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# The impact of sugar particle size manipulation on the physical and sensory

# properties of chocolate brownies

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

# **Graphical abstract**

# 1 The impact of sugar particle size manipulation on the physical and sensory

# 2 properties of chocolate brownies

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### 18 Highlights

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• Small sugar particles increase sweetness intensity perception in chocolate brownies.

• Small sugar particles enhance the soft and moist texture of chocolate brownies.

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• Sugar particle size manipulation significantly affects appearance, texture and colour liking of chocolate brownies.

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22

### 24 Abstract

25 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 26 (commercially available, 200-5181 µm) and four of its sieved sugar separates (mesh size of 27 28 710, 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 29 result, five sugar treatments were determined for chocolate brownie formulations; Control 30 (C<sub>200-5181 µm</sub>), Large-particle replacement (LPR<sub>924-1877 µm</sub>), Medium-particle replacement 31 (MPR<sub>627-1214 µm</sub>), Small-particle replacement (SPR<sub>459-972 µm</sub>) and a known MIX sample. 32 33 Samples were tested using sensory (hedonic & intensity), instrumental (texture and colour) 34 and compositional analyses (moisture and fat). Brownie samples containing the smallest 35 sugar fraction (SPR<sub>459-972 um</sub>) were perceived as significantly sweeter than any other sample (p < 0.05). Brownies containing this fraction were also the softest and moistest samples 36 (p<0.05). Texture liking was significantly associated with the LPR<sub>924-1877 µm</sub> brownie 37 (p < 0.05). Darkness of brownie samples increased (p < 0.05) as sugar particle size decreased. 38 39 Therefore, sugar particle size alteration affects the physical and sensory properties of

40 chocolate brownies and could be used as a viable approach to reduce sugar in confectionery-41 type products.

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#### 43 Keywords

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

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### 46 **1. Introduction**

The consumption of free and refined sugar in the diet is one of the main causes for obesity in 47 society today (Hu & Malik 2010; MacGregor & Hashem, 2014). Free and refined sugar 48 include; monosaccharides and disaccharides added to foods and beverages by the 49 manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices 50 and fruit juice concentrates, as defined by the World Health organisation (WHO, 2015). A 51 recent review involving a meta-analysis of randomised controlled trials and prospective 52 53 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 54 gain in adults (Te Morenga, Mallard, Mann & Morenga, 2013). In Ireland the Irish 55 56 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 57 Ireland survey (2015), 37% of adults that participated were overweight and a further 23% 58 were obese. Obesity is a strong risk factor for type 2 diabetes (Chan, Rimm, Colditz, 59 Stampfer & Willett, 1994; Rosner, Speizer & Manson, 1997) and the Slán (2007) study 60 reported that the estimated prevalence of pre-diabetes among over 45 year olds in Ireland was 61 19.8% (Morgan et al. 2008). A new guideline was published by the WHO in March 2015 62

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 66 reducing sugar in these products would be a significant development in reducing the dietary 67 intake of sugar (Irish Universities Nutrition Alliance (IUNA) 2011). However, sugar has a 68 huge part to play in the sensory properties of confectionery products, such as cake and cake-69 like products. Consequently, reducing sugar in these products presents a huge challenge for 70 71 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 72 Martínez-Cervera, Sanz, Salvador & Fiszman, 2012), sugar inhibits or reduces gluten 73 development during cake batter mixing by competing with gluten proteins for water and thus, 74 acts as a tenderiser of baked goods. The incorporation of air during batter creaming is 75 facilitated by the addition of sucrose (Shepard & Yoell, 1976). This lightens the batter and air 76 pockets formed during creaming expand and lift the batter, causing it to rise during baking. 77 Sugar binds moisture and moisture content varies between the different types of sugar, for 78 example liquid sugars contain more moisture than brown sugar and brown sugar contains 79 more moisture than crystalline white sugar (Manley, 2011). Therefore sugar is not only 80 responsible for the sweetness of cakes, but contributes significantly and positively to the 81 sensory and physical properties of cakes. 82

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,

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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 94 size is proposed. From extensive review of the scientific literature, we have not been able to 95 96 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 97 quality (Kissel, Marshall, Yamazaki, 1973). Manley, (2011) reported that sucrose crystal size 98 99 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 100 crystals increased salt perception in fried sliced potato crisps in a controlled chewing 101 environment. This proves that salt size manipulation can be used to reduce salt in crisp 102 products. Based on these findings, we hypothesise that smaller sugar particles increase 103 sweetness perception in chocolate brownies. 104

105 The primary objective of this study was to determine the effect of sugar particle size on the 106 sensory (hedonic, descriptive) and physical properties of chocolate brownies and to determine 107 if this approach might constitute an effective strategy for reducing sugar levels in 108 confectionery-type products.

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#### 110 **2. Materials and methods**

111 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 112 (81% total fat, 65.4% of which were saturated, Dunnes stores, Ireland); Cream plain flour 113 (1.4% fat, 82.7% carbohydrate, 2% of which sugars, 3.4% fibre, 11.7% protein and 0.81% 114 salt, Odlums, Ireland); Free range eggs (Upton, Ireland); Dark chocolate (34.7% total fat, 115 55.8% carbohydrate, 97.2% of which sugars, 3.6% protein and 0.1% salt, Homecook wonder 116 bar, Ireland). Food products were all purchased from a local supermarket and stored under 117 refrigerated or cool, dry conditions where appropriate prior to sample preparation. 118

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120 2.1 Sieving

121 Sugar was stored at ambient temperatures of 20°C 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 122 content for more effective sieving. Moisture content was obtained for the sugar, both before 123 and after drying, using methodologies described below. Moisture content (%) was kept 124 constant at 0.5% for all sugar fractions. Dried Sugar was ground by hand using rolling pins 125 and mechanically sieved through a sequence of sieves (90, 180, 212, 355, 500, 710, 1,180 and 126 2,360 µm ) set in a sieve shaker (Endeotts Octagon 200 London, England). Sieving was 127 carried out in batches of 200g of sugar for 10 minutes (min) at 5-mm amplitude and particle 128 size distributions of the sugar, both before and after grinding, were obtained using this 129 method. For the purpose of the baking trials, four sugar-sieve separates were established; 212, 130 355, 500, and 710µm. The un-ground, un-sieved, commercially-available parent sugar was 131 132 used as the control. Several separations were carried out until 1kg sugar quantities were available for all size ranges. 133

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135 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<sup>TM</sup> 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  $\mu$ m) 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).
- 143

144 2.3 Chocolate brownie preparation

Three independent batches of brownies for all experimental treatments were manufactured in 145 the preparation area of the sensory science laboratory, University College Cork. For the 146 purpose of the experiment, samples were identified as follows; C<sub>200-5181 um</sub> (Control), LPR<sub>924-</sub> 147 1877 µm (large-particle replacement), MPR<sub>627-1214 µm</sub> (medium-particle replacement), SPR<sub>459-972</sub> 148 um (small-particle replacement) and MIX (mix of 50% SPR, 40% MPR and 10% of the finer 149 particle size captured by the 212 µm sieve mesh size). Dark chocolate (175g) and butter 150 (175g) were melted in a heat stable bowl for one min in a microwave oven. The melted 151 mixture was stirred for 30 seconds before sugar (250g) was added and stirred by hand for 152 another one min. Eggs (180g) were beaten in a separate bowl and added to the mixture. All of 153 the ingredients were stirred by hand for one min until the flour (115g) was sieved into the 154 mixture. Mixture was stirred by hand until smooth (two mins). The batter was poured into 155 tinfoil trays (16.5x24cm) and batches were baked for 30 min at 180°C in a Zanussi 156 convection oven (C. Batassi, Conegliano, Italy). Batches of brownies were left to set for 30 157 min in the tray before being removed and cut into Individual brownie pieces (45x45mm). 158

159 Chocolate brownies were placed on a rack for cooling for one hour before being removed and160 placed into plastic containers for storage prior to testing.

161

162 2.4 Sensory analysis

163 Sensory affective evaluation

Sensory acceptance testing (SAT) was carried out in the panel booths of the sensory science 164 laboratory, food science building, University College Cork according to international 165 standards (ISO 11136:2014). SAT took place over three separate days as three independent 166 trials were carried out for all five treatments. SAT was conducted according to the methods of 167 Stone, Bleibaum & Thomas, (2012a) using a total of 70 untrained assessors (n=70) all of 168 which were regular consumers of chocolate brownies and had experience with SAT. Samples 169 (2x2x2cm) were assigned a randomised three-digit code and presented in duplicate (Stone, 170 Bleibaum & Thomas, 2012b). Thus, each samples was evaluated 140 times (70 x 2). Sessions 171 were carried out at room temperature under white light and sensory evaluators were 172 173 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. 174 Assessors were asked to indicate their degree of liking for samples on a 10cm continuous 175 line-scale ranging from 0 (extremely dislike) at the left to 10 (extremely like) at the right 176 (Rodrigue, Guillet, Fortin & Martine 2000; Fellendorf, O' Sullivan, Kerry, 2016). Overall 177 acceptability was also evaluated using the scale from 0 cm, extremely unacceptable to 10 cm, 178 extremely acceptable. 179

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181 Ranking descriptive analysis

182 Following sensory acceptance testing assessors were trained and participated in a separate ranking descriptive analysis (RDA) according to the method of Richter, Almeida, Prudencio 183 & Benassi, 2010. Training and RDA took place three separate times as three independent 184 trials were carried out for all five treatments. Sensory descriptors were selected from panel 185 discussion as the most appropriate and reflected the main variation in the samples profiled. 186 The consensus list of sensory descriptors (Table 1, intensity), were measured on a 10 cm 187 continuous line scale with the term "none" used as the anchor point for the 0 cm end of the 188 scale to "extreme" for the 10 cm end of the scale (Fellendorf, O' Sullivan, Kerry, 2016). 189 Each trained panellist was asked to rank each sample for each attribute. RDA was carried out 190 in the panel booths of the sensory science laboratory, food science building, University 191 College Cork using 70 trained assessors in total over three separate sessions (25+25+20=70). 192 The samples (2x2x2cm) were served coded in randomised order and presented 193 simultaneously to assessors (Stone, Bleibaum & Thomas, 2012b) in duplicate. 194

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196 2.5 Chocolate brownie images

197 Photographs were taken of the chocolate brownie samples portioned out for sensory analysis198 using a digital camera (Nikon D3200, Japan).

199

200 2.6 Instrumental analysis

201 *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).

210

211 *Colour* 

Two chocolate brownies (45x45mm) from the top right of each batch tray were used for 212 colour analysis. Crust and crumb colour characteristics were assessed by the CIE  $L^*a^*b^*$ 213 method. Lightness L\* was defined by means of a Minolta CR-200B Chroma Meter (Minolta 214 Camera Co. Ltd., Osaka, Japan). The  $L^*$  parameter (L\*=0 [Black], L\*= 100 [White]) for 215 crust was measured at two separate points directly from the top of each individual brownie 216 sample. The brownie samples were cut horizontally to remove the crust and crumb colour 217 was measured directly at two separate points. As a result four measurements for crust colour 218 and four measurements for crumb colour were taken for each treatment and as three trials 219 were carried out for each treatment results for crust and crumb colour represent a mean of 220 eight measurements. 221

222

223 2.7 Moisture and fat

Two chocolate brownies (45x45mm) from each independent trial (three) were used for moisture and fat determination ( $3 \times 2 = 6$ ). 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.

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237 2.8 Statistical analysis

As stated previously all chocolate brownie formulations were prepared in three independent 238 239 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 240 stated otherwise above. Raw data obtained from sensory evaluation was coded into Microsoft 241 excel and analysed using ANOVA- Partial Least Squares Regression (APLSR) using 242 Unscrambler software version 10.3 (CAMO ASA, Trondheim, Norway). The X-matrix was 243 defined as the different sample treatments. The Y – matrix contained the sensory variables of 244 the design. To achieve significant results for the relationships determined in the quantitative 245 APLSR, regression coefficients were analyzed by jack-knifing which is based on cross-246 validation and stability plots (Martens & Martens, 2000). Statistical significance for sensory 247 data was defined as P<0.05-0.01 (significant), P<0.01-0.001 (highly significant) and P<0.001 248 (extremely significant). Texture and compositional data were presented as a mean of six 249 250 values  $\pm$  standard deviation. Colour (crust and crumb) data was presented as a mean of eight values  $\pm$  standard deviation. One-way ANOVA was used to compare the means of the data 251 obtained from instrumental analysis and compositional analysis. Tukey's post-hoc test was 252

- used to adjust for multiple comparisons between treatment means using SPSS statistics 20
  software (IBM, Armonk, NY, USA).
- 255

#### 256 **3. Results and discussion**

257 3.1 Particle size distribution

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

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 ( $C_{200-5181 \,\mu\text{m}}$ ) was negatively associated with crust darkness, (*p*<0.001). Brownie samples containing LPR<sub>924-1877  $\mu\text{m}}$  were significantly positively associated with colour liking (p<0.05) whereas brownie samples containing SPR<sub>459-972  $\mu\text{m}}$  were negatively associated (p<0.05).</sub></sub>

Chocolate brownie samples with LPR<sub>924-1877 um</sub> were positively associated with texture liking 283 (p < 0.01). Samples containing SPR<sub>459-972 µm</sub> were extremely associated with having a moist 284 texture (p < 0.001). These samples were also significantly negatively associated with texture 285 hardness (p < 0.01). Therefore brownie samples containing this fraction (SPR<sub>459-972 µm</sub>) were 286 perceived as the softest and moistest samples. In contrast control samples ( $C_{200-5181 \text{ um}}$ ) were 287 perceived as the hardest samples (p < 0.05). It has been observed that replacement of sucrose 288 with different fibres increases crumb firmness in muffins (Struck, Gundel, Zahn & Rohm, 289 2016). The authors cite air cell incorporation as a contributing factor to mechanical 290 291 resistance. The presence of larger sugar particles in the  $C_{200-5181 \text{ um}}$  sample in this study could have impacted upon air cell incorporation and could therefore be contributing to the increased 292 hardness observed in samples. 293

The chocolate brownie samples containing the smallest sugar fraction (SPR<sub>459-972 µm</sub>) 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).

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

301

302 3.3 Texture and colour analysis

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

The slightly higher chewiness values (9.8  $\pm$  0.12 N-mm) associated with chocolate brownie samples containing LPR<sub>924-1877 µm</sub> 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 328 different (p < 0.05) from any other sample (Table 5). Trends showed that as sugar particle size 329 330 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 331 containing LPR<sub>924-1877 um</sub>. Trends showed that as sugar particle size decreased, darkness of 332 333 crumb colour increased, with samples containing SPR<sub>459-972 um</sub> having the darkest crumb colour (24.4  $\pm$  1.81). The darker crumb and crust colour can be associated with the lower 334 melting point of smaller sugar crystals which can caramelize quicker than larger crystals. The 335 darker crumb colour of SPR<sub>459-972 µm</sub> could be a reason why this sample was negatively 336 associated with colour liking as determined by sensory evaluation. 337

338

339 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<sub>200-5181 µm</sub> and LPR<sub>924-1877</sub> <sub>µm</sub> brownie samples had the lowest moisture content and were different (p<0.05) from

samples containing MPR<sub>627-1214 µm</sub> and SPR<sub>459-972 µm</sub>, but not significantly different from the MIX sample. Chocolate brownie samples containing SPR<sub>459-972 µm</sub> had the highest (p<0.05) moisture content (13.0 ± 0.84) compared to all other brownie samples, with the exception of samples containing MPR<sub>627-1214 µm</sub> which had the second highest moisture content (p<0.05).

350

#### 351 Conclusion

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

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374

# 375 **Conflicts of interest**

The authors declare that no conflicts of interests exist.

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Hedonic and sensory descriptors used in sensory evaluation questionnaires

	Ā	
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	$\mathcal{R}$	
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

			$\mathcal{R}$
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

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

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

e finer particle size

#### 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	Flavour	Texture	Colour	Overall	Crust	Hardness	Moisture	Sweet	Brownie	Off	Aftertaste
	Liking	Liking	Liking	Liking	acceptability	darkness			taste	Flavour	flavour	
Control <sub>200-5181 µm</sub>	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 <sub>924-1877 µm</sub>	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 <sub>627-1214 µm</sub>	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 <sub>459-972 µm</sub>	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\*= $P \le 0.05$ , \*\*=  $P \le 0.01$ , \*\*\*=  $P \le 0.001$ . – indicates whether the correlation is negatively correlated. LPR; large particle replacement MPR; medium particle replacement and SPR; small particle replacement

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

				TDA		*
				IPA		
Sample	Hardness (N)	Adhesiveness	Springiness	Cohesiveness	Chewiness	Resilience (n/a)
-			(mm)	(n/a)	(N-mm)	
Control <sub>200-5181µm</sub>	$54.5 \pm 1.45^{b}$	$-0.0 \pm 0.73^{a}$	$0.5\pm0.74^{\rm a}$	$0.3\pm0.05^{\rm a}$	$9.1 \pm 0.80^{ m d}$	$0.1\pm0.01^{a}$
LPR <sub>924-1877µm</sub>	$69.2 \pm 2.12^{\circ}$	$-0.0 \pm 0.59^{a}$	$0.5 \pm 0.06^{a}$	$0.3 \pm 0.04^{a}$	$9.8\pm0.12^{ m d}$	$0.1 \pm 0.01^{a}$
$MPR_{627\text{-}1214\mu\text{m}}$	$52.0 \pm 2.75^{b}$	-0.0 $\pm$ 0.01 <sup>a</sup>	$0.3 \pm 0.04^{a}$	$0.3 \pm 0.03^{a}$	$5.0\pm0.50^{ m b}$	$0.1 \pm 0.01^{a}$
$SPR_{459-972\mu m}$	$45.1 \pm 2.42^{a}$	$-1.0 \pm 1.17^{a}$	$0.3 \pm 0.07^{a}$	$0.3\pm 0.05^a$	$4.2\pm0.23^{\mathrm{a}}$	$0.1\pm0.02^{\mathrm{a}}$
MIX	$53.4 \pm 1.72^{b}$	$-0.0\pm0.81$ <sup>a</sup>	$0.3 \pm 0.04^{a}$	$0.3\pm0.05^{\rm a}$	$6.2 \pm 0.13^{\circ}$	$0.1\pm0.02^{a}$

<sup>abc</sup> mean values ( $\pm$  standard deviation) in the same row bearing different superscripts are significantly different, P < 0.05.

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

Sample	Colour (L*)	$\sim$
	Crust	Crumb
Control <sub>200-5181µm</sub>	$39.8 \pm 1.85^{a}$	$29.0\pm1.51^{\rm a}$
LPR <sub>924-1877µm</sub>	$34.2 \pm 0.93^{b}$	$27.1 \pm 1.82^{ab}$
MPR <sub>627-1214µm</sub>	$33.2 \pm 1.22^{b}$	$25.1 \pm 0.80^{b}$
SPR <sub>459-972µm</sub>	$33.1 \pm 1.95^{b}$	$24.4\pm1.81^{b}$
MIX	$32.6 \pm 0.80^{b}$	$25.4\pm1.73^{\rm b}$

<sup>abc</sup> mean values ( $\pm$  standard deviation) in the same row bearing different superscripts are significantly different, P < 0.05.

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

Sample	% Moisture	%Fat
Control <sub>200-5181µm</sub>	$9.2\pm0.80^{\mathrm{a}}$	$26.3 \pm 1.87^{a}$
LPR <sub>924-1877µm</sub>	$9.9 \pm 1.08^{a}$	$27.6 \pm 1.68^{a}$
MPR <sub>627-1214µm</sub>	$11.8 \pm 1.03^{bc}$	$26.6 \pm 1.95^{\rm a}$
SPR <sub>459-972µm</sub>	$13.0 \pm 0.84^{\circ}$	$26.9\pm1.28^{\rm a}$
MIX	$10.3 \pm 0.70^{ab}$	$26.2\pm0.77^{\rm a}$

<sup>abc</sup> mean values ( $\pm$  standard deviation) in the same row bearing different superscripts are significantly different, P < 0.05

rent superscripts are sign.



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



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

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



**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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