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Yaqin Wang: Methodology, Investigation, Formal analysis, Writing – original draft.

Antonio Trani: Investigation.

Antti Knaapila: Methodology, Supervision, Validation.

Sami Hietala: Supervision, Validation.

Rossana Coda: Supervision.

Kati Katina: Methodology, Supervision.

Ndegwa Henry Maina: Supervision, Funding acquisition.

To be more specific, Yaqin Wang planned the work together with other authors and performed most of the experiments and prepared the manuscript. The sourdough and bread preparation and analysis were done by Yaqin and supervised by Rossana Coda, Kati Katina, and Ndegwa Maina in the University of Helsinki (Finland). The sensory evaluations were conducted by Yaqin and supervised by Antti Knaapila in the University of Helsinki. The polyphenolic compound analysis was done by Antonio Trani in the International Center for Advanced Mediterranean Agronomic Studies of Bari (Italy). The rheological characterisation of dextran aqueous solutions was performed by Yaqin and supervised by Sami Hietala in the University of Helsinki.

With dextran concentration $> c^*$

Bread breakdown on chewing
releases flavour molecules

Control

The effect of *in situ* produced dextran on flavour and texture perception of wholegrain sorghum bread

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Abbreviations:

C*, critical overlap concentration; CMC, carboxymethyl cellulose; CSSB, control sorghum sourdough bread; CSSD, control sorghum sourdough; CSWB, control sorghum-wheat bread; CWB, control wheat bread; DSSB, dextran-enriched sorghum sourdough bread; DSSD, dextran-enriched sorghum sourdough; GAE, gallic acid equivalent; GEM, general edible medium; LAB, lactic acid bacteria; M_v , viscosity average molecular weight; TPA, texture profile analysis; TTA, total titratable acidity; UHPLC, ultra high performance liquid chromatography; WG, wholegrain.

Abstract

This study evaluated the effects of dextran produced *in situ* by *Weissella confusa* A16 on the flavour and texture perception of wholegrain sorghum bread containing 50% of wheat flour. Descriptive sensory profiling revealed that sorghum sourdough bread containing *in situ* produced dextran (0.56% bread weight) was more elastic, foldable, moist, cohesive, soft, flexible, and smooth compared to control sorghum sourdough or native sorghum breads ($p < 0.05$), consistently with the instrumental data. Fermentation significantly increased off-notes such as sour flavour, bitter taste, and aftertaste probably due to the acids production and release of small molecular weight polyphenol compounds (e.g. caffeic acid). The dextran-enriched sorghum sourdough bread, however, showed a significant reduction of flavour intensity perception compared to the control sorghum sourdough bread, despite similar levels of acidification and polyphenols. A trained sensory panel ($n = 17$) was employed to study specifically the masking effect of dextran on sour and bitter notes in model bread systems containing fixed amounts of tastants (acids or caffeine) and varying concentrations of dextran (0.12–0.96% bread weight) above and below the experimentally determined critical overlap concentration C^* of dextran (0.43%, w/w). Breads containing higher levels of dextran exhibited a more cohesive, springy, and soft texture with significantly less perceived sourness and bitterness intensity. The flavour suppressing seemed to occur at above the critical overlap concentration but remained unaffected at lower concentrations. Dextran produced by *W. confusa* A16 is a promising texture-enhancing and flavour-masking agent in wholegrain products, which may lead to future innovations in this area.

Keywords

Dextran; Sorghum; Wholegrain; Fermentation; Flavour; Phenolic compounds

1. Introduction

Wholegrain (WG) products that are rich in dietary fiber and other bioactive components have been increasingly considered as a preferred option than refined products (Seal, Jones, & Whitney, 2006). Researches frequently report that consumption of cereal products containing WG may be associated with reduced risk of major chronic diseases such as cardiovascular disease, obesity and type II diabetes (Ye, Chacko, Chou, Kugizaki, & Liu, 2012). Sorghum (*Sorghum bicolor* L. Moench) is one of the world's most important and oldest known crops, which is commonly consumed as wholegrain (Taylor, Schober, & Bean, 2006). Aside from its nutrition and health benefits, utilisation of sorghum in human diet would also contribute to global food security and sustainable agricultural production. However, even though its significance as human food has been well known/recognized, sorghum remains underutilized in the food production industry. The main limiting factors and barriers are the flavour and texture characteristics of WG sorghum products.

Incorporation of whole sorghum flour above 16% in wheat bread resulted in darker colour, intense bitter taste, lower specific volume and harder crumb, leading to negative consumer responses (Mariera, Owuoché, & Cheserek, 2017). Bitterness is a common sensory concern of wholegrain foods, which is often recognized as off-flavour (Drewnowski & Gomez-Carneros, 2000). Phenolic compounds, present in the outer layer (pericarp and testa) of the grain, are the most important contributor of bitter taste (Kobue-Lekalake, Taylor, & De Kock, 2007). However, phenolic compounds possess high antioxidant activities and are considered beneficial to human health (Awika & Rooney, 2004). Whole sorghum flour also has lower breadmaking quality than wheat flour due to the different technological functionality and types of proteins and the presence of bran fractions. High levels of substitution of wheat with whole sorghum flour induces "dilution" of gluten network and disruption of dough foam structure (Ferrero, 2017). This further results in decreased dough viscoelasticity and gas retention ability and consequently smaller volume and firmer crumb of the final bread.

Sourdough fermentation has been one of the most important bioprocessing technique to improve the nutritional value, texture, microbial safety, and shelf-life of WG and refined baked products (Gobbetti, Rizzello, Di Cagno, & De Angelis, 2014; Katina, Heiniö, Autio, & Poutanen, 2006). The positive effects are mainly attributable to the changes in pH and enzymatic activities, which affect the dough structural and nutritional components. On the other hand, the acidification and other biochemical changes during microbial fermentation might generate or enhance undesired flavours in subsequent bread, such as intense sour flavour and bitter taste (Katina, Poutanen, & Karin, 2004; Meignen et al., 2001).

With tailored fermentation, targeted functional metabolites such as texture enhancing dextran can be produced. Dextran is a natural hydrocolloid produced extracellularly by lactic acid bacteria (LAB) using sucrose as the substrate (Monsan et al., 2001). High molecular weight linear dextran is the most important in bakery formulations (Lacaze, Wick, & Cappelle, 2007; Rühmkorf et al., 2012). By binding high amount of water, these dextran are able to improve dough rheological properties, such as dough strength and water absorption capacity, resulting in increased loaf volume, moist mouthfeel, and crumb softness (Wang et al., 2019; Wang et al., 2018; Zannini, Waters, & Arendt, 2014). Dextran also act as staling inhibitors, which decrease amylopectin recrystallization and moisture loss during bread storage, leading to prolonged shelf life (Wang et al., 2019; Zhang et al., 2018). Such properties, along with their production *in situ*, enable the replacement of commercial hydrocolloids and circumvents the labelling requirement, conferring a “clean label” status.

Furthermore, the intensive texture modifications induced by dextran might also alter the flavour of the final breads. It is generally understood that the addition of hydrocolloids leads to a decrease in flavour perception. Texture-flavour interactions have been the subject of numerous studies in the last decades (Baines & Morris, 1987; Cook, Hollowood, Linforth, & Taylor, 2002; Costell, Peyrolón, & Duran, 2000; Koliandris, Lee, Ferry, Hill, & Mitchell, 2008), which were carried out

by addition of hydrocolloids (texturing agents) to model or food systems containing taste/aroma compounds. Two classes of systems were studied: a thickened solution or a gel system. For thickened solutions, the masking effect of a hydrocolloid is a modification of the viscosity above its critical overlap concentration (C^*) which coincides with a significant decrease in taste/aroma perception (Baines & Morris, 1987; Pangborn, Trabue, & Szaesniak, 1973). Additionally, the decrease is dependent on the hydrocolloid type and the nature of the taste or aroma compounds. For instance, Mälkki et al. (1993) compared different polymer solutions (oat gum/bran, CMC, and guar gum) presenting similar viscosity and showed that guar had the greatest suppressing effect on sweetness. Troszyńska et al. (2007) studied four hydrocolloids and revealed that CMC above C^* was the best masker for bitterness and astringency. Moreover, Pangborn et al. (1973) found sour and sweet taste intensities were markedly reduced in xanthan solution above C^* , whereas saltiness was not changed. In respect of hydrocolloid gels, an inverse relationship between strain at break (or gel strength) and flavour intensity perception was investigated (Koliandris et al., 2008; Lundgren et al., 1986). Nevertheless, rarely have the impact of hydrocolloid addition on flavour perception of baked goods been studied.

This work aimed to study the impact of *in situ* produced dextran by *Weissella confusa* A16 on flavour and texture perception of WG sorghum-wheat (ratio 50:50) bread: (1) to profile and quantify the flavour and texture attributes of the bread, by a trained sensory panel; (2) to analyze non-volatile flavour compounds (e.g. sugars, acids, and phenolic compounds) and instrumental texture parameters of the bread, and relate them to the sensory profiles; (3) to further investigate the hypothesis that dextran presence could mask the negative flavour notes of processed wholegrain products. A strategy of using a specific sensory technique, magnitude estimation, was adopted to follow the changes in taste perception in model bread systems containing dextran of varying concentrations, straddling the C^* transition. In this way, two taste modalities were studied, sourness and bitterness, by addition of organic acids (lactic and acetic acids) or caffeine in the breads.

2. Materials and Methods

2.1 Materials

The ingredients common to all breads prepared were wheat flour (Helsingin Mylly Oy, Finland; protein 12.5%, fat 2.1%, moisture 13.4%), red sorghum grains (purchased from the local market in Burkina Faso), fresh yeast (Suomen Hiiva Oy, Finland), sucrose (Rainbow, Finland), salt (Meira Oy, Finland), and oil (Bunge Oy, Finland). The whole sorghum flour was obtained by cleaning and milling the sorghum grains with hulls on a laboratory mill (Retsch GmbH, Germany) with a 0.5 mm sieve at a speed of 15,000 g (Wang et al., 2019). The flour was stored at 4°C until use (within 1 month). Catechin (99%), caffeic acid (>99%), quercetin (>99%), luteolin (>97%), apigenin (>99%), citric acid (≥99.5%), caffeine, lactic acid (≥85%), acetic acid (≥99.85%) and vinegar (10% acetic acid) were purchased from Fluka (Buchs, Switzerland), Sigma-Aldrich, and the local market. All other chemicals were of analytical or HPLC grade.

2.2 Strain Growth and Preparation of Sorghum Sourdough

Weissella confusa A16 previously isolated from Massa (a fried sourdough in Burkina Faso) and available at the Department of Food and Nutrition (University of Helsinki) was employed in this experiment. The strain was selected due to its ability to form high molecular weight dextran composed of 97% α -(1→6) linear linkages and 3% α -(1→6) branch linkages (Wang et al., 2019). The strain was maintained at –80°C in MRS broth supplemented with glycerol (20%, Sigma-Aldrich).

For sourdough preparation, the starter was first propagated in MRS broth (Oxoid, Basingstoke, UK) anaerobically at 30°C for 24 h, and then sub-cultured in general edible medium (GEM) as described in Wang et al. (2018) at 30°C for 24 h. Microbial cells were obtained subsequently from the overnight incubated GEM through centrifugation (15,000 g x 15 min), washed once with sterile sodium phosphate saline buffer (Sigma-Aldrich) and resuspended in distilled water. Milled sorghum

flour, cell culture, and distilled water were mixed to obtain an initial inoculum size of 10^6 cfu/g dough and a dough yield of 240.

Two types of sorghum sourdoughs were prepared as previously described (Table S1 in Supplementary Material) (Wang et al., 2018). Dextran-enriched sorghum sourdough (DSSD) was prepared by replacing 10% (w/w) of the sorghum flour with sucrose to ensure dextran production. Control sorghum sourdough (CSSD) was prepared without sucrose addition. Fermentations were carried out at 25°C for 24 h. LAB cell counts, sourdough viscosity, pH and total titratable acidity (TTA) were determined at 0 h and after 24 h of fermentation (Wang et al., 2018).

2.3 Determination of Sugars and Organic acids

Sugars and dextran in freeze-dried sourdough samples were quantified using a high performance anion exchange chromatography with pulse amperometric detection (HPAEC-PAD) system as previously described (Katina et al., 2009). To extract organic acids, one gram of freeze-dried sample was mixed with 4 mL of Tris-HCl Buffer (50mM, pH 8.8) with intensive shaking at 4°C for 1 h. After centrifugation (15,000 g x 15 min), an equal volume of perchloric acid (5%) was added to the supernatant and allowed to settle overnight at 4°C. The proteins and other polar precipitates were removed by centrifugation and the supernatants were filtered via 0.45 µm filters. The filtrate was injected to high performance liquid chromatography (HPLC) and analyzed according to Weiss et al. (1993). Organic acids were separated by an Agilent Hi-Plex H column (Agilent, CA, USA; 300 × 6.5 mm) and the detection was performed by a dual detector system, a refractive index detector (HP 1047A, HP, USA) and an ultraviolet (UV) detector (Waters 717) at 210 nm. The column was run at 40°C using sulfuric acid (10 mM) as the mobile phase with a flow rate of 0.5 mL/min. The sample volume injected was 20 µL using an autosampler (Waters 717 plus). Lactic acid (Sigma-Aldrich) and acetic acid (Merck) were used as standards for quantification.

2.4 Determination of Polyphenolic Compounds

172 Polyphenolic compounds of the native sorghum flour and lyophilized sorghum sourdoughs were
173 analyzed using ultra high performance liquid chromatography coupled with photodiode array and
174 mass spectrometer in series connected detectors (UHPLC-PDA-MS). Five grams of powdered
175 samples were weighed in 15 mL centrifuge tubes and mixed with 10 mL of methanol:water:formic
176 acid (80:19.9:0.1). The suspensions were shaken for 1 h using an orbital shaker, sonicated for 15
177 min (Sonorex RK 510 H, US nominal power 160W, Bandelin, Germany) and stored at 8°C
178 overnight to precipitate proteins and polysaccharides. After centrifugation (8000 g x 20 min, 8°C),
179 the clear supernatant was filtered using 0.2 µm regenerated cellulose filters and 5 µL of it was
180 injected into the UHPLC system. The analysis was performed using a Dionex Ultimate 3000 RS
181 system (composed by LPG-3400 RS quaternary pump, WPS-3000 TRS autosampler, TCC-3000
182 RS column oven and PDA), coupled by a HESI-II probe with the LTQ Velos Pro ion trap mass
183 spectrometer (Thermo Fischer Scientific, Rodano, MI, Italy). The analytical separation of
184 compounds was performed on the Hipersyl Gold aQ C₁₈ column, 1.9 µm particle size, i.d. 2.1 mm
185 100 mm length (Thermo Fischer) maintained at 30°C. A binary mobile phase was used (A: 0.1%
186 formic acid in water and; B: 0.1% formic acid in acetonitrile) at a constant flow rate of 0.3 mL/min.
187 The gradient program of solvent A was as follows: 0–1 min isocratic 93%; 1–20 min decreased to
188 40%; 20–25 min isocratic at 40%; then equilibration at the initial conditions for 10 min. The light
189 absorbance was acquired from 220 to 600 nm. The MS conditions were: capillary temperature
190 330°C; source heater temperature 280°C; nebulizer gas N₂; sheath gas flow 33 psi; auxiliary gas
191 flow 5 arbitrary units; capillary voltage -2.8 kV, S-Lens RF Level 60%. Data were acquired in
192 negative ionization mode using a data-dependent method. The data-dependent settings were: full
193 scan from 140 to 650 m/z, activation level 500 counts, isolation width 2 Da, default charge state 1,
194 CID energy 35. All data were acquired and processed using Xcalibur v.2 (Thermo Fischer
195 Scientific). The identification of compounds was achieved by comparing λ_{max} , [M-H]⁻ and MS/MS
196 fragmentation patterns with literature data (Kang, Price, Ashton, Tapsell, & Johnson, 2016). The

following compounds were identified both using literature data and external standards injection: catechin, caffeic acid, quercetin, luteolin, apigenin. The area percentage of each peak obtained by integrating the 280 nm chromatogram was used to calculate semi-quantitative data for each identified compound. The total amount of polyphenols of the sorghum extracts was determined with Folin Ciocalteu assay accordingly to Wrolstad et al. (2005). The concentration of each identified compound was calculated by multiplying the area percentage with the total polyphenol content and expressed as $\mu\text{g/g}$ of gallic acid equivalent (GAE).

2.5 Bread Making

Four groups of bread were prepared: control wheat bread (CWB), control sorghum-wheat bread (CSWB), control sorghum sourdough bread (CSSB) and dextran-enriched sorghum sourdough bread (DSSB) (Table S1 in Supplementary Material). One additional control bread was prepared using the CSWB recipe with added glucose (0.77% dough weight) and fructose (1.16%) to determine the impact of free sugar accumulation during dextran synthesis on bread textural properties. The sugar content was calculated based on glucose and fructose level detected after 24 h fermentation of dextran-enriched sorghum sourdough. All sorghum containing breads were formulated using wholegrain sorghum and wheat flour at a ratio of 50:50. Sorghum sourdoughs were applied in baking at 59% of the dough weight. The substitution level (50%) of wholegrain sorghum flour was determined to provide 28 g of whole grains per 100 g of bread. The Dietary Guidelines for Americans (DGA) announced that a wholegrain food must provide at least 8 g of whole grains per 30 g serving (27 g/100 g) (Ferruzzi et al., 2014). In Denmark (DTU 2008) and Sweden (SNF 2007), a food to be labelled as wholegrain must contain at least 50% (dry matter) of wholegrain ingredients.

The water absorption of wheat flour at 500 FU (60.3%) was measured using a Brabender Farinograph (Brabender GmbH & Co.KG, Germany) equipped with a 300 g mixing bowl, according to AACC method 54-21 (AACC 2000). The optimal water addition of sorghum

containing breads (60%) was determined by mixing trials in a Diosna spiral mixer (Dierks & Söhne GmbH, Germany) for 7 min, followed by subjective assessment. Baking tests were performed following a small-scale straight-dough baking process as previously described (Wang et al., 2018) with slight modifications. Briefly, ingredients were kneaded in the Diosna mixer for 3 min at slow speed and 4 min at high speed. Dough temperature after mixing was $26 \pm 1^\circ\text{C}$. The dough was rested for 15 min in a fermentation cabinet (Lillnord, Odder, Denmark) at 35°C with relative humidity 75%, scaled into 250 g portions and molded manually. Afterwards, the dough was placed in aluminium moulds and proofed for 45 min in the fermentation cabinet. The proven doughs were baked at 200°C for 15 min with 15 s steam injected at the beginning. The breads were depanned and allowed to cool for 1 h at room temperature and then stored in plastic bags. Texture Profile Analysis (TPA) of bread crumbs was performed using a texture analyzer (TA, TA-XT2i, Stable Micro Systems Ltd., UK) with a 36-mm diameter aluminum probe and a 5 kg load cell on days 1 and 4 of storage (Wang et al., 2019). The baking loss, specific volume, staling rate (during 4 days of storage), moisture content (on day 1), pH and TTA, residual sugars and acids of the breads were determined as described by Wang et al. (2019).

2.6 Descriptive Sensory Analysis

2.6.1 Panel Selection

The panelists ($n = 17$) were recruited from staff and graduate students at University of Helsinki: 9 women and 8 men between 20 and 50 years old. Panelists were selected based on their sensory acuity, for instance, their ability to correctly identify and rank the taste of aqueous solutions containing tastants at two concentrations (w/v): citric acid (0.2%, 0.3%) and caffeine (0.05%, 0.07%). Ethical principles applied in sensory research at the department were evaluated and approved by the University of Helsinki Ethical review board in the humanities and social and behavioural sciences (Statement 46/2016). Sensory profiling of the bread samples was performed using the generic descriptive analysis method (Lawless & Heymann, 2010). The evaluation was

carried out at the sensory laboratory of the University of Helsinki with individual booths and following standard sensory practices (Lawless & Heymann, 2010).

2.6.2 Samples

Breads were baked one day before the training or evaluation as described in section 2.5 and stored at room temperature overnight. Prior to the assessment, samples were sliced into 1 cm thickness (with crust and crumb) from the middle of the bread and presented in lidded plastic boxes (minimize moisture loss) marked with random 3-digit codes. Water was provided for palate rinsing.

2.6.3 Panel Training

The panelists had undergone three 2-h sessions of specialized training in analysis of flavour and texture of breads. In the first session, bread samples (CWB, CSWB, CSSB, and DSSB) were presented to panelists to generate the list of descriptors. A specific lexicon of sensory attributes for sandwich breads from the previously published booklet (U.S. Wheat Associates & Lesaffre, 2017) was provided to the panelists. Assessors were first asked to examine the samples individually with respect to the preliminary attributes and discussion with the panel group followed. The suitable descriptors (discriminate among the samples) were selected by consensus, including 8 texture and mouthfeel attributes and 8 flavour attributes (Table 1). In the following session, the reference standards, the methodology of evaluation and evaluating sequence were developed (Table 1). The references selected for inclusion in the subsequent evaluation were: a) the commercial rye (100%) bread named “Uotilan Maalaisruislimppu”, which was characterized by hard/rigid/coarse crumb and strong sour taste; b) caffeine solution (0.05%) with strong bitter taste; c) roasted wheat bread (10% sucrose addition), which had strong roasted flavour (crust) and sweet taste (crumb), and d) regular wheat bread. In the final session, panelists were asked to rate the attributes on continuous visual analogue scales (0–10) with endpoints anchored with verbal definitions (Table 1).

2.6.4 Evaluation Procedures

Two identical evaluations were performed on two independent days (replicates) with two separate sessions per day: one for evaluation of flavour and the other for evaluation of texture. Flavour attributes were evaluated in the morning session where the three categories of sorghum-containing breads (CSWB, CSSB, and DSSB) were examined. CWB was excluded in the flavour session since wheat and sorghum products exhibit different taste profiles and are therefore not comparable. The commercial rye bread, roasted bread, and caffeine solution were served as reference standards. Texture and mouthfeel attributes were evaluated in the afternoon session where the four types of breads (CWB, CSWB, CSSB, and DSSB) were assessed. The commercial rye bread and regular wheat bread were served as standards. The presenting order of the samples was randomized across the panelists and the evaluation sessions. The Fizz Acquisition 2.51 software (Biosystemes, Courternon, France) was used to collect the ratings.

2.7 Preparation of Food Grade Dextran

Dextran was produced by cultivating *W. confusa* A16 in GEM supplemented with 5% sucrose and incubated in anaerobiosis conditions at 30°C for 7 d. Dextran was isolated and purified from the GEM medium according to a previously established method with slight modification (Maina, Tenkanen, Maaheimo, Juvonen, & Virkki, 2008). The GEM medium was diluted 1:2 in sterile phosphate saline buffer (PBS, 0.01 M, pH 7.4, Sigma). The suspensions were shaken at a speed of 125 rpm for 10 min at 4°C. Afterwards, the suspensions were centrifuged at 15,000 g for 40 min at 4°C using a Beckman Avanti J-25I centrifuge (USA). The supernatants were collected by decanting and the sediments were discarded. Dextran was recovered from the cell-free supernatant by cold ethanol (99.9%) precipitation method. Three volumes of ethanol (4°C) were added to the supernatant and upon steadily stirring dextran was precipitated out of the solution. The dextran precipitate was added to Milli-Q water with constant heating and stirring at 60°C until completely dissolved. Dextran was re-precipitated and re-dissolved in Milli-Q water as mentioned above. This recovery step was repeated four times to remove the impurities and the final dextran aqueous

solution was freeze-dried. The purity of the isolated dextran was determined by calculating the ratio between the released glucose amount after acid hydrolysis (10 mg dextran in 2 mL 1 M sulfuric acid hydrolyzed at 100°C for 2 h) and the initial dextran content by HPAEC-PAD.

2.8 Rheological Characterisation of Dextran Aqueous Solutions

Dextran aqueous solutions were prepared at concentrations of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.5 and 2.0 g/100g. Samples were prepared by weighing the appropriate amount of Milli-Q water into a beaker and heated at 60°C with magnetic stirring. The freeze-dried dextran was carefully added to the side of the vortex with constant stirring at 200 rpm. The solution was heated at 60°C for 2 h and 40°C overnight and allowed to cool down, with continual stirring, at 25°C to ensure adequate hydration of the polymer chains. The flow characteristics of each solution were determined using a DHR2 rheometer (TA Instruments) with a Peltier heated double wall concentric cylinders geometry (inside cup diameter 40 mm, outside cup diameter 44.68 mm, inner cylinder height 55 mm, immersed height 59.5 mm, operating gap 0.5 mm) at 25°C, for a range of shear rates (10-500 s⁻¹). The homogenous dextran samples (6.8 mL) were loaded to the lower cup by pipetting. For each sample, the zero shear viscosity [η_0] was extrapolated from the data and used to produce a Huggins-Kraemer plot from which the intrinsic viscosity [η] was calculated. The viscosity average molecular weight (M_v) was calculated by Mark-Houwink-Sakurada equation: $[\eta] = K(M_v)^a$, using $K = 0.0901$ mL/g and $a = 0.5$ for aqueous dextran solutions (Kasaai, 2012). The value of the overlap concentration C^* was estimated from a log-log plot of concentration versus the specific viscosity [η_{sp}].

2.9 Relationship between Dextran Concentration and Sour/Bitter Taste Perception in Bread

2.9.1 Panel Training

A group of 17 assessors (14 from the previous panel) were recruited using the same inclusion criteria as in the descriptive analysis and based on their ability to perform magnitude estimation.

Panelists were trained over two 1-h sessions to understand the scaling instructions and develop their quantitative skills. During the training period, the panel received three sets of bitter taste breads prepared with added caffeine at concentrations of 0.2, 0.3, and 0.5% (flour weight), followed by three sets of sour taste breads prepared with added lactic/acetic acid at levels of 0.3/0.04, 0.45/0.06, 0.6/0.08% (f.w.) (Table S2 in Supplementary Material). The most suitable sour and bitter tastant concentrations were selected by consensus to be moderately strong in bread and can be recognized as the predominant taste, namely the bitter taste bread with 0.2% caffeine and sour taste bread with 0.6/0.08% lactic/acetic acid. Furthermore, the selected sour taste bread showed comparable amounts of lactic and acetic acid as measured in the above sorghum sourdough breads.

2.9.2 Preparation of Model Bread Samples

Six types of model wheat breads were prepared with dextran added at a concentration series of 0, 0.2, 0.4, 0.5, 0.6, 0.9, and 1.5% f.w. (accordingly 0, 0.12, 0.26, 0.38, 0.57, and 0.96% bread weight) (formulations and calculations were presented in Table S3 in Supplementary Material). The concentrations were selected below and above the C* and including the dextran contents presented in CSSB and DSSB. All model bread samples incorporated a fixed concentration of tastants, 0.2% (f.w.) caffeine or 0.6/0.08% lactic/acetic acid. Dextran was added by solubilization in distilled water as depicted in section 2.11. The breads were baked using a straight-dough baking process prior to the panel evaluations on the following day as explained in section 2.5. Samples were served as slices (1 cm thick without crust) in coded plastic cups with three-digit numbers in a randomized presenting sequence to reduce sample order effects. Loaf specific volume and TPA analysis of bread crumbs were performed on the same day of sensory evaluation.

2.9.3 Magnitude estimation test

The trained assessors (2.9.1) used magnitude estimation with a controlled modulus to rate the intensity of sourness and bitterness taste for each bread sample (Lawless & Heymann, 2010). The

modulus, or standard stimulus, was given to the participants as a reference. In this study, the modulus was “sour/bitter taste bread” with 0.26% (bread weight) dextran (chosen to be near the middle of the concentration range), which was pre-assigned a fixed score of 100. All subsequent samples were rated in correlation with this standard, which conformed to a ratio principle. As such, a sample perceived to be twice as sour or bitter as the standard would be given a value of 200, whereas a sample perceived to be half as sour or bitter would be rated 50. Sour attribute and bitter attribute were evaluated on two separate days, one for each day. On each assessment day, the six model bread samples as a whole sample set were examined in triplicate in 3 different sessions to prevent sensory fatigue. Each assessor first tasted the pre-scored reference bread followed by the six further samples. The reference bread was also included in the samples as a “blind” control. Evaluators were instructed to place the crumb into the mouth with chewing and holding for at least 5 s before swallowing the sample. Before evaluating a new sample, the panelists consumed a piece of unflavored corn snack as palate cleanser followed by rinsing their mouth with water.

2.10 Statistical Analysis

All chemical and instrumental measurements were taken in triplicate and results represent the average value. The data obtained were analysed by analysis of variance (ANOVA) using SPSS Statistics 24.0 program (SPSS Inc., Chicago, IL, USA). Differences between samples were tested for significance by Tukey’s HSD ($\alpha = 0.05$) multiple comparison test. Sensory data were subjected to normality test which showed normal distribution. A three-way ANOVA was applied to study the significant levels of the main effects (sample, panelist, and session) and interaction effects (panelist by sample, panelist by session, and sample by session). A one-way ANOVA was applied to identify significant difference among samples. Finally, the correlation between sensory texture attributes and instrumental texture parameters was determined using Pearson's Correlation.

3. Results

3.1 Cell Density, pH and TTA of Sourdoughs and Breads

The initial cell density of presumptive lactic acid bacteria was ca. 6.2 log cfu/g (Table 2). After 24 h of fermentation, the cell density reached approximately 9.3 log cfu/g in sorghum sourdoughs. The pH values decreased from 6.2 to the final pH of 4.1 in both CSSD and DSSD. TTA value of CSSD (8.1 mL) was slightly higher compared to DSSD (7.4 mL) at the end of fermentation. The addition of sourdoughs in bread making resulted in a significant decrease in pH and a concomitant increase of TTA compared to control breads. The level of TTA measured in the breads increased in the following order: CWB (3.1 mL) < CSWB (3.4 mL) < DSSB (6.5 mL) < CSSB (6.8 mL).

3.2 Acids, Sugars, and Dextran in Sourdoughs and Breads and Sourdough Viscosity

The sugar and acid content of sourdoughs and breads are summarized in Table 3. Similar amounts of lactic and acetic acids were formed in DSSD and CSSD. Correspondingly, the organic acid composition of their subsequent sourdough breads were identical, which were twice as much as the control sorghum bread. In DSSD, the added and flour endogenous sucrose (10% and 1.3%, respectively) was completely consumed at the end of fermentation, while a substantial amount of glucose (3.1%) and fructose (4.7%) accumulated. In CSSD, only a trace amount of fructose was detected. Likewise, breads prepared with DSSD exhibited significantly higher amounts of free glucose and fructose than breads prepared with CSSD and control sorghum breads. The amount of free maltose in all sorghum breads was low ($\leq 0.6\%$).

W. confusa A16 formed minor amounts of water-soluble oligosaccharides in sorghum sourdoughs (Figure S1 in Supplementary Material). The sucrose was mainly utilized for dextran synthesis, which resulted in a high yield of 2% (dry weight) in DSSD (Table 3). However, without sucrose supplementation, only 0.5% of dextran was produced in CSSD. The apparent viscosity value measured at a shear rate of 123 s^{-1} was significantly higher in DSSD compared to the CSSD and non-fermented sorghum dough (0 h).

3.3 Phenolic Compounds

Fig.2 shows an example of the chromatograms obtained at 280 nm of the methanol-acid extracts of native and fermented wholegrain sorghum. The identification and quantification of the phenolic compounds was carried out by LC–MS/MS fragmentation data and by comparison with published literature. Mass spectra, retention times, and UV absorbance of the identified components are presented in Table 4. Sixty compounds were detected in the sorghum extracts while forty-four of them were tentatively identified, including free phenolic acids, flavonoids, phenylpropane glycerides, and phenolamides. Additionally, a hydroxyl fatty acid (trihydroxy-octadecenoic acid) was also detected. The other compounds remain to be identified since they exhibited fragmentation patterns that did not match with any known substance in the literature. The concentration of the identified phenolic compounds obtained from the semi-quantitative method is reported in Table 5. In some cases, the co-elution of two or more compounds made it difficult to quantify the single component.

The results indicated that, apart from the distributed concentrations, the types (or variety) of the polyphenolic compounds of the native and fermented sorghum were almost similar. The total polyphenol content was comparable in the native and fermented sorghum extracts ranging from 1329 to 1390 $\mu\text{g/g}$ GAE. In native wholegrain sorghum flour, the most abundant group was flavone and flavanone derivatives, followed by phenylpropane glycerides and flavan-3-ol derivatives. The major flavonol compounds were isorhamnetin hexoside, dihydroxyflavone, pentahydroxy flavone, flavonoid hexoside, and naringenin hexoside. The main compounds of phenylpropane glycerides were 1,3-O-dicaffeoyl glycerol isomer, 2-O-caffeoylglycerol isomer, and 1,3-O-feruloyl-caffeoylglycerol. In flavan-3-ol derivatives, methyl afzelechin and its isomer were detected in significant amounts.

Fermentation profoundly altered the amount of individual sorghum polyphenols. Caffeic acid content was mostly affected by fermentation, leading to an increase from 45.8 μg GAE/g in native

sorghum flour to 164 and 183 $\mu\text{g/g}$ in DSSD and CSSD, respectively. Tetrahydroxy flavone content increased two folds after fermentation, to the levels of 52.6 and 56.5 $\mu\text{g/g}$ in respective DSSD and CSSD. Procyanidin B was also found in higher amounts in fermented sorghum extracts. In contrast, phenylpropane glycerides showed significant reduction during fermentation, including 2-O-caffeoylglycerol isomer, 1,3-O-dicaffeoylglycerol isomer, 1,3-O-feruloyl-dihydrocaffeoylglycerol, and 1,3-O-coumaroyl-caffeoyl-glycerol isomer. Similarly, some flavonoids, such as dihydroxyflavone and methyl catechin, were significantly decreased in fermented samples.

3.4 Bread Volume and Texture Characterization

The effect of dextran formation and sourdough addition on bread textural parameters is summarized in Table 6. No significant differences were observed in baking loss (~11%) for all breads (results not shown). The loaf specific volume of control sorghum-wheat bread (CSWB) was 35% lower than control wheat bread (CWB). The utilisation of control sorghum sourdough resulted in a further decrease of specific volume by 7% compared to CSWB. The addition of glucose and fructose also resulted in reduced specific volume by 3% in comparison to CSWB (Supplementary Material Table S4). Only the addition of dextran-enriched sorghum sourdough increased significantly the specific volume by 14% compared to CSWB. A similar trend was observed in TPA parameters. The CSWB showed increased crumb hardness by more than 3-fold and significantly reduced crumb springiness and cohesiveness in comparison to CWB. The crumb firmness continued to increase in the control sorghum sourdough bread (CSSB) by 16% compared to CSWB. The addition of glucose and fructose also generated an increase of crumb hardness by 22% compared to CSWB (Supplementary Material Table S4). In contrast, the dextran-enriched sorghum sourdough bread (DSSB) exhibited a significant reduction of crumb hardness by 53% compared to CSWB and showed a more springy and cohesive texture. The differences measured in crumb hardness persisted during 4 days of storage. Additionally, the staling rate of DSSB was 40-49% slower than CSWB and CSSB, which was comparable to wheat control. Great variability was observed in crumb moisture content (Table

6). CWB showed the highest value (44.4%), followed by DSSB (43.6%) and CSSB (43.2%). The CSWB, however, presented the lowest value for moisture content (42.9%).

3.5 Sensory Profiles

The flavour and texture profiles of the breads are depicted in Fig.2. More detailed information can be found in Supplementary Material Table S5 online. Analysis of the main effects and interaction effects by three-way ANOVA indicated a good level of concordance within the panel on their evaluations and good repeatability across sessions. Regarding the eight texture attributes for which the panel found significant perceptible differences among samples, none of the two-way interactions (sample x session, sample x panelist, and session x panelist) was significant. Whereas for the flavour attributes, the assessors were found to have significant influence on the estimation of sour smell and sweet taste, indicating a lack of consonance among the panel members for these two descriptors.

Texture Profile

The DSSB deviated significantly from CSWB and CSSB regarding all evaluated texture and mouthfeel attributes ($p < 0.05$) (Fig. 2A). DSSB, however, was assessed similar in texture to 100% wheat bread. DSSB received markedly higher ratings for elasticity, foldability, moist mouthfeel, and cohesive texture, and significantly lower scores for resistance to pressure (hardness), resistance to deformation (rigidity), coarseness, and resilience in mouth (toughness). The CSWB and CSSB did not differ significantly from each other in any assessed texture attribute, except resistance to pressure.

Pearson's correlation coefficients between perceived texture attributes and instrumental data are presented in Table 7. Large positive or negative values indicate a strong association. Instrumental crumb hardness was positively linearly related with sensory resistance to pressure, resistance to deformation, and resilience in mouth ($r = 1$, $p < 0.01$). Instrumental crumb hardness also showed a high positive correlation with perceived crumb coarseness ($p < 0.01$) and negative correlation with

elastic texture, foldability, moist mouthfeel, and dough-like texture ($p < 0.05$). The instrumental moisture content was significantly positively correlated with perceived elastic texture, foldability, moist mouthfeel, and dough-like texture ($p < 0.05$). Instrumental springiness had a high negative correlation with sensory resistance to pressure, resistance to deformation, crumb coarseness, and resilience in mouth ($p < 0.05$). Instrumental cohesiveness exhibited a strong positive correlation with sensory elastic texture ($p < 0.05$). The specific volume of bread was highly correlated with foldability, crumb moist mouthfeel and dough-like texture ($p < 0.05$).

Flavour Profile

The flavour notes varied significantly among the three sorghum breads except one attribute: overall smell intensity (Fig. 2B). Addition of control sorghum sourdough (CSSB) increased significantly the ratings of sour smell, sour taste, bitter taste, and aftertaste compared to CSWB. On the contrary, the incorporation of dextran-enriched sorghum sourdough (DSSB) resulted in significantly lower ratings for sour smell and sour taste intensities than CSSB, reaching levels comparable to CSWB. It is noteworthy that DSSB showed nominally lowest intensities for bitter taste and aftertaste in all evaluated bread samples. Additionally, DSSB was perceived as more sweet and with higher roasted flavour than CSSB and CSWB.

3.6 Determination of C^* for Dextran

The monosaccharide composition analysis revealed that the purity of the isolated dextran, calculated as the ratio of released glucose to the extracted dextran, was 82.09%. The yield of dextran in the fermentation medium was 12.5 g/L. Rheological studies of the aqueous dextran solutions showed Newtonian behaviour at concentrations ranging from 0.1 to 2% (Figure S2 in Supplementary Material). In this concentration range, the viscosity was almost constant for the measured shear rate values ($10\text{--}500\text{ s}^{-1}$) and the viscosity value obtained at a shear rate of 100 s^{-1} was taken as the zero shear viscosity $[\eta_0]$ for each sample and compared to solvent viscosity giving the specific viscosity for each concentration. Fig. 3 shows the concentration dependence of specific

viscosity, η_{sp} , for the diluted dextran solutions. The double-logarithmic plot of η_{sp} versus concentration shows an abrupt change of slope from 0.92 to 3.12, corresponding to the onset of polymer intermolecular association (the critical overlap concentration C^*). Resultant value of C^* was 0.43% w/w. The intrinsic viscosity $[\eta]$, which is directly related to the effective hydrodynamic volume of the polymer coils, was calculated to be 123.6 mL/g resulting in viscosity average molecular weight of the isolated dextran 1.9×10^6 mol/g.

3.7 The Effect of Dextran Concentration on Perception of Taste Intensity

To investigate the possibility that the produced dextran was related to the suppressed sour flavour and bitter taste sensation in the assessed breads, a sensory scaling technique (i.e. magnitude estimation) and multiple concentrations of dextran were applied to follow the perceptual changes as a function of polymer concentration. Tables 8 and 9 summarize the textural properties and magnitude of sourness and bitterness taste perception of the model breads studied. Analysis of variance showed a significant difference between panelists for sour and bitter taste. Despite the use of a reference modulus and extensive training employed in this study, individual assessors use the scales differently to rate the flavour attributes. The results for taste intensity were thus averaged for the panel from triplicate sessions to illustrate the general trend in the sensory data. In general, perception of sourness intensity was almost unaffected by dextran concentration across the range 0.12 to 0.38% (bread weight) in the “lactic/acetic acid” breads, comparing to the control acidified bread without dextran. However, when the dextran concentration reached 0.57%, there was a sharp decline of flavour intensity by 22% in comparison to acidified control ($p < 0.05$). With further increasing dextran concentration to 0.96%, the perceived intensity of sourness was slightly decreased by ~3% but not significantly different from the bread containing 0.57% of dextran. Similarly, apparent reduction of bitterness perception was observed for “caffeine” breads supplemented with 0.57 and 0.96% of dextran, which was 28 and 30% less bitter than control

“caffeine” bread, respectively. Bread samples with lower dextran concentrations (0.12–0.38%) and the control displayed constant scores for bitterness intensity.

3.8 Relationships between Dextran Concentrations and Texture Characteristics

Dextran exhibited a trend towards a positive dose-response effect in bread textural parameters (Table 8-9). Generally, the addition of increased amounts of dextran resulted in a progressive increase of bread specific volume and cohesive structure, and at the same time decrease of crumb hardness, gumminess, and chewiness. The “lactic/acetic acid” breads containing dextran can be divided into two distinct groups according to the statistical relevance of their textural parameters: group 1 with dextran utilization dosage at 0.12, 0.26, and 0.38% (bread weight); and group 2 with dextran concentration at 0.57 and 0.96%. The two groups were significantly different to each other and to control acidified bread. Incorporation of dextran at a dosage level of 0.57 and 0.96% resulted in a comparable magnitude of modifications in bread textural properties, which improved significantly the loaf specific volume by ~29% and reduced the crumb hardness by ~53% compared to acidified control. Furthermore, the dextran functioned in the same manner in “caffeine” breads although a narrower set of different textures among the samples was observed than in “lactic/acetic acid” breads. Addition of dextran at concentrations of 0.57 and 0.96% resulted in breads with ~13% higher specific volume and ~39% less hardness than control “caffeine” bread. At lower dosage levels (0.26 and 0.38%), bread texture quality was also improved but to a significantly lower extent than the higher dosage. The addition of dextran at 0.12% did not affect any measured texture parameters.

4. Discussion

Improving sensory characteristics of cereal products containing wholegrain could contribute to healthier diets and food security. To date, numerous studies have reported the positive effect of *in situ* formed dextran on bread texture attributes (Galle et al., 2012; Katina et al., 2009; Wang et al., 2019), which constitute a “clean label” alternative to added hydrocolloids. Contrary to texture

modifications, the scientific literature concerning the impact of dextran on flavour perception of baked goods is very limited. The research on texture-flavour interactions has a long history, but has almost only concentrated on taste and aroma perception in hydrocolloid solutions or gels (Hollowood, Linforth, & Taylor, 2002; Koliandris et al., 2008). This study investigated for the first time the impact of dextran produced *in situ* on flavour and texture perception of wholegrain sorghum bread containing 50% of wheat flour. In particular, the effect of varying the dextran concentration on the magnitude of flavour perception in the model bread matrix was investigated.

The dextran produced by *W. confusa* A16 exhibited higher intrinsic viscosity and lower critical overlap concentration (the point that dextran transfer from a dilute solution to a semi-dilute) than dextrans synthesized from *W. cibaria* Sj 1b and *Leucnostoc pseudomesenteroides* DSM 20193 (Xu et al., 2018). The viscosity average molecular weight (2×10^6 mol/g) of the dextran measured with water-based system was smaller than its weight average molecular weight (3×10^6 mol/g) as determined in our previous study by high performance size exclusion chromatography (HPSEC) with DMSO-based solvent (Wang et al., 2019). This might be due to the different technique used and the different dissolution and aggregation capacities of high molecular weight dextrans in aqueous and DMSO-based eluents (Maina et al., 2014). The amount of dextran formed *in situ* was 2% (dry weight) in sorghum sourdough, corresponding to 0.56% (bread weight) in the subsequent bread. The dextran yield in this study was higher than what previously reported for sorghum fermentation by *W. cibaria* MG1 (Galle et al., 2012). In that case, isomaltooligosaccharide (IMO) formation competing with dextran formation was also observed. However, considering the huge diversity of sorghum quality and the use of a different starter, a real comparison is not possible.

Apart from the dextran yield, the impact of other metabolites (sugars, enzymes, and organic acids) formed by the bacteria during fermentation also deserves attention. Incorporation of substantial amount of sourdough results in high concentration of dextran in the final bread but also a significant amount of acids that might negatively affect the flavour and bread texture (Wang et al., 2018).

Theoretically, equal amounts (5.6% f.w.) of glucose and fructose were released from the added and endogenous sucrose in DSSD. The glucose was partially consumed (2.5% f.w.) by the bacteria for dextran synthesis and metabolism. In CSSD, the flour endogenous sucrose was used, resulting in a minor amount of dextran production and fructose accumulation. Most of the remnant sugars from sourdoughs were unused during yeast fermentation as confirmed by the higher levels of free sugars in the final bread. The organic acid formation in sourdough fermented by *W. confusa* A16 was not affected by sucrose addition, which is in agreement with previous studies (Wang et al., 2019).

A great variety of polyphenols have been identified in the sorghum extracts such as free phenolic acids, phenolic acid esters, flavonoid, phenylpropane glycerides, phenolamides, and hydroxy fatty acids, as reported in the literature (Kang et al., 2016). Although sourdough fermentation did not change the total polyphenol content, it caused significant changes in the single polyphenolic compounds concentrations. Caffeic acid was the most affected, which increased 4 fold after fermentation. This might be ascribed to the partial conversion of phenolic acid esters (e.g. 2-O-caffeoylglycerol isomer) to phenolic acids by acid hydrolysis or enzymatic activity, such as cereal endogenous or bacterial esterases (Svensson, Sekwati-Monang, Lutz, Schieber, & Gänzle, 2010). On the one hand, the health-promoting (anti-oxidant and anti-microbial) activities might be improved by changing the phenolic compositions (Salazar-López, González-Aguilar, Rouzaud-Sáñez, & Robles-Sánchez, 2018). On the other hand, the bitterness of the resulted sorghum sourdough bread could increase. Previous studies showed that bitter taste of the polyphenol compounds are related to their structure (Robichaud & Noble, 1990). Generally, larger molecules such as polymeric fractions, dimers, and trimers tend to be less bitter than small size molecules, such as monomeric gallic acid and caffeic acid. Furthermore, the presence of certain polyphenols could prevent the microbial activity which may explain the partial utilisation of the released glucose in DSSD. The adaptation of the inoculated bacteria in this specific sorghum might be very slow, considering the substantial amount of polyphenol compounds presented which have been reported

to exhibit antimicrobial activities (Sekwati-Monang, Valcheva, & Gänzle, 2012). Additionally, the liberation of specific polyphenol compounds during sourdough fermentation such as caffeic acid might even enhance the inhibitory actions on bacterial performance (Lima et al., 2016).

The incorporation of 50% of wholegrain sorghum flour in bread making resulted in a deterioration of bread quality and high staling rate. When the control fermented sorghum was added bread technological characteristics were worsened as compared to bread prepared with unfermented sorghum. In contrast, the high level of *in situ* formed dextran demonstrated significant texture enhancing capacity, increased sourdough viscosity and further resulted in a bread with higher volume and moisture content, more springy and cohesive texture, and slower firming process. The functional performance of dextran has been suggested to be related to its ability to 1) bind high amount of water; 2) improve dough strength and gas retention; and 3) reduce starch retrogradation (Lynch, Coffey, & Arendt, 2018; Wang et al., 2019). The free sugars produced in parallel with dextran formation negatively affected the bread volume and textural properties, suggesting an inhibition (or slowing down) effect on yeast fermentation activity (Cauvain, 2015). For further research, it is recommended to include analyses of the fermentation rate by means of e.g. a fermentograph to clarify the influence of the free sugars on the fermentation process. The high yield of dextran was sufficient to compensate for the negative effects of acidification and excessive sugars.

The sensory perception of texture and mouthfeel can be statistically explained by the instrumental texture parameters. The resistance to pressure, resistance to deformation, and resilience in mouth were significantly closely related to instrumental crumb hardness, which seemed to measure the same property. The instrumental cohesiveness was found to be a good predictor of the sensory attribute elasticity. The instrumental crumb moisture content was a good evaluation of the perceived moist mouthfeel. The perception of dough-like texture was most likely associated with the moisture content and crumb softness. Furthermore, the instrumental crumb firmness might be a contributor to

the perceived coarseness. In addition, the perceived coarser structure of the sorghum bread may also suggest changes in microstructure such as cell wall thickness of the crumb (Ferrero, 2017).

Sourdough fermentation had a profound impact on flavour perception of wholegrain sorghum bread. In the present study, the high utilization dosage of sourdough resulted in a final bread (CSSB) with strong sour flavour, bitter taste and aftertaste generally not appreciated by the consumers (data not published). The enhanced undesirable flavours during fermentation are probably related to: 1) the liberation of small molecular weight polyphenol compounds which present strong bitter taste as elaborated above, 2) the release of bitter peptides and amino acids due to intensive proteolysis and peptidolysis by cereal endogenous and/or bacteria proteases activated at low pH (Fallico et al., 2005; Zhao, Schieber, & Gänzle, 2016), and 3) intensive acidification.

An apparent flavour-masking effect was observed for dextran-enriched (0.56% bread weight) sorghum sourdough bread (DSSB), which showed decreased perception of sourness, bitterness, and aftertaste, compared to CSSB. It has to be noted that these two types of bread presented similar organic acid profile and acidity level. Moreover, the dextran-enriched sorghum sourdough and its counterpart showed identical polyphenol profiles. This means that, theoretically, these two breads should have received similar scores for sourness and bitterness flavour intensity. Additionally, the DSSB was perceived as more sweet and roasted. The residual sugars present in DSSB likely contribute to the sweet taste and promote the Maillard reaction and the caramelization during baking. The enhanced sweetness in DSSB may be partially responsible for the bitter and sour taste masking. However, this does not seem to be the dominate factor since the amount of remnant sugars (1.7% bread weight) in the final bread was rather limited compared to sweeteners utilized as flour-masking agents in industrial production of bran-enriched cereal foods (over 10% sugars) (Heiniö et al., 2015).

A more possible explanation was the masking effect of dextran, which was further confirmed in the dextran containing model food systems, namely the “lactic/acetic acid” bread and the “caffeine”

bread. A dramatic decrease in sourness and bitterness perception was observed at dextran concentrations of 0.57 and 0.96% (bread weight). This support the above observations in the sorghum sourdough breads that DSSB containing 0.56% of dextran showed significantly less sour and bitter taste than CSSB with 0.11% dextran. There seems to be a close relationship between texture parameters and flavour perception. In both real and model food systems, an increase of dextran concentration resulted in an increase of cohesive, springy, and soft texture of the bread corresponding to a sharp decrease of flavour intensity. However, our study strongly suggests that the reduction of perceived flavour intensity by dextran is not a linear phenomenon. The suppressing effect seems to occur at concentrations higher than its critical overlap concentration (0.43%). Similar results were observed previously in hydrocolloid solutions that flavour perception was modified only above the point of C^* (Baines & Morris, 1987; Cook et al., 2002). At or above C^* polymer chains overlap and interpenetrate, resulting in an abrupt increase in solution viscosity and a marked decrease in flavour perception.

Various mechanisms have been proposed to explain the flavour-masking phenomenon of hydrocolloids. Flavour perception is a dynamic process involving two critical steps, the flavour release upon food structure breakdown on mastication (or chewing) and the transportation to taste receptor cells in the oral cavity and/or the olfactory receptors in the nasal cavity by the retronasal route (Thomson, 1984). Three possibilities might have arisen upon the addition of hydrocolloids: (1) the modification of the food structure which affects the release (i.e. diffusion and mass transfer coefficient) of the flavour compounds; (2) the molecular interactions (chemical or physical binding) between hydrocolloids and flavour molecules; and (3) the adhesion of hydrocolloids to taste buds (also known as mucoadhesion) (Cook et al., 2017; Guichard, 2007; Voilley & Souchon, 2006). Concerning hydrocolloid solutions, the polymer entanglement induced an inefficient mixing behaviour thus hindered the diffusion of flavour molecules to respective receptors (Cook et al., 2002). For our study, a most likely interpretation is that the texture properties of the bread were

significantly changed by the addition of dextran above its C^* , which altered the degree of bread particle size reduction during chewing (breakage function) and thus the flavour release kinetics (Lucas, Prinz, Agrawal, & Bruce, 2002). Assuming that the flavour molecules are evenly distributed within the bread matrix, the breakage results in new surfaces for flavour release. Bread with high levels of dextran had a more cohesive and dough-like texture (or ability to form a ball) during chewing which might trap the flavour molecules within the matrix and making it less available for the taste receptors. In contrast, bread with lower dextran content (below C^*) had a more brittle or crumbly structure resulting in smaller particle size distribution during chewing and consequently greater exposed area and higher levels of flavour stimuli released to the surrounding saliva or vapour phase. Another possibility is that the dextran can bind/interact with flavour compounds or the taste buds via hydrogen bonding, Van der Waals forces, or forming complex (molecular inclusion), thus block the taste sensation (Braudo et al., 2000; Yven, Guichard, Giboreau, & Roberts, 1998). However, the direct binding mechanism seems unlikely to be a significant factor in our case due to the similar results obtained for the two distinct stimuli, involving very different chemical mechanisms, and also the similar magnitude of reduction at the two different polymer concentrations (0.57% and 0.96%), which was supposed to be altered in a binding process.

Conclusion

In conclusion, dextran formed *in situ* by *W. confusa* A16 improved the texture and masked undesirable flavours of wholegrain bread; thus dextran could be used to substitute flavour-masking agents such as sweeteners. For both real food and model bread systems, a clear flavour suppressing effect was observed at dextran concentrations above its overlap concentration C^* . Dextran below C^* did not affect significantly the perception of sour and bitter taste of breads. Furthermore, our results showed a positive correlation between dextran concentration and bread texture enhancement. The extensive texture modifications were thus suggested to be a major factor accounting for the flavour reduction. Nevertheless, since this work studied only a single type of polymer and limited

concentration variations, the conclusion for critical concentration transition and flavour masking in bread can be considered as a tentative.

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Appendix A. Supplementary data

The following is the Supplementary data to this article:

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Figure captions

Fig. 1. UHPLC-PDA–MS chromatograms at 280 nm of the three methanol extracts of (A) native sorghum flour, (B) CSSD, and (C) DSSD. Peak numbers correspond to those reported in Table 4.

Fig. 2 Texture (A) and flavour (B) profiling (ratings from 0–10) of wholegrain sorghum and wheat bread samples. See Table 2 for sample codes. Please note CWB has been used in the texture evaluation sessions as an anchor for endpoints of the scales (see Table 1).

Fig. 3. Determination of C* concentration for dextran produced by *W. confusa* A16, from a double-logarithmic plot of specific viscosity versus concentration.

Table 1. Lexicon used to describe flavour and texture properties of the breads.

Descriptor	Definition	References (scale)	Scale anchors (0, 10)
<i>Smell</i>			
Roasted smell of crust	Aroma associated with toasted/burnt cereals	Roasted bread (10)	Not at all, Very strong
Sour smell of crumb	Aroma associated with fermented sourdough	Rye bread (10)	Not at all, Very strong
Overall smell intensity of crumb	Overall intensity of aroma of bread crumb		Not at all, Very strong
<i>Taste</i>			
Roasted taste of crust	Taste associated with toasted/burnt cereals	Roasted bread (10)	Not at all, Very strong
Bitter taste of crumb	Basic taste associated with caffeine and alkaloids	Caffeine solution (10)	Not at all, Very strong
Sour taste of crumb	Basic taste associated with acids	Rye bread (10)	Not at all, Very strong
Sweet taste of crumb	Basic taste associated with sugars	Roasted bread (10)	Not at all, Very strong
Aftertaste	The intensity of any after taste (1 min after swallow the bread)		Not at all, Very strong
<i>Texture</i>			
Resistance to pressure	Assess the behaviour of the slice when the surface is pressed	Wheat (0) & rye (10) bread	Very soft, Very hard
Resistance to deformation	Assess the behaviour when the sides of the slice are squeezed between the thumb and the finger	Wheat (0) & rye (10) bread	Very flexible, Very rigid
Elastic texture	Firmly press the center of the slice with one finger and assess the ability to spring back to its initial shape	Wheat bread (10)	Not at all elastic, Very elastic
Crumb coarseness	Gently rub the center crumb against the tip of the nose and assess the coarseness of the slice	Wheat (0) & rye (10) bread	Very smooth, Very coarse
Foldability	Assess the behaviour when the slice is bended and folded in two	Wheat bread (10)	Not foldable, Very foldable
<i>Mouthfeel</i>			
Resilience in mouth	Assess the resilience by squeezing a piece of crumb between the tongue and palate	Wheat (0) & rye (10) bread	Very soft, Very hard
Crumb moisture	Place a piece of crumb in the mouth and assess the level of moisture	Wheat bread (10)	Very dry, Very moist
Dough-like/cohesive texture	Assess how cohesive the texture of a piece of crumb is after melting in the mouth	Wheat bread (10)	Very crumbly, Very dough-like

Table 2. Lactic acid bacteria cell density (log cfu/g) of sorghum sourdoughs before (0 h) and after (24 h) fermentation, and acidity (pH and TTA) of sourdoughs and bread crumbs.

	Sourdough 0 h			Sourdough 24 h			Bread crumb	
	pH	TTA (mL)	Lactic acid bacteria	pH	TTA (mL)	Lactic acid bacteria	pH	TTA (mL)
CWB ¹							5.7 ± 0.0 ^a	3.1 ± 0.1 ^a
CSWB							5.8 ± 0.0 ^a	3.4 ± 0.1 ^b
CSSB	6.2 ± 0.0 ^a	2.5 ± 0.2 ^a	6.1 ± 0.1 ^a	4.1 ± 0.1 ^a	8.1 ± 0.2 ^a	9.3 ± 0.0 ^b	4.7 ± 0.0 ^b	6.8 ± 0.1 ^d
DSSB	6.2 ± 0.1 ^a	2.7 ± 0.0 ^a	6.2 ± 0.1 ^a	4.1 ± 0.0 ^a	7.4 ± 0.1 ^b	9.2 ± 0.1 ^b	4.7 ± 0.0 ^b	6.5 ± 0.1 ^c

¹ CWB = control wheat bread; CSWB = control sorghum-wheat bread; CSSB = control sorghum sourdough bread; DSSB = dextran-enriched sorghum sourdough bread.

Different superscript letters in the same column indicate statistical significance (Tukey's test, p<0.05).

Table 3. Amount (% dry weight) of organic acids, free sugars, and dextran in sorghum sourdoughs (before and after 24 h of fermentation) and

	Lactic acid (%)	Acetic acid (%)	Sucrose (%)	Glucose (%)	Fructose (%)	Maltose (%)	Dextran (%)	Viscosity (Pa/s)
<i>Sourdough</i>								
Sorghum flour			1.3 ± 0.1	nd ¹	nd	nd		0.2 ± 0.0 ^{a 2}
CSSD ³	0.95 ± 0.01 ^a	0.15 ± 0.00 ^a	nd	nd	0.6 ± 0.0 ^a	nd	0.5 ± 0.1 ^a	0.2 ± 0.0 ^a
DSSD	0.94 ± 0.03 ^a	0.14 ± 0.00 ^a	nd	3.1 ± 0.1	4.7 ± 0.1 ^b	nd	2.0 ± 0.1 ^b	2.6 ± 0.2 ^b
<i>Bread</i>								
CWB ⁴			nd	nd	nd	1.4 ± 0.1 ^c		
CSWB	0.29 ± 0.02 ^a	0.04 ± 0.00 ^a	nd	0.5 ± 0.0 ^a	0.2 ± 0.0 ^a	0.6 ± 0.1 ^b		
CSSB	0.54 ± 0.01 ^b	0.08 ± 0.00 ^b	nd	0.6 ± 0.0 ^a	0.5 ± 0.0 ^b	0.2 ± 0.0 ^a	0.2 ± 0.1 ^a	
DSSB	0.58 ± 0.00 ^c	0.07 ± 0.00 ^b	nd	1.1 ± 0.1 ^b	1.7 ± 0.1 ^c	0.2 ± 0.0 ^a	0.9 ± 0.1 ^b	

various breads, together with the apparent viscosity values (shear rate at 123 s⁻¹) of sorghum sourdoughs.

¹ nd = not detected.

² Viscosity of 0 h non-fermented sorghum dough (sorghum flour and water, dough yield 240) was served as control.

³ CSSD = control sorghum sourdough; DSSD = dextran-enriched sorghum sourdough.

⁴ See Table 2 for details about the abbreviations.

Different letters in the same column indicate statistical significance (p<0.05), mean differences are compared within the sourdough groups and within the bread groups.

Table 4. Polyphenolic compounds identified in the methanol-acid extracts of native (non-fermented) sorghum flour and lyophilized sorghum sourdoughs.

ID	RT ¹ (min)	Identified compounds ²	[M-H] ³ (m/z)	MS ^{2,4} m/z (intensity, %)	λ_{max} (nm)
1	2.39	Protocatechuic acid	153.31	109	262, 294
2	2.56	Unknown	323.25	119(100), 101(74), 113(70), 143(51), 179(49), 161(33), 131(28), 149(16)	262, 294
3	3.31	Catechin hexoside	451.21	137(100), 271(96), 289(65), 313(11)	280
4	3.48	Unknown	395.22	293(100), 351(22), 333(17), 251(14)	280
5	4.2	Procyanidin B	577.14	425(100), 407(42), 451(25), 289(17)	256
6	4.58	1-O-caffeoyl-2-O-glucosylglycerol	415.29	253	282
7	4.86	Catechin*	289	245(100), 205(35), 179(12)	282
8	5.01	2-O-caffeoylglycerol	253.23	161(100), 135(45), 179(30)	282, 318
9	5.1	Unknown	367.35	193	290, 330
10	5.27	1-O-caffeoyl-2-O-glucosylglycerol	415.29	253	288, 320
11	5.47	Caffeic acid*	179.33	135	292, 324
12	5.55	Caffeic acid	179.33	135	292, 324
13	5.82	2-O-caffeoylglycerol isomer	253.23	135100, 161(56), 179(49)	289 326
14	5.9	2-O-caffeoylglycerol isomer	253.23	135100, 161(56), 179(49)	289 326
15	6.8	Unknown	365.41	203(100), 245(10), 199(7)	
16	7.22	Coumaroyl glycerol	237.35	119(100), 163(72), 145(39)	296, 316
17	7.22	N1-N4-dicaffeoyl spermidine	468.3	332(100), 306(17), 323(7), 161(4), 333(4)	296, 316
18	7.22	Taxifolin hexoside isomer	465.25	303	296, 316
19	7.46	Catechin isomer	289.21	245(100), 179(26), 125(21), 109(7)	282
20	7.6	Quercetin hexoside	463.25	301(100), 161(8)	284
21	7.69	Unknown	520.24	397(100), 505(10),	

22	7.89	Tetrahydroxy flavone	287.14	161(100), 125(61), 243(17), 151(3)	288, 322
23	8.11	N1-N8-caffeoyl feruloyl spermidine	482.22	332(100), 306(49), 346(45)	282, 488
24	8.12	Trihydroxy flavone	269.14	269(100), 225(7), 241(3), 197(3)	282, 488
25	8.28	flavonoid hexoside	449	287(100), 193(9), 147(2)	282, 488
26	8.29	Nrungenin hexoside	433.14	271(100), 313(11), 151(2)	282, 488
27	8.53	Quercetin hexoside isomer	463.18	301	284
28	8.53	Dicaffeoyl glycerol	415.4	1798(100), 369(38), 161(20), 225(17), 253(15)	284
29	8.62	Luteolin hexoside	447.27	285(100), 191(13)	284
30	8.72	Unknown	473.3	311(100), 441(37), 249(29), 293(20), 261(18)	284
31	8.91	dihydroxyflavone	253.23	253(100), 209(12), 210(2)	280, 474
32	9.07	Naringenin	271.2	151(100), 177(23)	286, 330, 484
33	9.07	Unknown	496.27	346(100), 331(12), 481(7)	286, 330, 484
34	9.07	Taxifolin	303.13	177(100), 285(51), 193(42), 125(39)	286, 330, 380, 484
35	9.24	Gallic acid monohydrate	187.29	125	286
36	9.24	Unknown	1284	561(100), 563(66), 498(42), 493(35)	286
37	9.24	Unknown	283.23	268(100), 284(96), 240(5)	286
38	9.24	Unknown	639.15	315(100), 300(17)	286
39	9.28	Unknown	475.26	429	284, 484
40	9.55	Isorhamnetin hexoside	477.2	314(100), 357(21), 478(16), 285(7), 271(6)	284
41	9.9	Methyl catechin	303.17	193(100), 109(19), 163(10), 151(9)	282, 472
42	9.97	Pentahydroxy flavone	301.23	161(100), 191(4)	284, 378
43	10.51	Methyl afzelechin	287.22	125(100), 193(50)	284
44	10.83	Unknown	573.31	429(100), 471(86), 411(37), 511(35), 253(7)	284
45	11.15	Dicaffeoyl glycerol isomer	415.13	253(100), 179(75), 161(21), 135(20), 235(10)	288, 344

46	11.15	5-methoxy-7,4'-dihydroxy flaven-3-ol	285.19	191(100), 165(35), 93(4)	288, 344
47	11.36	1,3-O-Dicaffeoyl glycerol isomer	415.16	253(100), 161(26), 179(5)	302, 328
48	11.47	Methyl afzelechin isomer	287.16	193(100), 147(51), 139(29), 151(8)	282
49	11.56	Unknown	439.24	245(100), 227(9), 289(8)	284, 340, 390
50	11.8	Quercetin*	301.08	179(100), 151(79), 301(40), 272(19), 255(15)	286
51	11.81	Luteolin*	285.12	285(100), 241(24), 175(3), 199(3), 243(3)	286
52	11.89	Isorhamnetin	315.11	300	270, 340, 480
53	12.31	1,3-O-Coumaroyl-caffeoyl-glycerol	399.23	235(100), 163(92), 252(52), 179(19)	280, 316
54	12.58	1,3-O-Feruloyl-dihydrocaffeoylglycerol	431.08	431(100), 254(65), 236(29), 193(25)	280, 314
55	12.58	1,3-O-Coumaroyl-caffeoyl-glycerol isomer	399.19	253(100), 235(25), 163(12), 145(9)	280, 314
56	12.81	1,3-O-feruloyl-caffeoylglycerol	429.2	253(100), 235(48), 193(34), 161(16)	296, 326
57	13.48	Apigenin*	269.22	269(100), 225(7), 149(3), 201(2), 151(2)	280, 322, 484
58	13.66	Tricin	329.2	314(100), 299(3)	286, 330, 484
59	13.8	Unknown	299.21	284	284, 326
60	13.9	1,3-O-Dicoumaroylglycerol	383.25	161(100), 219(54), 237(25), 145(23), 119(19)	288, 330, 484
61	14.11	Trihydroxy-octadecenoic acid	329.33	229(100), 211(72), 311(28), 293(19), 171(10)	290, 330, 486
62	14.11	1,3-O-coumaroyl-feruloylglycerol	413.11	235(100), 177(345), 193(27), 329(18), 161(17), 163(11)	290, 330, 486

¹ Retention time.

² Tentatively identified based on MS² data and retention time and literature data.

* Identified using both external standard and bibliographic data.

³ [M-H]⁻, deprotonized ions observed in negative mode mass spectrometry (m/z, mass-to-charge ratio).

⁴ MS², tandem mass spectrometry (or MS/MS), contains all fragment ions of the product.

Table 5. Quantification of polyphenolic compounds in native (non-fermented) sorghum flour and lyophilized sorghum sourdoughs.

ID ¹	RT ² (min)	Native sorghum flour ($\mu\text{g GAE g}^{-1}$)	DSSD ³	CSSD
1	2.38	6.2 ± 0.1^a	6.3 ± 0.4^a	7.2 ± 0.6^a
2	2.56	10.9 ± 0.3^a	12.6 ± 1.0^{ab}	13.3 ± 0.5^b
3	3.32	4.1 ± 1.3^a	3.2 ± 1.0^a	1.5 ± 0.1^a
4	3.48	5.6 ± 1.3^a	5.2 ± 0.8^a	5.6 ± 0.3^a
5	4.19	22.9 ± 0.6^a	28.6 ± 2.1^b	28.2 ± 1.1^b
6	4.58	11.5 ± 0.3^a	13.3 ± 0.8^b	11.3 ± 0.6^a
7	4.86	7.4 ± 0.2^a	8.8 ± 0.4^a	10.8 ± 0.5^b
8	5.09	1.6 ± 0.1^a	0.0^b	1.1 ± 0.2^a
9	5.1	0.0^a	3.9 ± 0.3^b	5.7 ± 1.1^b
10	5.27	2.9 ± 0.2^a	3.5 ± 0.2^a	0.0^b
11+12	5.54	45.8 ± 1.2^a	164.1 ± 10.3^b	183.4 ± 10.5^b
13	5.81	18.4 ± 0.6^a	6.7 ± 0.6^c	9.8 ± 0.5^b
14	5.9	39.8 ± 1.4^a	17.2 ± 1.1^b	20.5 ± 1.0^b
15	6.8	4.4 ± 0.2^a	4.0 ± 0.3^a	3.5 ± 0.4^a
16+17+18	7.22	154.0 ± 5.6^a	157.9 ± 11.9^a	169.9 ± 9.5^a
19	7.46	7.6 ± 0.3^a	6.1 ± 0.6^a	6.1 ± 0.5^a
20	7.59	17.7 ± 0.6^a	15.9 ± 1.3^a	14.7 ± 0.8^a
21	7.69	5.0 ± 0.5^a	5.3 ± 0.4^a	4.6 ± 0.5^a
22	7.88	22.7 ± 0.8^a	52.6 ± 4.2^b	56.5 ± 3.3^b
23+24	8.11	44.0 ± 1.7^a	25.9 ± 1.4^b	21.5 ± 1.1^c
25+26	8.29	67.3 ± 2.7^a	58.6 ± 3.5^{ab}	54.6 ± 2.6^b
27+28	8.53	15.3 ± 1.3^a	13.8 ± 1.0^a	15.0 ± 0.8^a
29	8.62	3.1 ± 1.0^a	0.0^b	0.0^b

30	8.73	14.5 ± 1.7^a	11.1 ± 1.0^b	9.9 ± 0.6^b
31	8.91	45.1 ± 2.3^a	35.3 ± 2.3^b	30.8 ± 1.6^b
32+33+34	9.07	39.6 ± 1.9^a	33.1 ± 1.6^a	34.1 ± 2.3^a
35+36+37+38+39	9.24	242.3 ± 6.3^a	222.3 ± 14.3^a	228.5 ± 13.2^a
40	9.54	106.1 ± 2.7^a	101.0 ± 6.4^a	104.1 ± 8.1^a
41	9.9	29.1 ± 0.5^a	25.5 ± 1.5^b	26.6 ± 0.6^b
42	9.97	41.8 ± 2.5^a	37.0 ± 2.7^a	40.4 ± 4.5^a
43	10.51	46.3 ± 4.0^a	46.5 ± 0.7^a	40.7 ± 1.8^a
44	10.83	6.4 ± 0.5^a	6.3 ± 0.1^a	8.5 ± 0.6^b
45+46	11.15	26.8 ± 1.2^a	22.5 ± 2.5^a	23.1 ± 1.8^a
47	11.36	58.5 ± 1.6^a	23.7 ± 1.2^b	24.6 ± 2.5^b
48	11.48	44.2 ± 0.8^a	45.3 ± 4.9^a	47.8 ± 5.4^a
49	11.57	8.4 ± 0.1^a	0.0^b	9.4 ± 3.3^a
50+51	11.81	28.8 ± 0.8^a	34.7 ± 2.6^a	37.7 ± 4.7^a
52	11.89	11.3 ± 0.6^a	13.2 ± 1.1^a	15.3 ± 3.6^a
53	12.31	2.0 ± 0.1^a	0.9 ± 0.1^b	0.0^b
54+55	12.58	34.5 ± 1.3^a	13.4 ± 0.7^b	12.7 ± 0.6^b
56	12.8	31.4 ± 1.2^{ab}	29.0 ± 2.1^b	34.2 ± 1.9^a
57	13.47	3.6 ± 1.4^a	4.8 ± 0.4^a	5.8 ± 0.4^a
58	13.65	1.8 ± 0.1^a	1.8 ± 0.2^a	2.2 ± 0.2^a
59	13.79	1.2 ± 0.3^b	2.1 ± 0.1^a	2.5 ± 0.2^a
60	13.9	1.9 ± 0.5^a	0.9 ± 0.1^a	1.2 ± 0.1^a
61+62	14.1	6.9 ± 0.5^a	4.5 ± 0.4^b	4.6 ± 0.3^b
Total polyphenolic content		1344.1 ± 33.9^a	1328.6 ± 85.5^a	1389.9 ± 77.4^a

¹ See Table 4 for ID (identification number). ² Retention time. ³ See Table 3 for details about the abbreviations. Different letters in the same row indicate statistical significance (p<0.05).

Table 6. Baking properties and TPA profile of sorghum-wheat control and sourdough breads in comparison to wheat equivalent.

	CWB ¹	CSWB	CSSB	DSSB
Sp.volume ² (mL/g)	4.3 ± 0.1 ^a	2.8 ± 0.1 ^c	2.6 ± 0.0 ^d	3.2 ± 0.1 ^b
Moisture content (% , on day1)	44.4 ± 0.0 ^a	42.9 ± 0.1 ^d	43.2 ± 0.0 ^c	43.6 ± 0.0 ^b
Springiness (g, on day1)	0.96 ± 0.02 ^a	0.92 ± 0.01 ^c	0.90 ± 0.02 ^c	0.94 ± 0.01 ^{ab}
Cohesiveness (on day1)	0.76 ± 0.01 ^a	0.50 ± 0.04 ^b	0.56 ± 0.04 ^b	0.72 ± 0.07 ^a
Hardness (g, on day1)	127.0 ± 9.8 ^a	564.6 ± 39.3 ^c	655.4 ± 34.9 ^d	266.4 ± 32.6 ^b
Hardness (g, on day4)	253.4 ± 28.7 ^a	855.0 ± 42.5 ^c	925.5 ± 57.7 ^d	414.4 ± 38.3 ^b
Staling rate (g per day) ³	42.1 ^a	96.8 ^b	90.0 ^b	49.3 ^a

¹ See Table 2 for details about the abbreviations.

² Sp. volume: specific volume = loaf volume/loaf weight, measured after 24 h of baking.

³ Staling rate = [hardness (day 4 – day 1) / days of storage].

Different letters in the same row indicate statistical significance (p<0.05).

Table 7. Pearson's correlation coefficients between sensory texture attributes and instrumental texture parameters.

	Resistance to pressure	Resistance to deformation	Elastic texture	Crumb coarseness	Foldability	Resilience in mouth	Crumb moisture	Dough-like/cohesive texture
Moisture content	-0.89	-0.93	0.96*	-0.94	0.98*	-0.91	0.97*	0.98*
Crumb hardness	1.00**	1.00**	-0.98*	0.99**	-0.96*	1.00**	-0.98*	-0.96*
Springiness	-0.98*	-0.97*	0.93	-0.97*	0.95	-0.98*	0.95	0.94
Cohesiveness	-0.93	-0.95	0.98*	-0.95	0.92	-0.94	0.95	0.91
Sp. volume	-0.92	-0.94	0.93	-0.95	0.99*	-0.93	0.97*	0.99*

* Correlation is significant at the 0.05 level ** Correlation is significant at the 0.01 level

Table 8. Results of sensory evaluation for sour taste of bread with dextran addition at varying concentrations and the bread texture parameters.

Dextran (% bread weight)	Sour taste intensity ¹	Sp. volume ² (mL/g)	Hardness (g)	Cohesiveness	Gumminess (g)	Chewiness (g)
0	97.2 ± 5.0 ^b	3.4 ± 0.0 ^d	202.3 ± 18.0 ^e	0.75 ± 0.03 ^c	150.3 ± 24.4 ^e	146.1 ± 23.1 ^e
0.12	101.7 ± 4.0 ^b	3.8 ± 0.1 ^c	156.3 ± 9.8 ^d	0.76 ± 0.01 ^{bc}	118.9 ± 7.2 ^d	115.3 ± 6.8 ^d
0.26	94.5 ± 3.2 ^b	3.7 ± 0.0 ^c	135.6 ± 13.5 ^{cd}	0.79 ± 0.01 ^{ab}	106.4 ± 9.5 ^{cd}	103.5 ± 8.9 ^{cd}
0.38	93.4 ± 3.5 ^b	4.1 ± 0.0 ^b	122.3 ± 14.7 ^{bc}	0.78 ± 0.02 ^{bc}	95.3 ± 9.4 ^{bc}	93.2 ± 9.0 ^{bc}
0.57	74.9 ± 4.3 ^a	4.3 ± 0.1 ^a	107.2 ± 15.5 ^a	0.81 ± 0.01 ^a	83.6 ± 6.9 ^a	81.9 ± 9.1 ^a
0.96	72.2 ± 4.9 ^a	4.4 ± 0.0 ^a	94.5 ± 15.0 ^a	0.80 ± 0.01 ^a	71.7 ± 10.1 ^a	67.9 ± 9.0 ^a

¹ Sour taste of chemically acidified wheat bread prepared by addition of lactic and acetic acid (0.6 and 0.08% flour weight, respectively). The magnitude estimation scale was anchored with a 'reference modulus', the acidified bread with 0.26% dextran on bread weight which was pre-assigned a fixed score of 100. Values are a mean ± standard deviation.

² Sp. volume: specific volume.

Different letters in the same column indicate statistical significance (p<0.05).

Table 9. Results of sensory evaluation for bitter taste of bread with dextran addition at varying concentrations and the bread texture parameters.

Dextran (% bread weight)	Bitter taste intensity ¹	Sp. volume ² (mL/g)	Hardness (g)	Cohesiveness	Gumminess (g)	Chewiness (g)
0	98.7 ± 5.1 ^b	3.9 ± 0.1 ^d	148.0 ± 14.2 ^c	0.77 ± 0.01 ^{bc}	114.0 ± 9.9 ^c	108.8 ± 9.4 ^c
0.12	90.1 ± 4.7 ^b	3.9 ± 0.1 ^{cd}	145.5 ± 15.1 ^c	0.77 ± 0.01 ^c	111.6 ± 10.3 ^c	105.5 ± 9.8 ^c
0.26	90.0 ± 4.3 ^b	4.2 ± 0.1 ^{bc}	121.9 ± 13.5 ^b	0.78 ± 0.02 ^{abc}	95.0 ± 9.3 ^b	90.7 ± 9.6 ^b
0.38	91.8 ± 4.1 ^b	4.1 ± 0.0 ^{bcd}	122.6 ± 13.5 ^b	0.78 ± 0.01 ^{abc}	95.4 ± 9.7 ^b	91.0 ± 8.8 ^b
0.57	71.2 ± 4.5 ^a	4.4 ± 0.1 ^a	99.6 ± 11.5 ^a	0.80 ± 0.04 ^a	78.5 ± 6.2 ^a	74.6 ± 5.8 ^a
0.96	69.2 ± 4.5 ^a	4.4 ± 0.0 ^a	90.7 ± 11.8 ^a	0.80 ± 0.02 ^a	70.6 ± 7.6 ^a	66.3 ± 6.9 ^a

¹ Bitter taste of wheat bread prepared from addition of caffeine at 0.2% (flour weight). The 'reference modulus' used to anchor the magnitude estimation scale was the caffeine bread containing 0.26% dextran on bread weight which was pre-assigned a fixed score of 100. Values are a mean ± standard deviation.

² Sp. volume: specific volume.

Different letters in the same column indicate statistical significance (p<0.05).

Fig. 1

RT: 2.00 - 16.00 SM: 7B 280nm

Fig. 2

(B) FLAVOUR

Fig. 3

Highlights

1. Sourdough fermentation can be tailored to decrease intensity of off-notes in sorghum bread.
2. This was attributed to the *in-situ* produced dextran and improved bread texture.
3. Masking of sour and bitter notes occurred above the critical overlap concentration.
4. The relevance of dextran in flavour masking of solid food products is a novel concept.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: