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The impact of sugar particle size manipulation on the physical and sensory properties of chocolate brownies

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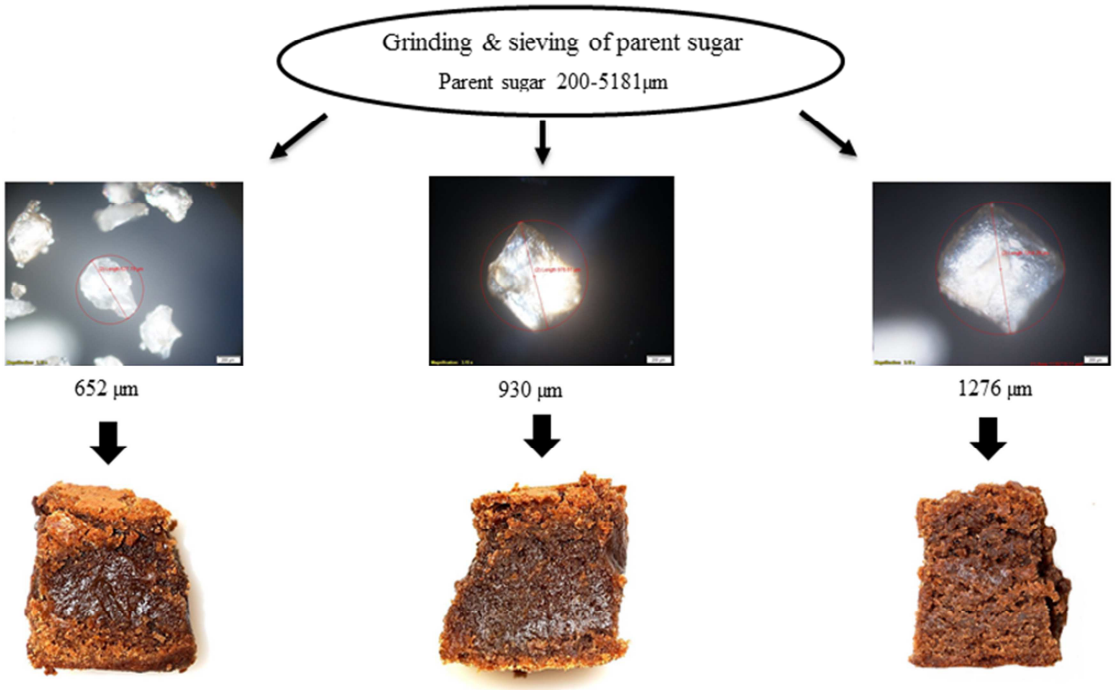
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Impact of sugar particle size on the physical properties and sensory attributes

Graphical abstract

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The impact of sugar particle size manipulation on the physical and sensory properties of chocolate brownies

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Highlights

- Small sugar particles increase sweetness intensity perception in chocolate brownies.
- Small sugar particles enhance the soft and moist texture of chocolate brownies.
- Sugar particle size manipulation significantly affects appearance, texture and colour liking of chocolate brownies.

Abstract

The overall objective of this research was to assess the effect of sugar particle size manipulation on the physical and sensory properties of chocolate brownies. A control sugar (commercially available, 200-5181 µm) and four of its sieved sugar separates (mesh size of 710, 500, 355 and 212 µm) were determined by grinding and sieving. The particle diameter and diameter distributions of the control sugar and each sugar fraction were measured. As a result, five sugar treatments were determined for chocolate brownie formulations; Control ($C_{200\text{-}5181\ \mu m}$), Large-particle replacement ($LPR_{924\text{-}1877\ \mu m}$), Medium-particle replacement ($MPR_{627\text{-}1214\ \mu m}$), Small-particle replacement ($SPR_{459\text{-}972\ \mu m}$) and a known MIX sample. Samples were tested using sensory (hedonic & intensity), instrumental (texture and colour) and compositional analyses (moisture and fat). Brownie samples containing the smallest sugar fraction ($SPR_{459\text{-}972\ \mu m}$) were perceived as significantly sweeter than any other sample ($p<0.05$). Brownies containing this fraction were also the softest and moistest samples ($p<0.05$). Texture liking was significantly associated with the $LPR_{924\text{-}1877\ \mu m}$ brownie ($p<0.05$). Darkness of brownie samples increased ($p<0.05$) as sugar particle size decreased. Therefore, sugar particle size alteration affects the physical and sensory properties of

chocolate brownies and could be used as a viable approach to reduce sugar in confectionery-type products.

Keywords

Sugar fraction, sensory analysis, texture, colour, sieved sugar

1. Introduction

The consumption of free and refined sugar in the diet is one of the main causes for obesity in society today (Hu & Malik 2010; MacGregor & Hashem, 2014). Free and refined sugar include; monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates, as defined by the World Health organisation (WHO, 2015). A recent review involving a meta-analysis of randomised controlled trials and prospective cohort studies has established that intake of sugars is a determinant of body weight, with a clear positive association between higher intakes of sugars, body fat and long-term weight gain in adults (Te Morenga, Mallard, Mann & Morenga, 2013). In Ireland the Irish Universities Nutrition Alliance (IUNA, 2011) reported that free sugars account for 14.6% of the total energy intake of Irish adults who participated in the study. According to the Healthy Ireland survey (2015), 37% of adults that participated were overweight and a further 23% were obese. Obesity is a strong risk factor for type 2 diabetes (Chan, Rimm, Colditz, Stampfer & Willett, 1994; Rosner, Speizer & Manson, 1997) and the Slán (2007) study reported that the estimated prevalence of pre-diabetes among over 45 year olds in Ireland was 19.8% (Morgan et al. 2008). A new guideline was published by the WHO in March 2015

which strongly recommends that adults and children reduce their daily intake of free sugars to less than 10% of their total energy intake. A conditional recommendation was also made to further reduce free sugar intake to below 5% of total energy intake (WHO 2015).

Confectionery and snacks account for 9% of carbohydrate intake in Irish adults, therefore reducing sugar in these products would be a significant development in reducing the dietary intake of sugar (Irish Universities Nutrition Alliance (IUNA) 2011). However, sugar has a huge part to play in the sensory properties of confectionery products, such as cake and cake-like products. Consequently, reducing sugar in these products presents a huge challenge for the food industry. Sugar is responsible for the sweetness in cakes and muffins and sucrose is the most commonly used sugar in cake making (Bennion and Bamford, 2013). According to Martínez-Cervera, Sanz, Salvador & Fiszman, 2012), sugar inhibits or reduces gluten development during cake batter mixing by competing with gluten proteins for water and thus, acts as a tenderiser of baked goods. The incorporation of air during batter creaming is facilitated by the addition of sucrose (Shepard & Yoell, 1976). This lightens the batter and air pockets formed during creaming expand and lift the batter, causing it to rise during baking. Sugar binds moisture and moisture content varies between the different types of sugar, for example liquid sugars contain more moisture than brown sugar and brown sugar contains more moisture than crystalline white sugar (Manley, 2011). Therefore sugar is not only responsible for the sweetness of cakes, but contributes significantly and positively to the sensory and physical properties of cakes.

Recent reports indicate that the global sugar substitutes market is valued at around $11.5 billion and it is expected to grow up to $14 billion by 2019 (Markets and markets. 2015). The inclination for combination of non-nutritive sugar substitutes with sugar alcohols to produce a low-calorie bakery product has increased, with artificial sweeteners such as aspartame and sucralose providing sweetness and sugar alcohols providing the bulking properties. However,

controversy exists over the use of artificial sweeteners in foods and beverages (Suez et al. 2014; Azad et al. 2016). In a recent US Mintel survey it was found that 64% of respondents indicated they were concerned about the safety of "artificial" sweeteners. (Gardner et al. 2012). This is an important finding for the food industry if companies are to implement replacement strategies using artificial sweeteners. Therefore, it is necessary to pursue other strategies for sugar reduction/replacement in such products.

In this study, a new strategy of sugar reduction based on the manipulation of sugar particle size is proposed. From extensive review of the scientific literature, we have not been able to detect research investigating the effect of sugar particle size on sweetness perception and overall acceptability of cakes. Sugar particle size has been shown to affect flour cookie quality (Kissel, Marshall, Yamazaki, 1973). Manley, (2011) reported that sucrose crystal size and their rate of dissolution affects the appearance and crunchiness of baked biscuits. Rama et al. (2013) conducted a study on salt particle size manipulation and found that smaller salt crystals increased salt perception in fried sliced potato crisps in a controlled chewing environment. This proves that salt size manipulation can be used to reduce salt in crisp products. Based on these findings, we hypothesise that smaller sugar particles increase sweetness perception in chocolate brownies.

The primary objective of this study was to determine the effect of sugar particle size on the sensory (hedonic, descriptive) and physical properties of chocolate brownies and to determine if this approach might constitute an effective strategy for reducing sugar levels in confectionery-type products.

2. Materials and methods

Food ingredients used in this trial, included; Light golden soft brown sugar (1.1% moisture, 98% sucrose, cane molasses and invert sugars, Siucra brand, UK); Irish Creamery butter (81% total fat, 65.4% of which were saturated, Dunnes stores, Ireland); Cream plain flour (1.4% fat, 82.7% carbohydrate, 2% of which sugars, 3.4% fibre, 11.7% protein and 0.81% salt, Odlums, Ireland); Free range eggs (Upton, Ireland); Dark chocolate (34.7% total fat, 55.8% carbohydrate, 97.2% of which sugars, 3.6% protein and 0.1% salt, Homecook wonder bar, Ireland). Food products were all purchased from a local supermarket and stored under refrigerated or cool, dry conditions where appropriate prior to sample preparation.

2.1 Sieving

Sugar was stored at ambient temperatures of 20ºC prior to grinding and sieving. Sugar was dried at 70˚C for one hour (h) in an oven (Binder, ED 115, Germany) to reduce moisture content for more effective sieving. Moisture content was obtained for the sugar, both before and after drying, using methodologies described below. Moisture content (%) was kept constant at 0.5% for all sugar fractions. Dried Sugar was ground by hand using rolling pins and mechanically sieved through a sequence of sieves (90, 180, 212, 355, 500, 710, 1,180 and 2,360 µm) set in a sieve shaker (Endeotts Octagon 200 London, England). Sieving was carried out in batches of 200g of sugar for 10 minutes (min) at 5-mm amplitude and particle size distributions of the sugar, both before and after grinding, were obtained using this method. For the purpose of the baking trials, four sugar-sieve separates were established; 212, 355, 500, and 710µm. The un-ground, un-sieved, commercially-available parent sugar was used as the control. Several separations were carried out until 1kg sugar quantities were available for all size ranges.

2.2 Measurement of particle size

Sugar-sieve separates obtained by milling and sieving were analysed by microscopy using a light microscope (Olympus BX-61 Tokyo, Japan) and cellSens™ standard software (version 510_UMA_Database_cellsens19-Krishna-en_00). The average particle size and distributions of the parent sugar and each separate (212, 355, 500 and 710 µm) were determined by obtaining and recording the 2D longest diameter of 100 particles per fraction in transparent light mode. Particle images within each fraction were captured using a microscope digital camera lens (Olympus DP73 Tokyo, Japan).

2.3 Chocolate brownie preparation

Three independent batches of brownies for all experimental treatments were manufactured in the preparation area of the sensory science laboratory, University College Cork. For the purpose of the experiment, samples were identified as follows; $C_{200\text{-}5181\ \mu m}$ (Control), $LPR_{924\text{-}1877\ \mu m}$ (large-particle replacement), $MPR_{627\text{-}1214\ \mu m}$ (medium-particle replacement), $SPR_{459\text{-}972\ \mu m}$ (small-particle replacement) and MIX (mix of 50% SPR, 40% MPR and 10% of the finer particle size captured by the 212 µm sieve mesh size). Dark chocolate (175g) and butter (175g) were melted in a heat stable bowl for one min in a microwave oven. The melted mixture was stirred for 30 seconds before sugar (250g) was added and stirred by hand for another one min. Eggs (180g) were beaten in a separate bowl and added to the mixture. All of the ingredients were stirred by hand for one min until the flour (115g) was sieved into the mixture. Mixture was stirred by hand until smooth (two mins). The batter was poured into tinfoil trays (16.5x24cm) and batches were baked for 30 min at 180°C in a Zanussi convection oven (C. Batassi, Conegliano, Italy). Batches of brownies were left to set for 30 min in the tray before being removed and cut into Individual brownie pieces (45x45mm).

Chocolate brownies were placed on a rack for cooling for one hour before being removed and placed into plastic containers for storage prior to testing.

2.4 Sensory analysis

Sensory affective evaluation

Sensory acceptance testing (SAT) was carried out in the panel booths of the sensory science laboratory, food science building, University College Cork according to international standards (ISO 11136:2014). SAT took place over three separate days as three independent trials were carried out for all five treatments. SAT was conducted according to the methods of Stone, Bleibaum & Thomas, (2012a) using a total of 70 untrained assessors (n=70) all of which were regular consumers of chocolate brownies and had experience with SAT. Samples (2x2x2cm) were assigned a randomised three-digit code and presented in duplicate (Stone, Bleibaum & Thomas, 2012b). Thus, each samples was evaluated 140 times (70 x 2). Sessions were carried out at room temperature under white light and sensory evaluators were instructed to use the water provided to cleanse their palates between tastings. Participants used the Hedonic descriptors summarised in Table 1 to rate chocolate brownie samples. Assessors were asked to indicate their degree of liking for samples on a 10cm continuous line-scale ranging from 0 (extremely dislike) at the left to 10 (extremely like) at the right (Rodrigue, Guillet, Fortin & Martine 2000; Fellendorf, O' Sullivan, Kerry, 2016). Overall acceptability was also evaluated using the scale from 0 cm, extremely unacceptable to 10 cm, extremely acceptable.

Ranking descriptive analysis

Following sensory acceptance testing assessors were trained and participated in a separate ranking descriptive analysis (RDA) according to the method of Richter, Almeida, Prudencio & Benassi, 2010. Training and RDA took place three separate times as three independent trials were carried out for all five treatments. Sensory descriptors were selected from panel discussion as the most appropriate and reflected the main variation in the samples profiled. The consensus list of sensory descriptors (Table 1, intensity), were measured on a 10 cm continuous line scale with the term "none" used as the anchor point for the 0 cm end of the scale to "extreme" for the 10 cm end of the scale (Fellendorf, O' Sullivan, Kerry, 2016). Each trained panellist was asked to rank each sample for each attribute. RDA was carried out in the panel booths of the sensory science laboratory, food science building, University College Cork using 70 trained assessors in total over three separate sessions (25+25+20=70). The samples (2x2x2cm) were served coded in randomised order and presented simultaneously to assessors (Stone, Bleibaum & Thomas, 2012b) in duplicate.

2.5 Chocolate brownie images

Photographs were taken of the chocolate brownie samples portioned out for sensory analysis using a digital camera (Nikon D3200, Japan).

2.6 Instrumental analysis

Texture

As outlined already three independent trials were carried out for all five treatments. Two chocolate brownies (45x45mm) from the centre of each batch tray were used for texture analysis (3 x 2 = 6). Texture profile analysis (TPA) was carried out on samples using a

Texture Analyser 16 TA-XT2I (Stable Micro Systems, Surrey, UK). A 50% double compression test was carried out on each sample to a height of 2cm with a 75mm diameter flat-ended cylindrical probe (P/75), at a speed of 1mm/s with a 5 sec waiting time between the two cycles. This was carried out in accordance with the method of Martínez-Cervera, Sanz, Salvador & Fiszman, (2012).

Colour

Two chocolate brownies (45x45mm) from the top right of each batch tray were used for colour analysis. Crust and crumb colour characteristics were assessed by the CIE *L*a* b** method. Lightness *L** was defined by means of a Minolta CR-200B Chroma Meter (Minolta Camera Co. Ltd., Osaka, Japan). The *L** parameter (L*=0 [Black], L*= 100 [White]) for crust was measured at two separate points directly from the top of each individual brownie sample. The brownie samples were cut horizontally to remove the crust and crumb colour was measured directly at two separate points. As a result four measurements for crust colour and four measurements for crumb colour were taken for each treatment and as three trials were carried out for each treatment results for crust and crumb colour represent a mean of eight measurements.

2.7 Moisture and fat

Two chocolate brownies (45x45mm) from each independent trial (three) were used for moisture and fat determination (3 x 2 = 6). Samples were homogenised for compositional analysis using Büchi Mixer B-400 (Büchi Labortechnik AG, Switzerland). Moisture content was determined using the CEM SMART system and fat was determined using the SMART Trac system (CEM GmbH, kamp-Lintfort, Germany). Two fibreglass pads were placed in the

drying chamber of the CEM SMART system and the weight of the pads were tared. Homogenised samples (2-4g) were weighed accurately on the fibreglass pads and afterwards one pad was placed over the sample and pressed together. Percent of fats was determined by wrapping the fibreglass pads with the sample in a sheet of Smart Trac film. Wrapped samples were placed in Smart Trac tube and positioned in the Smart Trac NMR unit. Percentage fat is displayed after roughly 5 min. Methods were carried out in accordance with that of Bostian, Fish, Webb & Arey, (1985) with slight modifications for confectionery samples.

2.8 Statistical analysis

As stated previously all chocolate brownie formulations were prepared in three independent batch trials and two independent samples for each experimental treatment from each of these batches were assessed for each parameter, providing a total of 6 independent samples, unless stated otherwise above. Raw data obtained from sensory evaluation was coded into Microsoft excel and analysed using ANOVA- Partial Least Squares Regression (APLSR) using Unscrambler software version 10.3 (CAMO ASA, Trondheim, Norway). The X-matrix was defined as the different sample treatments. The Y – matrix contained the sensory variables of the design. To achieve significant results for the relationships determined in the quantitative APLSR, regression coefficients were analyzed by jack-knifing which is based on cross-validation and stability plots (Martens & Martens, 2000). Statistical significance for sensory data was defined as $P<0.05$-0.01 (significant), $P<0.01$-0.001 (highly significant) and $P<0.001$ (extremely significant). Texture and compositional data were presented as a mean of six values ± standard deviation. Colour (crust and crumb) data was presented as a mean of eight values ± standard deviation. One-way ANOVA was used to compare the means of the data obtained from instrumental analysis and compositional analysis. Tukey's post-hoc test was

253 used to adjust for multiple comparisons between treatment means using SPSS statistics 20
254 software (IBM, Armonk, NY, USA).

255

256 ## 3. Results and discussion

257 3.1 Particle size distribution

258 Particle size distribution (PSD) of brown sugar, both before and after grinding, can be seen in
259 Fig 1. It is clear from this chart that significant particle size differences exist within the parent
260 sugar employed for this trial. Sugar particles captured by 710, 500 and 355 µm sieves
261 increased by 34.1%, 17.4% and 7.1%, respectfully after grinding. No particles >2,360 µm
262 were present after grinding and particles captured by the sieve with the second largest
263 aperture (1,180 µm) decreased by 21.31%. Finer sugar particles <212 µm were present after
264 grinding. Visual representation of the particle diameter distribution of control sugar and
265 individual sugar separates can be seen in Fig 2. Particle size diameter differences between
266 control sugar and sugar separates were evident. Control sugar had the widest particle size
267 distribution as expected with particles ranging from 200-5181 µm. After grinding and
268 separation, particle size distribution within each fraction became smaller, in the range of 924-
269 1877 µm for LPR, 627-1214 µm for MPR and 459-972 µm for SPR. Particle size ranges and
270 mean sizes for control sugar and each sieved sugar-separate are shown in Table 2.
271 Microscopic images for brown sugar particles with 2D diameters for different mesh sizes are
272 represented in Fig 3.

273

274 3.2 Sensory analysis

A total of 54.8% of the sensory evaluators who participated in this study were female and 45.2% were male. Ages of assessors ranged from 18-45. Significance of estimated regression coefficients for the relationship of sensory terms and chocolate brownies are presented in Table 3.

The control sample ($C_{200\text{-}5181\ \mu m}$) was negatively associated with crust darkness, ($p<0.001$). Brownie samples containing $LPR_{924\text{-}1877\ \mu m}$ were significantly positively associated with colour liking ($p<0.05$) whereas brownie samples containing $SPR_{459\text{-}972\ \mu m}$ were negatively associated ($p<0.05$).

Chocolate brownie samples with $LPR_{924\text{-}1877\ \mu m}$ were positively associated with texture liking ($p<0.01$). Samples containing $SPR_{459\text{-}972\ \mu m}$ were extremely associated with having a moist texture ($p<0.001$). These samples were also significantly negatively associated with texture hardness ($p<0.01$). Therefore brownie samples containing this fraction ($SPR_{459\text{-}972\ \mu m}$) were perceived as the softest and moistest samples. In contrast control samples ($C_{200\text{-}5181\ \mu m}$) were perceived as the hardest samples ($p<0.05$). It has been observed that replacement of sucrose with different fibres increases crumb firmness in muffins (Struck, Gundel, Zahn & Rohm, 2016). The authors cite air cell incorporation as a contributing factor to mechanical resistance. The presence of larger sugar particles in the $C_{200\text{-}5181\ \mu m}$ sample in this study could have impacted upon air cell incorporation and could therefore be contributing to the increased hardness observed in samples.

The chocolate brownie samples containing the smallest sugar fraction ($SPR_{459\text{-}972\ \mu m}$) were perceived as significantly sweeter than any other sample ($p<0.05$). This finding is in agreement with results obtained for salt crystal size manipulation, with smaller salt particles being shown to increase saltiness perception in crisps (Rama et al., 2013).

298 Images of chocolate brownie samples divided out for sensory analysis can be seen in Fig 4.
299 Visual variation in brownie texture was evident. In agreement with the sensory data presented
300 in this study, brownie samples containing $SPR_{459\text{-}972\ \mu m}$ had the greatest moist appearances.

301

302 3.3 Texture and colour analysis

303 Texture profile analysis (TPA) results are shown in Table 4. In agreement with sensory data,
304 chocolate brownie samples containing $SPR_{459\text{-}972\ \mu m}$ were the softest samples with the force
305 (45.1 ± 2.42 N) required to compress brownie samples being lower (p<0.05) than determined
306 for any other sample. Contradictory to the sensory data, brownie samples containing $LPR_{924\text{-}1877\ \mu m}$
307 were the hardest samples (69.2 ± 2.12 N) (p<0.05). As sugar particle size decreased,
308 hardness values decreased significantly (p<0.05) with the exception of the Control and Mix
309 samples. These results are similar to mean cake strength results obtained by Dozan, Benković
310 & Bauman (2014), who found that cake strength increased with increasing sugar particle size
311 due to the force required for crystal breakage, as well as cake breakage. Similarly, Dozan,
312 Benković & Bauman (2014) demonstrated that the force required to compress cakes with
313 larger crystals was greater than the force required to compress cakes with smaller crystals. In
314 our study, chewiness values (N-mm) varied significantly between samples. Chocolate
315 brownies containing $SPR_{459\text{-}972\ \mu m}$ were found to have the lowest value (4.2 ± 0.23 N-mm) for
316 chewiness (chewiness hardness x cohesiveness x springiness) and different (p<0.05) from all
317 other samples. Brownie samples containing $MPR_{627\text{-}1214\ \mu m}$ presented the second lowest value
318 (p<0.05) for chewiness (5.0 ± 0.50 N-mm) and samples containing a mix of sugar particle
319 sizes (MIX) obtained the third lowest value (p<0.05) for chewiness 6.2 ± 0.13 N-mm).
320 $Control_{200\text{-}5181\ \mu m}$ and $LPR_{924\text{-}1877\ \mu m}$ brownie samples were not significantly different from
321 each other with regards chewiness, but both samples presented the highest values (p<0.05).

The slightly higher chewiness values (9.8 ± 0.12 N-mm) associated with chocolate brownie samples containing $LPR_{924\text{-}1877\ \mu m}$ could be a reason why these samples were liked so much in terms of texture and also may be a reason why these samples were not perceived correctly as the hardest samples as determined during sensory evaluation (see Table 3). No significant differences were observed between brownie samples with respect to other physical product parameters such as adhesiveness, springiness, cohesiveness, or resilience.

In accordance with sensory data, control brownie samples had the lightest crust, which was different (p<0.05) from any other sample (Table 5). Trends showed that as sugar particle size decreased, darkness of crust colour increased. The control sample also had the lightest crumb colour (p<0.05) compared to all other brownie samples, with the exception of those samples containing $LPR_{924\text{-}1877\ \mu m}$. Trends showed that as sugar particle size decreased, darkness of crumb colour increased, with samples containing $SPR_{459\text{-}972\ \mu m}$ having the darkest crumb colour (24.4 ± 1.81).The darker crumb and crust colour can be associated with the lower melting point of smaller sugar crystals which can caramelize quicker than larger crystals. The darker crumb colour of $SPR_{459\text{-}972\ \mu m}$ could be a reason why this sample was negatively associated with colour liking as determined by sensory evaluation.

3.4 Moisture and fat content

As anticipated, fat (%) did not vary between samples as fat content remained constant in samples during baking. The average fat content determined in baked brownies ranged from 26.24 to 27.64% as shown in Table 6. However, moisture content varied significantly between samples. As sugar particle size decreased, moisture content increased in brownie samples, with the exception being that of the MIX sample. $Control_{200\text{-}5181\ \mu m}$ and $LPR_{924\text{-}1877\ \mu m}$ brownie samples had the lowest moisture content and were different (p<0.05) from

346 samples containing $MPR_{627\text{-}1214\ \mu m}$ and $SPR_{459\text{-}972\ \mu m}$, but not significantly different from the
347 MIX sample. Chocolate brownie samples containing $SPR_{459\text{-}972\ \mu m}$ had the highest (p<0.05)
348 moisture content (13.0 ± 0.84) compared to all other brownie samples, with the exception of
349 samples containing $MPR_{627\text{-}1214\ \mu m}$ which had the second highest moisture content (p<0.05).

350

351 Conclusion

352 This work demonstrates that sugar particle size manipulation has a significant impact on the
353 physical and sensory properties of chocolate brownies. Chocolate brownies formulated with
354 $LPR_{924\text{-}1877\ \mu m}$ received the highest scores for liking of texture, appearance and colour. Thus,
355 replacement of the parent sugar with this experimental fraction improved acceptance of the
356 final product. Therefore, sugar within this size range could be used to improve the texture and
357 appearance of low-sugar or partially-replaced sugar in confectionery-type products.
358 Chocolate brownies prepared with the smallest sugar particle size ($SPR_{459\text{-}972\ \mu m}$) were the
359 softest and moistest of all samples as supported by sensory, instrumental and compositional
360 analysis. This is an important finding as sugar within this size range could be employed to
361 retain moisture and softness in low sugar/low fat confectionery type products. Chocolate
362 brownies formulated with the smallest sugar particles were perceived as the sweetest
363 samples. Based on these findings sugar particle size reduction would permit sugar reduction
364 as sweetness perception is increased in samples with smaller sugar particles. Further research
365 needs to be carried out to demonstrate this finding further. In conclusion, sugar particle size
366 reduction increases the sensory perception of sweetness in chocolate brownies and could be
367 used as a viable technological approach to effectively reduce the sugar content of
368 confectionery-type products and be of benefit to the baking industry in the formulation of
369 low-calorie, clean-label baked goods.

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Conflicts of interest

The authors declare that no conflicts of interests exist.

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Table 1

Hedonic and sensory descriptors used in sensory evaluation questionnaires

Descriptors	Scale	Definition
Hedonic		
Appearance	0 = extremely dislike 10 = extremely like	
Flavour	0 = extremely dislike 10 = extremely like	
Texture	0 = extremely dislike 10 = extremely like	
Colour	0 = extremely dislike 10 = extremely like	
Overall acceptability	0 = extremely unacceptable 10 = extremely acceptable	
Intensity		
Appearance		
Crust darkness	0 = none 10 = extreme	Degree of darkness of crust
Texture		
Hardness	0 = none 10 = extreme	Force needed to compress the sample
Moisture	0= none 10=extreme	Moist/wet texture in mouth
Flavour		
Sweet taste	0=none 10=extreme	Flavour sensation associated with sucrose
Brownie flavour	0=none 10=extreme	Characteristic chocolate brownie flavour
Off flavour	0=none 10=extreme	Off-flavour (rancid)
Aftertaste	0=none 10=extreme	A taste remaining in the mouth after eating

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Table 2

Particle size ranges of parent sugar and sugar sieve separates (µm)

Sugar-sieve separates (µm)	Sample	Particle size ranges (µm)	Average particle size (µm)
Parent sugar	Control (C)	200-5181	1533
710	LPR	924-1877	1276
500	MPR	627-1214	930
355	SPR	459-972	652
212	10% of MIX	330-700	479

MIX sample was made up of 50% SPR, 40% MPR and 10% of the finer particle size captured by the 212µm sieve mesh size

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Table 3

Significance of estimated regression coefficients (ANOVA values) for the relationship of sensory terms (hedonic & intensity) and Chocolate Brownies prepared with varying sugar particle sizes

Sample	Appearance Liking	Flavour Liking	Texture Liking	Colour Liking	Overall acceptability	Crust darkness	Hardness	Moisture	Sweet taste	Brownie Flavour	Off flavour	Aftertaste
$Control_{200\text{-}5181\ \mu m}$	0.289	0.478	0.366	0.669	0.463	-0.003**	0.021*	0.061	0.519	0.695	0.574	0.886
$LPR_{924\text{-}1877\ \mu m}$	0.041*	0.186	0.012**	0.050*	0.359	0.809	0.134	0.507	0.433	0.431	0.897	0.530
$MPR_{627\text{-}1214\ \mu m}$	0.607	0.102	0.439	0.939	0.258	0.104	0.662	0.602	0.432	0.192	0.422	0.449
$SPR_{459\text{-}972\ \mu m}$	0.187	0.657	0.134	-0.012**	0.877	0.413	-0.002**	0.001***	0.045*	0.850	0.370	0.502
MIX	0.521	0.996	0.720	0.439	0.655	0.595	0.980	0.544	0.105	0.272	0.805	0.413

Significance of regression coefficients*=P≤ 0.05, **= P≤ 0.01, ***= P≤ 0.001. – indicates whether the correlation is negatively correlated. LPR; large particle replacement MPR; medium particle replacement and SPR; small particle replacement

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Table 4

Texture profile analysis (TPA) values for Chocolate brownies made with decreasing sugar particle size.

	TPA					
Sample	Hardness (N)	Adhesiveness	Springiness (mm)	Cohesiveness (n/a)	Chewiness (N-mm)	Resilience (n/a)
$Control_{200\text{-}5181\mu m}$	54.5 ± 1.45^{b}	-0.0 ± 0.73^{a}	0.5 ± 0.74^{a}	0.3 ± 0.05^{a}	9.1 ± 0.80^{d}	0.1 ± 0.01^{a}
$LPR_{924\text{-}1877\mu m}$	69.2 ± 2.12^{c}	-0.0 ± 0.59^{a}	0.5 ± 0.06^{a}	0.3 ± 0.04^{a}	9.8 ± 0.12^{d}	0.1 ± 0.01^{a}
$MPR_{627\text{-}1214\mu m}$	52.0 ± 2.75^{b}	-0.0 ± 0.01^{a}	0.3 ± 0.04^{a}	0.3 ± 0.03^{a}	5.0 ± 0.50^{b}	0.1 ± 0.01^{a}
$SPR_{459\text{-}972\mu m}$	45.1 ± 2.42^{a}	-1.0 ± 1.17^{a}	0.3 ± 0.07^{a}	0.3 ± 0.05^{a}	4.2 ± 0.23^{a}	0.1 ± 0.02^{a}
MIX	53.4 ± 1.72^{b}	-0.0 ± 0.81^{a}	0.3 ± 0.04^{a}	0.3 ± 0.05^{a}	6.2 ± 0.13^{c}	0.1 ± 0.02^{a}

^{abc} mean values (± standard deviation) in the same row bearing different superscripts are significantly different, $P < 0.05$.

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Table 5

Colour lightness values (L*) for Chocolate brownies made with decreasing sugar particle size

Sample	Colour (L*)	
	Crust	Crumb
$Control_{200\text{-}5181\mu m}$	39.8 ± 1.85^{a}	29.0 ± 1.51^{a}
$LPR_{924\text{-}1877\mu m}$	34.2 ± 0.93^{b}	27.1 ± 1.82^{ab}
$MPR_{627\text{-}1214\mu m}$	33.2 ± 1.22^{b}	25.1 ± 0.80^{b}
$SPR_{459\text{-}972\mu m}$	33.1 ± 1.95^{b}	24.4 ± 1.81^{b}
MIX	32.6 ± 0.80^{b}	25.4 ± 1.73^{b}

^{abc} mean values (± standard deviation) in the same row bearing different superscripts are significantly different, $P < 0.05$.

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Table 6

Moisture and fat of chocolate brownie samples prepared with decreasing particle size

Sample	% Moisture	%Fat
$Control_{200\text{-}5181\mu m}$	9.2 ± 0.80^{a}	26.3 ± 1.87^{a}
$LPR_{924\text{-}1877\mu m}$	9.9 ± 1.08^{a}	27.6 ± 1.68^{a}
$MPR_{627\text{-}1214\mu m}$	11.8 ± 1.03^{bc}	26.6 ± 1.95^{a}
$SPR_{459\text{-}972\mu m}$	13.0 ± 0.84^{c}	26.9 ± 1.28^{a}
MIX	10.3 ± 0.70^{ab}	26.2 ± 0.77^{a}

^{abc} mean values (± standard deviation) in the same row bearing different superscripts are significantly different, $P < 0.05$

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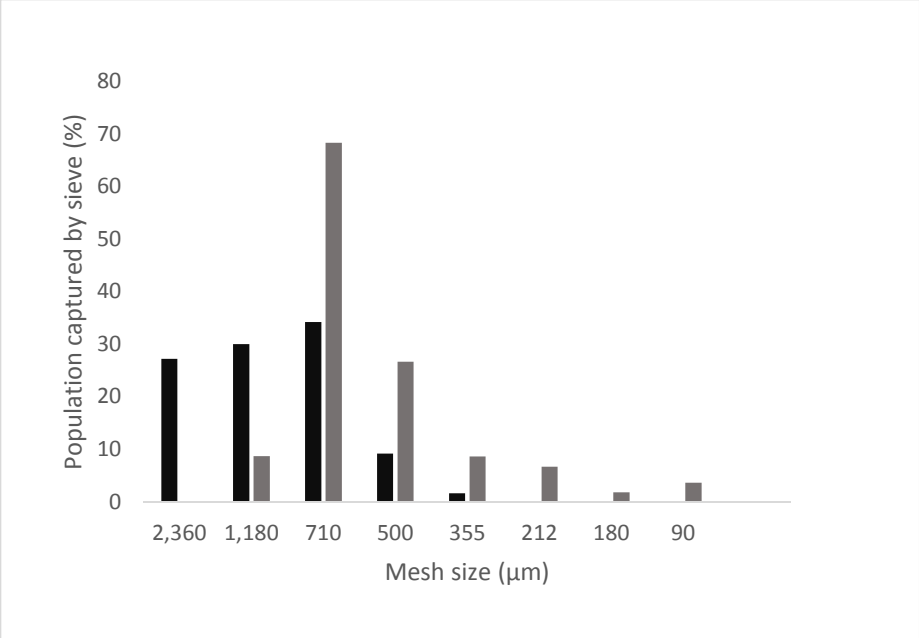


Fig 1. Particle size distribution of dried brown sugar (200g, 0.5% moisture) before (■) and after (■) grinding.

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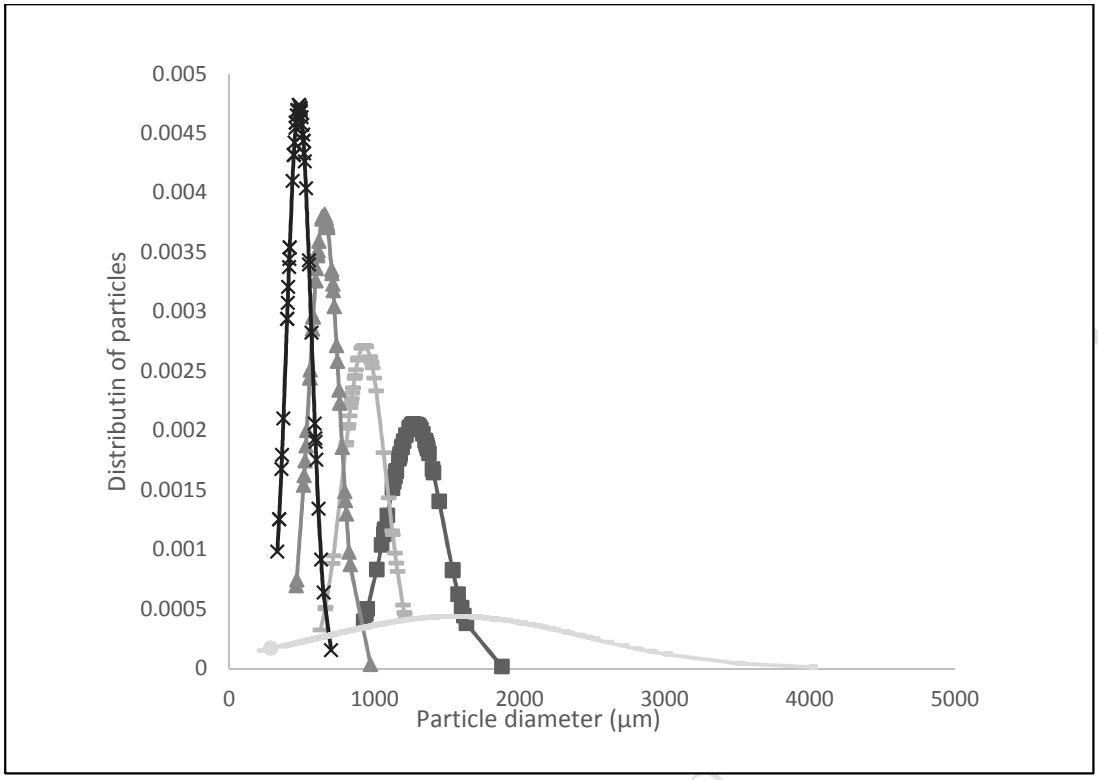


Fig 2. Particle diameter distribution of parent brown sugar before grinding: control ( ) and sugar-sieve separates; 710 ( ), 500 ( ), 355 ( ) and 212 µm ( ) after grinding.

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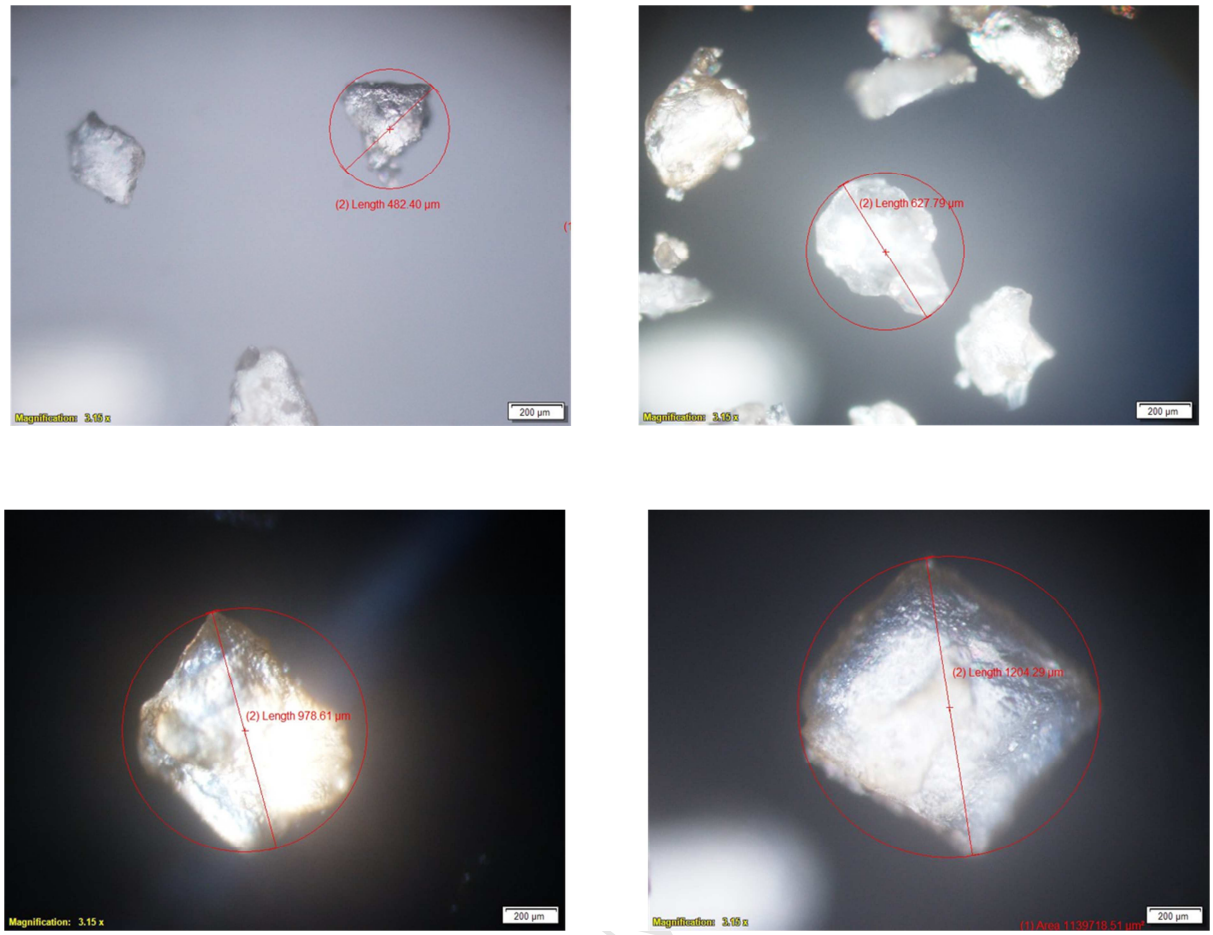


Fig 3. Microscopic images of brown sugar particles captured by different sieve apertures after grinding. From top left, 212µm and 355µm apertures and from bottom left 500µm and 710µm apertures. Red line across particle indicates diameter of the particle.

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Fig 4. Cross section images of chocolate brownies (2 x 2 x 2 cm). Samples were taken from the upper right midsection of each batch tray. From left: Control, LPR, MPR, SPR and MIX sample.

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Highlights

- Small sugar particles increase sweetness intensity perception in chocolate brownies.
- Small sugar particles enhance the soft and moist texture of chocolate brownies.
- Sugar particle size manipulation significantly affects appearance, texture and colour liking of chocolate brownies.

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