The terms cooking salt, table salt, food salt and salt are often used synonymously in colloquial speech. In this respect the majority (in most cases >97%) of cooking salt, table salt and food salt consists of sodium chloride (NaCl). However, the term “salt” encompasses all chemical compounds that are composed of anions (negatively charged ions) and cations (positively charged ions) (and should therefore not be equated to common salt). Sodium chloride is soluble in water and dissociates into one positive sodium ion (Na+) and one negative chloride ion (Cl–). Thus strictly speaking there is no NaCl in the human body, only Na+ and Cl– ions. NaCl has a wide variety of effects in doughs and baked products: a) on the rheology of doughs by modifying the protein network (gluten; see figure 1), b) an influence on yeast activity, c) an influence on the texture of bread due to the forgoing points (see figure 2), and d) an effect on starch gelatinization (during baking) and starch recrystallization (during storage) [1-4]. However, the clearest effect arises due to e) its strong sensory perception.

**Sensory perception of sodium chloride**

The tastes perceived by the human sense of taste are divided into five categories (sweet, sour, salty, bitter and umami). The background to this is an evolutionary development of the respective flavor types, e.g. the purpose of bitterness is to warn against eating harmful plants. The impression of sweetness is intended to ensure the body is supplied with sufficient amounts of carbohydrates. On the other hand the purpose of salty is to guarantee the isotonic state of the body’s cells.

The characteristic perception of salt in the oral cavity is based on an ion channel called the ENaC (epithelial Na+ channel), which is permeable for Na+ ions. Na+ ions flow through the ENaC due to a concentration gradient on the...
tongue, causing the membrane to depolarize. As a result, Na⁺/K⁺ channels are opened and an action potential is produced. The action potential leads to a release of Ca²⁺ ions, which in turn liberate neurotransmitters and activate primary sensory neurons that convey the signals onwards to the brain. After this complex sequence, the signals are compared with other impulses and are interpreted as a salty taste impression. Furthermore, the anions adhering to Na⁺ ions can produce various other nuances in addition to the sensation of a salty flavor. The most strongly perceptible Na⁺ salt is NaCl, because only Cl⁻ is small enough to diffuse through the so-called “tight junctions” between the taste buds and thus generate an additional effect (anion paradox) [5, 6]. However, other chemical molecules such as halide anions (Br⁻, I⁻) or metal cations (Li⁺, K⁺, Mg²⁺), can produce a salt-like taste because small ions like Li⁺ and Na⁺ stimulate two different receptors [7] while bigger ions such as K⁺ stimulate only one of the receptors [8].

Furthermore, the use of NaCl promotes the volatility of flavor components and the repulsion of volatile flavor molecules, with the result that the perception of other kinds of taste is intensified [8]. The intensity of the sensory salty perception is directly related to the solubility rate of the salt in the food medium. Rapid solubility can intensify the salty taste, with the result that smaller concentrations of NaCl can be added to the food while retaining a constant salty flavor. Thus the interaction between salt molecules and the components of the dough system, and ultimately the type of distribution of the salts in the dough matrix, affect the sensory impression.

The influence of crumb texture on sensory perception

At the same time, the perception of the salty taste depends not only on the composition of the food constituents but also particularly on their arrangement in the food. In this connection, experiments have already confirmed the effect of the viscosity of the accompanying material on the release of sodium chloride and thus concluded that there is an altered perception. This behavior on the perception of salt was also confirmed in model media not containing starch [9]. In addition to studies in model media, a corresponding basic understanding was also acquired in edible foods such as baked products. Thus wheat breads with various different textures were examined in a study by Pflaum et al. [10]. Examination of the sodium content in the saliva revealed that a large-volume bread clearly and significantly accelerated the release of salt into the saliva, thus leading to a greater salty perception. The texture in bread is determined principally by the size, arrangement and distribution of the sponge-like interconnected gas bubbles of the bread and the thickness of the surrounding bread matrix (lamellae). In this respect the texture affects the perception in the oral cavity in three phases [11]:

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1. The release of sodium from the food matrix into the oral cavity. This is influenced for example by the availability of the sodium and its migration ability during texture deformation (chewing).
2. The distribution of the sodium in the oral cavity. In this respect mainly the viscosity of the saliva, which is affected by the food matrix, has a large effect.
3. The perception of sodium at the salt receptors (TRCs [taste receptor cells]). A role in this is played especially by the physical availability of the sodium, as well as by interactions with other taste perceptions or intensifying effects such as that caused by fat.
Thus the texture of foods has a decisive influence on the sensory perception of sodium chloride or of sodium.

The significance of sodium in nutritional physiology
Sodium stands center stage from both the sensory and the nutritional-physiological point of view: an increased sodium intake is directly related to cardiovascular diseases caused by arterial hypertension (high blood pressure) [12]. Since more than 35 % of the body’s daily sodium requirement is taken in via cereal products [13], this group of foods must be regarded as the main supplier of sodium in the human diet.

Sodium is very important for a large number of metabolic processes in the human body. Na⁺ ions influence particularly the osmotic pressure, membrane potentials, enzyme activities, transport processes and buffering [13]. In healthy organisms the concentration of Na⁺ ions is maintained as constant as possible via complex regulatory processes. An adult needs an average daily NaCl intake of approx. 1.5 g of NaCl to maintain the physiological processes [14]. To simplify the conversion: 1.00 g of sodium corresponds to 2.54 g of NaCl.

Most of the kitchen salt in Germany is offered for sale with added iodine, fluoride and occasionally also folic acid. Of these, iodine is an essential trace element which the body cannot produce by itself, and is mostly added as sodium or potassium iodate. It supports the functioning of the thyroid gland and is important especially for children, adolescents and pregnant women. About 70 % of the kitchen salt in Germany is marketed with added sodium or potassium fluoride to prevent caries (tooth decay).

The causal connection of an excess intake of NaCl as the cause of hypertension (high blood pressure) has been scientifically demonstrated in a great variety of ways by epidemiological, interventional and therapeutic studies and in numerous animal experiments. However, a few studies were unable to confirm the relationships. Nonetheless, current studies indicate that a reduced sodium intake can reduce high blood pressure, especially of “salt-sensitive” individuals, which has a beneficial effect on the occurrence of cardiovascular complications. However, other measures such as weight reduction, avoidance of alcohol, exercise, stress reduction and a changed diet also show a reduction in high blood pressure [15]. It has also been reported that a reduced consumption of NaCl is associated with a reduction in the risk of stomach cancer, improved bone mineralization and the prevention of kidney stones [13]. In parallel with this, however, adverse physiological effects can also occur due to a reduction in NaCl, such as reduced blood vessel elasticity, a raised cholesterol level, chronic exhaustion, an increasing risk of heart attack due to raised activity of the renin/angiotensin system, and increased resistance to insulin [16, 17].

The assumed daily NaCl intake in Western Europe is approx. 9–14 g for men and approx. 7–10 g for women [18]. Since this intake represents considerably more than the physiologically necessary amount of NaCl, the WHO is aiming at a daily NaCl consumption of 5 g [19]. To meet this recommendation, various research papers in recent decades have dealt with the reduction and substitution of NaCl in many areas of the food industry sector.
Potentials for reducing sodium chloride in baked products
There are four promising strategies to achieve this: A) salt substitutes, B) intensifying the perception of salty flavor, C) technological and process engineering possibilities, and D) cognitive approaches:

A) Salt substitutes: In the past sodium chloride has already been successfully replaced by individual compounds to reduce the sodium content of baked goods. Combinations of ingredients acting as salt substitutes are based on replacing sodium by potassium and calcium, for example, and also by anions such as phosphate and glutamate. Although they produce a salt-like taste, salts such as lithium and ammonium chloride are unsuitable due to their low heat stability and, in the case of lithium, because of their toxic effect. The use of salt substitutes also often entails adverse flavor changes, resulting in wheat baked products being described with the attributes metallic, bitter or chemical [20]. Moreover, the above-mentioned cations are also used as their iodide, sulfate and gluconate salts, but in sensory terms these can also display an off-flavor or can alter the texture of wheat bread. Potassium salts in particular are often used as substitutes, but they also frequently create an adverse metallic or bitter foreign taste in baked products [21]. However, they enable sodium reductions by 25% without large negative sensory restrictions. Substitutes are now available on the market that offer only minor flavor impairments.

B) Intensifying the perception of salty flavor: The food sector also uses substances that enhance the salty perception of a substance with a salty flavor, but without themselves showing any significant saltiness. The chemical structures of these ‘salt intensifiers’ vary greatly and comprise glycine, lysine, arginine, ornithine, trehalose and glutamate, but also include lactic acid salts. It can be assumed that the substitutes in question can be combined in such a way that both the taste and the quality of the baked goods are largely retained. It also helps if the baked products have an intensified, multi-layered flavor. For example in a study by the North Rhine-Westphalia Consumer Advice Center in Germany in 2012, rye and wholegrain breads were marketed with a slightly reduced average sodium chloride content. It can be concluded from this that the more intense flavor of rye and wholegrain products enables a lower amount of added sodium while retaining the same intensity of flavor. This can also be achieved through roasted flavors (e.g. malt). Another possibility is the use of fermented products such as fermented soya, which allowed a 25% reduction in sodium chloride to be achieved [22]. The beneficial effect of sourdough on sodium reduction has already been confirmed in our own study in the context of the thesis “Fundamental studies on sodium reduction in processing cereal-based foods” (TU München, 2012) by Dr. Margit Beck.
C) Technological and process engineering possibilities: As described above, the perception of saltiness is influenced greatly by its intensity and above all contrast effect. This can be achieved for example by using coated sodium chloride crystal granules. The sodium chloride is thus deliberately unevenly distributed in the crumb. As a result a reduction of up to 50% of the sodium chloride used was achievable, while the perceived saltiness remained constant. However, it must be noted that the use of excessively large crystals led to localized discoloration of the crumb color and a marked reduction in popularity [23]. Konitzer et al. showed that coarse uncoated crystals also accelerated the release of sodium chloride into the saliva and intensified the salty impression. Thus it was possible to achieve a 25% reduction in sodium chloride content [24]. Layers with a reduced and an increased sodium chloride content can be used when manufacturing laminated doughs. With a sufficiently large concentration difference, the contrast is increased so far that a 28% reduction in sodium chloride was possible [25].

D) Cognitive approaches: This is exactly the starting point of the statutory requirements and self-imposed guidelines or campaigns in Europe. Examples include Portugal with its legal limit value of 1.4 g of NaCl per 100 g of finished product since 2010, the Netherlands with its voluntary guideline at 1.8 g of NaCl per 100 g of dry matter or Austria with its voluntary campaign aimed at a target of 1.7% NaCl relative to flour (in this respect the different quantity reference must expressly be noted. For assistance: 2 g NaCl per 100 g of flour (the usual baker’s percentage) corresponds to about 1.4 g of NaCl per 100 g of final product and thus to 0.56 g of sodium). The aim behind it is that the consumer slowly becomes accustomed (voluntarily or through compulsion) to lower salty taste impressions and is thus “educated” to a lower consumption of sodium. However, this is also supported by scientific knowledge. For example it was possible to show that with a steady reduction of sodium chloride in tomato juice during 16 weeks, the reduced sodium juices were assessed as distinctly more pleasant at the end of this time than at the start of the study. However, it could also be shown that highest sodium contents continued to be assessed as the most popular. This shows that scarcely any losses would be expected as a result of a simultaneous reduction in sodium chloride across the entire industry. However, if individual companies step out of line from this strategy and offer products with the original NaCl content, this would undermine the strategy [26].

Summary
Increasing dietary awareness, the legislator’s efforts to influence public consumption habits and the fact that more than 35% of the daily intake of sodium is ingested via baked products is forcing the baking sector to respond to the changed situation. In particular, a combination of the points mentioned above represents a very promising strategy for a reduction in sodium while keeping the sensory quality of the baked goods constant. As a result of this it is possible for bakeries to adapt their products for the future, including in particular even bakeries with process technology solutions ranging from the simple (use of sourdough or malt production) to the complex.

References
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