R&D Technologist at Straguss Group) for her constant support and advice during the experimental work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2022.113837.

References

Baltsavias, A., Jurgens, A., & van Vliet, T. (1999). Fracture properties of short-dough biscuits: Effect of composition. *Journal of Cereal Science, 29*(3), 235–244. https://doi.org/10.1006/jcrs.1999.0249

Bodart, M., de Peñaranda, R., Deneyer, A., & Flamant, G. (2008). Photometry and colorimetry characterisation of materials in daylighting evaluation tools. *Building and Environment, 43*(12), 2046–2058. Retrieved from http://www.sciencedirect.com/science/article/B6V23-4RC6R5C-1/2/f9e37b77023b0f7f7d4792cb9ef9a18d.

Chevallier, S., Della Valle, G., Colonna, P., Broyart, B., & Trystram, G. (2002). Structural and chemical modifications of short dough during baking. *Journal of Cereal Science, 35*(1), 1–10. https://doi.org/10.1006/jcrs.2001.0388

Curley, L. P., & Hoseney, R. C. (1984). Effects of corn sweeteners on cookie quality. *Cereal Chemistry, 61*(4), 274–278.

Deparment of Health and Social Care. (2020). Tackling obesity: Empowering adults and children to live healthier lives. Retrieved from https://www.gov.uk/government/publications/tackling-obesity-government-strategy/tackling-obesity-empowering-adults-and-children-to-live-healthier-lives.

Francis, F. J., & Clydesdale, F. M. (1975). *Food colorimetry: Theory and applications*. Westport, CT, USA: The Avi Publishing Company, Inc.

Franck, A. (2002). Technological functionality of inulin and oligofructose. *British Journal of Nutrition, 87*(S2), S287–S291. https://doi.org/10.1079/BJN/2002550

Gallagher, E., O'Brien, C. M., Scannell, A. G. M., & Arendt, E. K. (2003). Evaluation of sugar replacers in short dough biscuit production. *Journal of Food Engineering, 56* (2–3), 261–263. https://doi.org/10.1016/S0260-8774(02)00267-4

Handa, C., Goomer, S., & Siddhu, A. (2012). Physicochemical properties and sensory evaluation of fructoligosaccharide enriched cookies. *Journal of Food Science & Technology, 49*(2), 192–199. https://doi.org/10.1007/s13197-011-0277-4

James, C. E., Laing, D. G., Oram, N., & Hutchinson, I. (1999). Perception of sweetness in simple and complex taste stimuli by adults and children. *Chemical Senses, 24*(3), 281–287.

Kweon, M., Slade, L., & Levine, H. (2010). Exploration of functionality of low-glycemic-impact sugars and polyols, using src, dsc, rva, and cookie baking. In J. W.v. d. Kamp

(Ed.), *Dietary fibre - new frontiers for food and health* (pp. 513–528). Wageningen, Netherlands: Wageningen Academic Publishers.

Kweon, M., Slade, L., & Levine, H. (2016). Potential sugar reduction in cookies formulated with sucrose alternatives. *Cereal Chemistry, 93*(6), 576–583. https://doi.org/10.1094/CCHEM-01-16-0016-R

Kweon, M., Slade, L., Levine, H., & Gannon, D. (2014). Cookie- versus cracker-baking—what's the difference? Flour functionality requirements explored by src and alveography. *Critical Reviews in Food Science and Nutrition, 54*(1), 115–138. https://doi.org/10.1080/10408398.2011.578469

Kweon, M., Slade, L., Levine, H., Martin, R., & Souza, E. (2009). Exploration of sugar functionality in sugar-snap and wire-cut cookie baking: Implications for potential sucrose replacement or reduction. *Cereal Chemistry, 86*(4), 425–433. https://doi.org/10.1094/CCHEM-86-4-0425

Laguna, L., Primo-Martín, C., Salvador, A., & Sanz, T. (2013a). Inulin and erythritol as sucrose replacers in short-dough cookies: Sensory, fracture, and acoustic properties. *Journal of Food Science, 78*(5), S777–S784. https://doi.org/10.1111/1750-3841.12119

Laguna, L., Primo-Martín, C., Salvador, A., & Sanz, T. (2013b). Inulin and erythritol as sucrose replacers in short-dough cookies: Sensory, fracture, and acoustic properties. *Journal of Food Science, 78*(5), S777–S784. https://doi.org/10.1111/1750-3841.12119

Laguna, L., Vallons, K. J. R., Jurgens, A., & Sanz, T. (2013). Understanding the effect of sugar and sugar replacement in short dough biscuits. *Food and Bioprocess Technology, 6*(11), 3143–3154. https://doi.org/10.1007/s11947-012-0968-5

Mancebo, C. M., Rodríguez, P., Martínez, M. M., & Gómez, M. (2018). Effect of the addition of soluble (nutriose, inulin and polydextrose) and insoluble (bamboo, potato and pea) fibres on the quality of sugar-snap cookies. *International Journal of Food Science and Technology, 53*(1), 129–136. https://doi.org/10.1111/ijfs.13566

Manley, D. (2011). Classification of biscuits. In D. Manley (Ed.), *Manley's technology of biscuits, crackers and cookies* (4th ed. ed., pp. 271–279). Cambridge: Elsevier Science & Technology.

Manley, D., Pareyt, B., & Delcour, J. (2011). Short dough biscuits. In D. Manely (Ed.), *Manley's technology of biscuits, crackers and cookies* (pp. 331–346). Cambridge, UNITED KINGDOM: Elsevier Science & Technology.

Pareyt, B., Brijs, K., & Delcour, J. A. (2009). Sugar-snap cookie dough setting: The impact of sucrose on gluten functionality. *Journal of Agricultural and Food Chemistry, 57*(17), 7814–7818. https://doi.org/10.1021/jf9010774

Pareyt, B., & Delcour, J. (2008a). The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: A review on sugar-snap cookies. *Critical Reviews in Food Science and Nutrition, 48*(9), 824–839. https://doi.org/10.1080/10408390701719223

Pareyt, B., & Delcour, J. (2008b). The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: A review on sugar-snap cookies. *Critical Reviews in Food Science and Nutrition, 48*(9), 824–839. https://doi.org/10.1080/10408390701719223

Pareyt, B., Talhaoui, F., Kerckhofs, G., Brijs, K., Goesaert, H., Wevers, M., et al. (2009). The role of sugar and fat in sugar-snap cookies: Structural and textural properties. *Journal of Food Engineering, 90*(3), 400–408. https://doi.org/10.1016/j.jfoodeng.2008.07.010

Peressini, D., & Sensidoni, A. (2009). Effect of soluble dietary fibre addition on rheological and breadmaking properties of wheat doughs. *Journal of Cereal Science, 49*(2), 190–201. Retrieved from http://www.sciencedirect.com/science/article/B6WHK-4TTMJRV-4/2/c2ea9e16aeed41a36326fb00eb5b63c0.

Public Health England. (2015). Sugar reduction, the evidence for action. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/470179/Sugar_reduction_The_evidence_for_action.pdf.

Public Health England. (2020). Ndns: Results from years 9 to 11 (2016 to 2017 and 2018 to 2019). Retrieved from https://www.gov.uk/government/statistics/ndns-results-from-years-9-to-11-2016-to-2017-and-2018-to-2019.

Rodriguez-Garcia, J., Laguna, L., Puig, A., Salvador, A., & Hernando, I. (2013). Effect of fat replacement by inulin on textural and structural properties of short dough biscuits. *Food and Bioprocess Technology, 6*(10), 2739–2750. https://doi.org/10.1007/s11947-012-0919-1

Rodriguez-Garcia, J., Puig, A., Salvador, A., & Hernando, I. (2012). Optimization of a sponge cake formulation with inulin as fat replacer: Structure, physicochemical, and sensory properties. *Journal of Food Science, 77*(2), C189–C197. https://doi.org/10.1111/j.1750-3841.2011.02546.x

Struck, S., Jaros, D., Brennan, C. S., & Rohm, H. (2014). Sugar replacement in sweetened bakery goods. *International Journal of Food Science and Technology, 49*(9), 1963–1976. https://doi.org/10.1111/ijfs.12617

Tarancón, P., Hernández, M. J., Salvador, A., & Sanz, T. (2015). Relevance of creep and oscillatory tests for understanding how cellulose emulsions function as fat replacers in biscuits. *LWT - Food Science and Technology, 62*(1), 640–646. https://doi.org/10.1016/j.lwt.2014.06.029

Tsatsaragkou, K., Methven, L., Chatzifragkou, A., & Rodriguez-Garcia, J. (2021). The functionality of inulin as a sugar replacer in cakes and biscuits; highlighting the influence of differences in degree of polymerisation on the properties of cake batter and product. *Foods, 10*(5), 951. Retrieved from https://www.mdpi.com/2304-8158/10/5/951.

World Health Organization. (2003). Diet, nutrition and the prevention of chronic diseases: Report of a joint who/fao expert consultation. *World Health Organisation Techinal Report Series, 916*, 1–149. Retrieved from http://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf;jsessionid=4AE2C26FFBF4A1F2ABA7D59EFC6B3C49?sequence=1.