Sugar reduction in food products based on first principles:

The WUR sugar reduction strategy

With obesity, diabetes and cardiovascular diseases becoming increasingly common, it is desirable to reduce the sugar content in food products and create a healthier product range. Ideally, sugar replacement should go hand in hand with additional nutritional improvements, such as an increase in dietary fibres. This represents a considerable challenge for food manufacturers as sugar has multiple functions in many products. As well as providing sweetness, sugar also determines the structure and mouthfeel of products.

Experts at Wageningen Food & Biobased Research have performed a great deal of research over recent years into the behaviour of sugar in food. This has resulted in a definition of the physical principles behind the multiple functionalities of sugar. Based on these insights, the scientists have developed a new, practical strategy which can calculate sugar reduced formulations for a wide range of food products in a very specific way without requiring extensive practical testing. The strategy also allows for a concomitant dietary fibre enrichment. The WUR sugar reduction strategy saves both time and money, and the approach has resulted in various successes.

The challenges of sugar reduction

Sugars like sucrose (or sacharose), glucose and fructose are often used in food products to deliver sweetness, but they are also of crucial importance to the structure and mouthfeel, i.e. textural properties such as crispiness, softness and smoothness. This is why replacing sugar in food products is such a complex process: as well as finding

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another sweetener, it also requires one or more other ingredients that ensure the same structure and texture. To date, most food manufacturers have applied a trial & error approach of replacing (part of) the sugar in their products by just one other ingredient with a sweet flavour. This often modifies the structure and mouthfeel, and the resulting acceptance by consumers. Moreover, the polyols, a group of commonly used sugar replacers, such as maltitol, have another disadvantage: they have a laxative effect in high concentrations.

Successful sugar reduction therefore demands an entirely different approach and Wageningen Food & Biobased Research has invested in gaining the required knowledge over the past years. "We studied the sugar functionalities from a physical perspective taking into account the complexity of the food matrix application. This means that we didn't look at each ingredient separately – like traditionally trained food scientists – but searched for the principles behind the functionalities," say Ruud van der Sman and Stefano Renzetti, senior scientists. Their specific field – the integration of soft matter physics with molecular and food sciences – has seen significant developments over the past 20 years, and Wageningen University & Research (WUR) is a frontrunner in its application in food products.

WUR sugar reduction strategy

Physical principles

Mouthfeel and structure are important characteristics for how consumers value many food products [1]. Bakery products like cake and cookies should be soft and aerated, or crispy and crumbly instead. Meanwhile, desserts such as ice-cream and custard are mainly valued for their creaminess. These characteristics are determined by physical processes during preparation.

Soft matter physics

The extensive integration of soft physics with molecular and food sciences into the physical principles behind the various functions of sugar led to several conclusions on which the WUR sugar reduction strategy is based [2-6]:

- The physical role of sugar in food products is twofold: sugar is both a plasticiser (which makes food products soft) as well as a humectant (which absorbs water);
- For food products it does not matter whether the plasticising and humectant properties are provided by sugar or by (a combination of) sugar-replacing ingredients;
- If sugar-replacing ingredients have the same plasticising and humectant properties as sugar in the original product, the structure, texture and consumer acceptation remain the same;
- Properties such as sweetness and browning can be controlled independently by adding small doses of high intensity sweeteners (like stevia) or reducing sugars (like fructose).

An aerated cake, for instance, is the result of the water evaporating into steam from the dough. At some point the steam should escape from the rising dough, which requires stiffening of the biopolymer matrix. This complex process creates the soft, spongy structure that consumers love. On the other hand, there are crispy bakery products such as crackers which should be porous and easy to break while producing a sound. This involves similar principles as for soft bakery products, but now the products should become crispy as more moisture escapes. For the softness of ice-cream, it is important that the ice crystals that develop on the wall of the ice machine during freezing are sufficiently small.
The physical processes which determine the structure development of food products depend to a large extent on the type of sugar and sugar content. This means that simply replacing the sugar by a random sweetener is not an option.

The theory of plasticisers and humectants

Plasticisers make food products soft. Examples include crispy cereals that become soft just seconds after coming into contact with milk. The plasticisers make the strong entangled network of biopolymers in food products (which creates crispiness) fall apart as the long molecules of proteins and polysaccharides like starch disentangle. The

Roadmap for WUR sugar reduction strategy

The application of the strategy can be done in a relatively short research project, which can involve the following steps:

The various **functions** of sugar in a food product are investigated and evaluated in how far they are characterised by the plasticising and humectant properties of sugar.

The **possible combinations** of sugar replacers are calculated. In certain cases it will be necessary to experimentally verify the relation between crucial sugar functionality and its plasticising and humectant properties.

In consultation with the manufacturer, **a number of sugar replacing** ingredients are identified. In certain cases, the plasticising and humectant properties of novel alternatives to current sugar replacers. can be assessed

Practical testing with various recipes determines the best formulation, possibly combined with sensory research into flavour and mouthfeel.

most powerful plasticiser is water. Sugar resembles water at the molecular level as it interacts by hydrogen bonds and also acts as a good plasticiser. Wageningen scientists have found that the plasticising properties of sugars are determined by the density of the hydrogen bonds that can be made with other molecules [3,4].

Humectant ingredients in food products have the tendency to retain water. Sugar is one such humectant, like proteins and polysaccharides. All ingredients that absorb water affect the freezing and boiling point of water. Freezing and boiling are key processes in the transformation of a mixture of various ingredients into a structured food product.

As said, the preparation of bakery products involves two temperature-dependent processes: the development of steam, which results in the aeration of a product, and the stiffening of the biopolymer networks, which fixates the aerated structure that has been formed. A higher sugar content increases the boiling point of water, resulting in a different steam production and, therefore, a different structure than with a lower sugar content. It also increases the temperature at which structural transitions of the biopolymers occur during baking, contributing to transform a soft or liquid dough into a solid product [1,4,6].

The scientists found that the water activity determines the humectant property of sugars. A reduced sugar content requires sugar replacers that provide the same water activity. To determine this, a predictive theoretical model based on the Flory-Huggins theory was built [2].

WUR sugar reduction strategy in practice

The sugar reduction strategy states that a food product with less sugar but with a similar structure and texture can be obtained if the plasticising and humectant values are virtually the same as those of the reference product [6]. To apply the strategy in practice, the scientists included the most common sugar replacers and their plasticising and humectant values in a database. This can be used to determine which (combinations of) sugar replacers are suitable based on the values of the original product.

There are often various options for product reformulation. In that case, manufacturers can consider additional constraints for product formulation like nutritional aspects, such as a maximum level of soluble dietary fibres and a minimal use of polyols like maltitol (with its laxative properties). In practice, there are usually at least two ingredients needed to replace the sugar and achieve a similar product quality.

After the theoretical part of the strategy, which results in a limited number of high-quality recipes, practical testing is being carried out to validate the approach and fine-tune the optimization towards the best formulation, in accordance with manufacturer's requirements. This approach has already proven its value in practice in applications for biscuits, gingerbread and cake.

Practical case studies: Successes with the WUR sugar reduction strategy

The WUR sugar reduction strategy was successfully applied to the reduction of the sugar content in products such as biscuits, cake, gingerbread and fudges [1, 6-8]. This has also shown that the strategy is applicable to food products with different functionality of the biopolymer networks:

- For biscuits the gluten proteins should denaturate and polymerize into a network while the starch should remain in its semi-crystalline form [6];
- For cake the starch must be gelatinized, and the egg white protein should denaturate and polymerize into a network [1,7];
- For gingerbread it involves the gelatinization of starch in presence of nutritional fibres from rye (beta-glucans) [8].

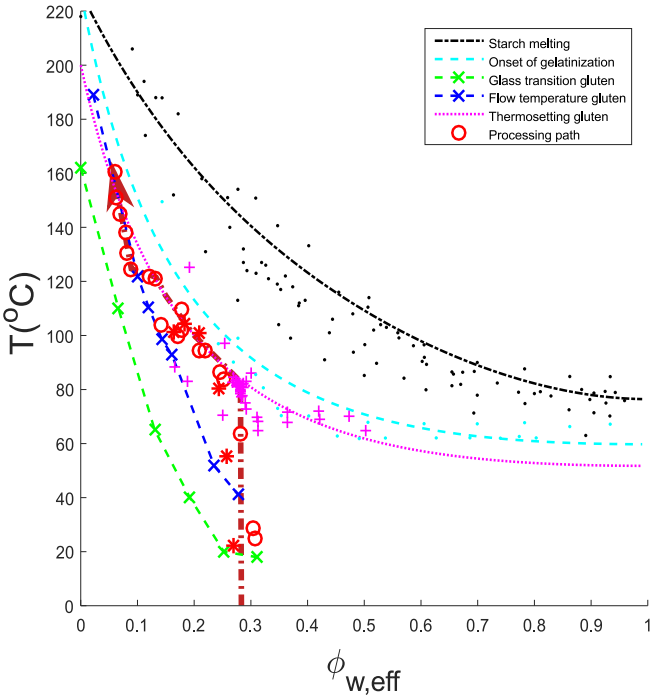

figure 1 Phase transitions during baking of biscuits as a function of the characterizing number $\phi_{w,eff}$. The glass transition, and stiffening of both gluten and starch are controlled by the same characterizing number. The red circles show how the state of the food material changes during baking, showing that gluten stiffens, but that starch does not gelatinize. Other symbols indicate the stiffening of gluten as measured in biscuits with different sugar contents, and different sugar replacers as polyols. For more details see reference [6].

1 A biscuit manufacturer asked Wageningen Food & Biobased Research to substantially reduce sugar while complying with a number of ingredient labelling and nutritional requirements. The use of a combination of sugar replacers, including fibres like inulin, with plasticising and humectant properties equal to the original product led to a 50 to 100% reduction of the sugar content (see figure 2). The newly formulated biscuits met the quality demands of the manufacturer and scored almost the same on look and mouthfeel in sensory tests with consumers.

figure 2 Examples of reformulated biscuits. Biscuits 1-3 deviated from the reference (REF) biscuit with respect to the two characterizing numbers, while biscuit 4 had about the same characterizing numbers. Biscuit 4 mimics the reference biscuit well in terms of texture, mouthfeel and visual appearance.

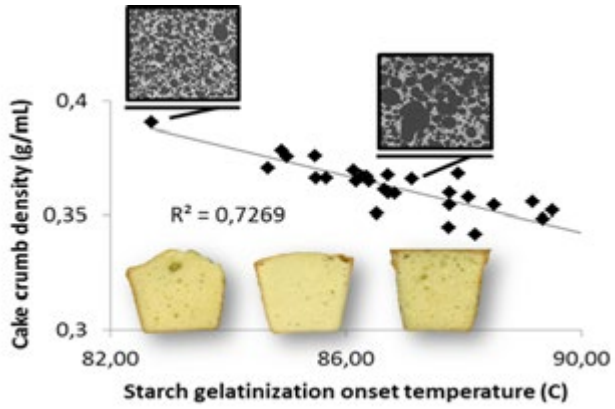

figure 3 Relation between cake crumb density and the onset temperature of starch elatinization. The variations observed were obtained in products where sugar was replaced by various ingredients such as polyols, dextrins and soluble fibres. Such relation highlights the importance of the gelatinization process in influencing the behaviour of the product during baking and its final quality. The pictures in the squares visualize the differences in porosity (grey is the cake matrix, black is air) of the microstructure of the cake crumb.

2 In cake it is not just the protein denaturation but also the starch gelatinisation that makes an essential contribution to the formation of a solid, yet soft and aerated structure during the baking process. The temperature of the starch gelatinisation changes when the sugar replacing mixture is not optimized, resulting in an unacceptable product quality (see figure 3). Cake variations with 50% less sugar or with no added sugars, in which the sugar replacers had the same plasticising and humectant values, have a similar quality. Using the WUR sugar reduction strategy, the protein denaturation and starch gelatinisation occur in the same way as in the original high-sugar cake formulation.

3 A research collaboration between the Wageningen scientists and the bakery product manufacturer Peijnenburg resulted in the introduction of Ontbijtkoek Zero (a type of gingerbread) in late 2015, which contains no added sugars and contains 18% of ditary fibres compared to the 3% of the original sugar-rich product. After the commercial success of this product, a no added sugars whole-wheat variety was introduced in 2017 and one with low calories in 2018. Peijnenburg Zero has been patented [8].

Frequently asked questions on the reduction of the sugar content

To which products can this sugar reduction strategy be applied?
The strategy can be applied to most food products that contain sugar, such as bakery products, sweets, cereals, desserts, ice-cream, soups and sauces. The strategy isn't applicable on products in which sugar is only responsible for the sweet taste, e.g. beverages.

How can the WUR sugar reduction strategy help food manufacturers?
The strategy offers food manufacturers the option to develop a low-sugar or no-sugar alternatives with the same structure and mouthfeel for their products in a very specific way. In many cases, it could even help improve the nutritional value, for example by adding fibres. The new recipes already take into account the applicable technological, quality and labelling requirements. Experiments can be performed to validate the strategy and fine tune the formulations towards optimization. The powerfulness of WUR strategy allows formulating products concepts of high quality , considerably reducing the time-to-market of the low-sugar or no-sugar alternatives.

How can the strategy benefit ingredient suppliers?
The strategy gives ingredient suppliers greater insight into the functionality of their sugar-replacing ingredients and, more particularly, new sugar-replacing ingredients. This could involve alternatives to polyols, such as, fragmented nutritional fibres from grain, fruit and vegetables. This knowledge enables the ingredient suppliers to better advise clients on the optimal application of their sugar replacers in a variety of food products.

Is this knowledge applicable in the development of new food products?
Absolutely. The theoretical insights about the various properties of sugar-replacing ingredients is based on an extensive physical theory on interactions between a multitude of food ingredients and forms a good basis for the development of new products. Examples include food products with a better nutritional value, such as high-fibre products, or the development of a totally new concept.

Why is Wageningen Food & Biobased Research an ideal partner?
Wageningen Food & Biobased Research has developed the sugar reduction strategy and the integration of the underlying physical theories themselves with the food science and technology aspects and applied it successfully to various food products like bakery. This has given them a unique position in the world. Leveraging on our knowledge of the behaviour of sugar and sugar replacers in food products and our state-of-the-art laboratories, we can address formulation and processing issues to a wide range of products.

More information?

Looking to reduce the sugar content in your products?

Contact Joost Blankestijn for an informal discussion about the possibilities

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More intrinsic information on the strategy?

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