Universität für Bodenkultur Wien
University of Natural Resources and Life Sciences, Vienna

Sticking of waffles on baking plates – Influence of ingredients, baking plate material, baking parameters and release agents

Doctoral thesis

Submitted by Regina Huber, MSc.

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Supervised by Assoc. Prof. Dr. Regine Schönlechner

University of Natural Resources and Life Sciences, Vienna
Department of Food Science and Technology

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Hiermit versichere ich, die hier vorliegende Arbeit selbstständig und nur mit den angegebenen Hilfsmitteln erstellt zu haben. Diese Arbeit wurde nicht vorher an anderer Stelle eingereicht.

Declaration of originality

I hereby declare to the best of my knowledge that the content of this doctoral thesis at the University of Natural Resources and Life Sciences, Vienna is based on my own original research. All assistance received and references cited have been acknowledged. Furthermore I declare that this thesis has not been previously or concurrently submitted to any other educational institution for achieving any other academic degree.

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Regina Huber, MSc.

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1. Introduction

1.1 Waffle production and important sticking influences

Waffles are defined as sweet convenience products with a soft texture, similar to a cake. Typical ingredients for waffles are eggs, water, sugar and sugar substitutes, flour and starch, fat, leavening agents, emulsifiers, preservatives and flavours (Tiefenbacher 2009). In industrial scale, waffles are produced by first dissolving sugar and sugar substitutes, preservatives, flavours, part of the leavening agents and eggs in water. Then starch, emulsifiers and flours are added until a typical batter structure is achieved. Fat is added last and only shortly stirred into the mixture. During mixing high shear forces must be avoided, because risk of gluten development increases. Batter aeration provides softer structure. The pH of batter is lowered by flour and sugar syrups, and increased by sodium bicarbonate, eggs and hard water. Batter density ranges usually for waffles from 1.05 to 1.15 g/m^3. After a resting time of 15 to 30 min batter is deposited onto the hot baking moulds, which are closed immediately, and baked at 140 to 180 °C for 110 to 180 s, depending on the thickness of the waffle and batter type (Tiefenbacher and Wrigley, 2004; Ashokkumar and Adler-Nissen, 2011). During baking steam expansion and starch gelatinisation forms the waffle (Caballero et al., 2003). Moisture content of waffles should be approx. 10 to 15 %, although during cooling down the moisture content decreases by about 2 %. Water activity of waffles should be below 0.8, optimally 0.75 for a longer shelf life. Equilibrated moisture content and water activity are important for packaging waffles to avoid condensation of water vapor (Tiefenbacher and Wrigley, 2004).

During the **baking process** it is important that the waffles are fully baked but not burnt, and in particular that they do not stick onto the baking plates. If a waffle sticks to the baking plate, completely or partly (when it is torn during take-off due to insufficient waffle stability), it must be removed. An industrial waffle oven produces 5,000 to 20,000 waffles per hour, which are approx. 500 to 1,000 kg. One percent of sticking waffles are between 50 to 200 waffles, or five to ten kg loss of raw material in the case of such an oven from CFT Haas. On one day 40 to 80 kg of raw material would then be lost. Further, sticking waffles lead to more sticking problems, which means more sticking waffles and residues on the baking plates, until blocking of the downstream line or the whole oven system. Baking plates with sticking waffle waste must be cleaned. This interrupts continuous waffle baking in industry, which can cause significant product loss and increased costs and therefore has to be kept to an absolute minimum. However, reasons for sticking are not known in detail (Huang et al. 1990; Määttä et al., 2007; Piispanen et al., 2009; Tiefenbacher, 2009; Chavan et al., 2016; Liu et al., 2002).

Sticking of waffles is greatly influenced by baking plate material, release agent, baking temperature and time, room temperature and humidity, and also by batter ingredients like flour or starch type, sugar and sugar sources, fat sources, emulsifiers or leavening agents. Sticking waffles show worst release behaviour due to its increased sticking characteristics (Tiefenbacher and Dobrovics, 1999; Sadd et al., 2008; Ashokkumar et al. 2012).

1.2 Influence of the ingredients

As one of the main **ingredients starch and flour** type greatly influence texture of the waffle as in any other bakery product (Huang et al., 1988; Onyango et al., 2011; Maghaydah et al. 2013; Pérez et al. 2013; Ronda et al. 2011; Hadnađev et al. 2015; Kiyoshi et al. 2016) and thus highly influence waffle stability. For waffles soft wheat with fine granulation, low to medium protein content and low water absorption capacity should be used (Tiefenbacher, 2009). In soft-milled wheat the adhesion between protein and starch is weaker. Low water absorption means that less water is needed to get a fluid batter, which is better. Flours maturing time should be 1 to 2 weeks (Mößner, 2009; Palav, 2016). Flours for waffles and wafers should have the following ideal analytical parameters: moisture content approx. 14.5 %, protein content approx. 9.5 %, protein (dry matter) approx. 11 %, wet gluten approx. 25 %, ash content approx. 0.4-0.6 %, absorption below 55 %, no ascorbic acid addition. Particle size distribution influences waffle quality – the finer the flours, the more water is bound and the smoother the waffle surface. Coarser particles are less stable in the batter – a proper balance is required (Tiefenbacher, 2009). In contrast to bread flour, waffle quality cannot be predicted by classical rheological analysis like farinogramm or extensogramm.

Starch in flour swells during mixing and gelatinises during baking. Proteins build up a gluten network, which provides mechanical stability, but can make a batter unusable if a too strong network is formed, which increases batter viscosity (Patel and Chakrabarti-Bell, 2013). Therefore also the mixing step of the waffle batter is important – high shear forces or high batter temperatures should be avoided (Tiefenbacher and Dobrovics, 1999; Tiefenbacher and Wrigley, 2004). Another possibility to reduce the amount of gluten is to add starch. Up to 20 % of the wheat flour can be replaced by other flours and starches for flour dilution, colour effects, taste or texture influences. Lupine and rice flour, corn, tapioca, potato and wheat starch can be used to compensate high gluten content. They can increase the batter solids and final waffle stability, but they give also a drier structure and shorten the shelf life of waffles due to increased retrogradation (Tiefenbacher, 2009; Onyango, et al. 2011).

Sugar and sugar substitutes are known to influence browning behaviour due to the Maillard reaction (Ameur et al., 2007; Mohd et al., 2009; Pareyt et al., 2009; Purlis, 2010), which has effects on the sticking behaviour of waffles. Burnt waffles tend to stick. Browning is intensified with increased sugar amount and increased pH, e.g. by addition of sodium bicarbonate or ammonium bicarbonate (Schünemann and Treu, 2009). Additionally, dissolved sugar increases the surface tension, which results in a more liquid batter, and can reduce starch swelling during mixing, thus change the amount of required water (Ameur et al., 2007; Tiefenbacher, 2009; Purlis, 2010). Sugar granulation is very important, because it influences solubility in batter and finally waffle texture. Non-dissolved sugar particles lead to dark spots. Residues from sugar batters increase the carbonised plate residues. Sugar during mixing reduces swelling of starch and further required water amount, reduces risk of gluten development, and increases the gelatinisation temperature of starch (Tiefenbacher, 2009). Effects of sugar rheological behaviour are also known for other sweet bakery products. Cookie properties are influenced by increasing diameter and decreasing height, when sugar content is increased. Cookie dough hardness decreased with increasing sucrose level. Higher sucrose levels lead to increased dissolution during baking and further higher spread rate. Sugar delays the chemical leavening action and influences the vertical expansion during baking, because of a longer oven rise followed by a more pronounced collapse. Cookie moisture decreased with increasing sugar amount (Pareyt et al., 2009). With new equipment sugar content of waffles could reach up to 30 %, but sticking of waffles was increased with increasing sugar content (Haas et al., 1991).

Replacing sucrose by other sugars or **sugar substitutes** changes batter characteristic and further process parameters. Some polyols decrease the water activity and increase freshness – glycerol and sorbitol are recommended. Glycerol E 422 is a liquid polyol, a very good humectant, has a similar sweetness to sucrose, shows no browning reaction, and is used as solvent for flavours, colours and other additives. Sorbitol E420 has no browning characteristics, and is pH and heat stable. Sorbitol has lower water activity values than sucrose. Sucrose is sweeter than sorbitol and glycerol, but sorbitol and glycerol are more hygroscopic than sucrose (Schünemann and Treu, 2009). Polyols are used from 1 to 10 % (Tiefenbacher, 2009).

Fat and oils in waffle batters lead to softer texture of the waffle and are a good flavour carrier (Mößner, 2009). Fat provides a release film during baking due to higher heat conductivity. Disadvantageous effects are residues of fat waste on baking plates. Depending on chain length and number of unsaturated fatty acids fats show different stability. The more double bonds in fatty acids, the more thermal instable they are due to auto-oxidation. Melting point decreases with shorter chain length and increasing number of double bonds. For waffles stable fats with little content of unsaturated fatty acids and iodine values below 85 should be used to minimise thermal fat degradation and increase shelf life. Additives in fats, such as emulsifier, antioxidants or colorants can change baking characteristics. Moisture content in margarines is different depending on the type. Fat for waffles and wafers should be solid at 25 to 30 °C; at 37 °C the taste should be greasy. Trans-fatty acids in baking fats provide higher stability during high baking temperatures, which influences cleaning intervals, but they are limited to 2 % in the product by the law. The use of highly unsaturated fatty acids is not recommended for waffles (Schünemann and Treu, 2009; Tiefenbacher, 2009). Higher fat levels lead to higher spreading rate of cookies due to increased mobility of the dough. Fat replacers can be fat-based emulsifiers, such as mono- and diglycerides (Pareyt et al., 2009). The required fat amount depends on recipe and other batter ingredients, baking plate coating and the amount of waste left on the baking plates during the production process – the more waste on a plate, the more fat is required to improve waffle release. Usual fat amounts of waffle batters are 18 to 29 % (Tiefenbacher, 2009). Fat might retard chemical leavening action and affect swelling of the cells during baking of cookies. Cookie weight and moisture content decreased with increasing fat level, probably due to incorporated air. The surface became uneven with decreasing fat levels (Pareyt et al., 2009).

Leavening agents are chemicals like sodium bicarbonate, sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate and mono calcium phosphate, which lead to better steam release, softer, more porous and lighter waffles (Schünemann and Treu, 2009; Vetter, 2003). Sodium bicarbonate (E500ii) increases the pH, which leads to more intensive browning and increases alkaline taste (Hesso 2015). Ammonium bicarbonate (E503i) increases the pH and intensifies browning as well, but pore size is more homogeneous, because of faster reaction, which makes the waffle softer and increases volume; further it has a strong characteristic flavour and increases residues and waste on baking plates. Ammonium bicarbonate is added at a maximum of 0.1 % (Sadd et al., 2008). Sodium pyrophosphate (E450i) reacts with sodium bicarbonate and should be used in the ratio 1 : 0.73 sodium pyrophosphate : sodium bicarbonate. It is activated by heat during baking. The lower the sodium pyrophosphate amount, the lower is the leavening reaction and the smaller the pore size. Too much sodium pyrophosphate gives a metallic taste. Mono-calcium phosphate (E341i) has a very fast leavening reaction compared to other leavening agents and is used usually for American breakfast waffles (Miller, 2016). Magnesium hydroxide carbonate (E504) improves waffle release and can protect water from moisture migration (Haas et al., 1991).

Water hardness and pH value of water influences the batter rheology and the batter pH. The pH of the batter can be adjusted by the amounts of leavenings. High water hardness is no problem for waffles, but may require a slight reduction in leavenings. Baking plate residues are increased with high water hardness. Softer water shows softer waffle texture. Stable waffles can be taken off easier. Water temperature between 20 to 30 °C for batter preparation should be constant during the process, because the warmer the water, the thicker the batter (Tiefenbacher and Wrigley, 2004).

Water also influenced the adhesive strength of other food products such as tomato paste. The adhesive strength of the tomato paste deposit could be reduced by hydration (Liu et al., 2002). Water type also influences food products in their sensory behaviour, as different types of whiskey or wine show (Bringhurst, 2014; Forghani et al., 2015). Overall, water hardness and the total mineral content are important for waffles because: 1^{st}) a weak waffle structure results in an easy take-off with less required energy, but the waffle can break and partly stick to the baking plate; or 2^{nd}) the waffle structure is strong, then the waffle can be taken off in one piece with low required take-off force because there is no sticking; or 3^{rd}) the waffle structure is strong and the required take-off force is high, which shows increased adherence tendencies. The required water amount in the batter depends on flour quality and egg source. The water amount in waffle batter should be about 5 to 15 %, when liquid eggs and no additional milk products are used. Depending on water hardness recipe can be adjusted by leavening agents and salt to balance this influence (Tiefenbacher, 2009).

1.3 Influence of the baking plate material

1.3.1 Basic baking plate materials

The **baking plate material** used in waffle industry is often ductile iron because of its volumetric heat capacity, heat conductivity and mechanical robustness. The baking plate must be resistant against high pressure during closing of the baking plate at common oven speed. Baking plates should be long durable, provide improved release characteristics and have sufficient volumetric heat capacity. Additionally, they should be easy to clean and be resistant against cleaning methods. The cleaning method should be compatible with the surface materials, such that the surface is not damaged, regardless of whether it is a chemical, physical or mechanical treatment (Reinhart et al., 2012; Haas et al., 2006). Ductile iron exhibits all of these characteristics except good release properties. Pre-tests showed that other baking plate materials and surface treatments might show better release properties. Good release characteristic requires less cleaning. If these alternative materials also show high robustness, good heat storage capacity and high resistance against cleaning procedures with a long durability of the baking plate and the production price is comparable, then such baking plate materials or surface treatments might be an alternative to ductile iron. Coatings are applied to improve the release properties and decrease the adherence of baked goods by the principle of reducing surface energy (Valipour et al., 2013).

Ductile iron is used in several common household kitchen articles such as pans, which might be specially treated (Zhang and Wang, 2008) with non-sticking and heat insulation coatings (Jin and Li, 2010), as well in waffle and wafer industry as basic material with or without coating (Haas et al., 1991; Bischof, 2010). Graphite treatment increases cohesiveness and robustness of such material applications. Ductile iron with lamellar graphite is corrosion resistant, while ductile iron with spheroidal graphite shows steel similar properties (Weißbach, 1994). Common baking plates are often made from ductile iron, but it quickly gets dirty during the baking process (Reinhart et al., 2012).

Grey iron is used as alternative to the standard baking plate material ductile iron in wafer and waffle industry. Grey iron has graphite inclusions and provides better heat storage capacity than ductile iron, but quickly gets dirty in waffle oven baking processes. Further it is often used as basic material when coated baking plates are used (Bischof, 2010; Reinhart et al., 2012).

Steel is chemically resistant, easy to clean, mechanical robust, often used in food industry (especially stainless steel) and has a good volumetric heat capacity. Low alloyed steel can be used in wafer industry (Reinhart et al., 2012). Choosing the right stainless-steel has an impact on the growth of microorganisms and hygiene of food materials (Stone and Zottola, 1985). Steel was used in several studies as basic material for coatings, which mostly showed better release characteristics than steel itself (Dong, 2000; Xubiao, 2002; Bong-Ki, 2004; Saikhwan et al., 2006; Yang et al., 2009; Yu et al., 2010; Goleus et al., 2012; Bodycote, 2013; Valipour et al., 2013). A pan can be made from a three-layer system with medical stainless steel, aluminum and magnetic stainless steel, the last material being on the outside. Properties of such special stainless steel pans are a smokeless effect, good insulation properties, continuous heat distribution and non-sticking characteristics (Yang, 2010). Xubiao (2002) described another pan, also made from similar layer combinations, which had a heat conduction coating outside, which results in good heat conduction and non-sticking properties as well.

Generally stainless steel has a lower conductivity and transfers less heat compared to alloyed steel and ductile iron (Venkateshmurthy and Raghavaro, 2011). Therefore stainless steel provides not such good conditions as low alloyed steel for wafer industry (Reinhart et al., 2012).

Whey protein fouling deposits, sweetened condensed milk and caramel have been studied on stainless steel and showed that the adhesion of whey protein to stainless steel is higher at increasing temperature (over 75 °C). Above the caramelisation and polymerisation temperature it is assumed that adhesion to the steel surface would increase strongly (Goode et al., 2013). Pre-adsorption of whey protein onto steel heat exchanger surfaces at room temperature influenced the protein fouling at pasteurisation temperature only little (Lv et al., 2015). Beside these influences of material type, reduced surfaces of steel showed higher release rates. Steel is often used for heat treatments of food, especially in milk industry and for cooking. With increasing temperature steel shows more adherence and sticking behaviour, but this can be equilibrated with coatings, which improve the release characteristics (Ashokkumar and Adler-Nissen, 2011).

1.3.2 Coatings

Titanium nitrite coating (TiN) combines advantages of other coatings. A nitridic-carbidic-oxidic diffusion surface treatment is applied with a Corr-I-Dur treatment on cookware, which shows good release and non-corrosion characteristics to baked food products. This coating is an option for surface treatment and coating of baking plates. The thermo-chemical process includes nitrocarburisation with subsequent oxidation and shows excellent abrasion properties (Bodycote, 2013). A new aluminium-chromium nitride coating improves the release of food from contact materials (Oerlikon, 2015). Titanium-copper sintered alloy (Ti-Cu alloy) provides antibacterial properties, which prevents the adhesion of bacteria. The Ti-Cu alloy showed increased hardness and compressive strength and slightly improved corrosion resistance compared to a Ti reference material (Zhang et al., 2013). Steel cookware with titanium enamel and less fluoride and anhydrous boron inclusions was more heat stable than commercial enamel (Goleus et al., 2012).

Therefore titanium might be an alternative for baking plate materials, applied as nitrite to combine abrasion properties with antibacterial characteristics.

1.4 Influence of the baking process

The **baking process** is influenced by the following baking parameters: the heating system, the baking temperature of the baking surface, the temperature of the deposited raw material, the baking or contact time, the air humidity and the air circulation. Often earlier a uniform temperature and water content within the product was generally assumed. But during baking physical, chemical and biochemical changes occur such as volume expansion, evaporation of water, formation of porous structure, denaturation of protein, gelatinisation of starch, crust formation and browning reaction, that influence baking process and sticking behaviour. Heat and water transport within the bakery product happens by convection, radiation, conduction from baking plates, evaporation of water and condensing steam (Sablani et al., 1998). The major transport mechanism of heat and water during baking biscuits is the evaporation-condensation of water rather than heat conduction. Temperature should be stable during baking (Reinhart et al., 2012; Haas et al., 2006).

Heating systems of baking apparatuses for a low number of baking plates usually use electrical current (Carbon and Green, 1994), but further ovens can be heated inductively, or gas-fired. The heat transfer of tunnel ovens to the products such as biscuits is such optimised to reduce baking time, to optimising band temperature, baking chamber temperature and humidity. Baking time was reduced for cakes baked in an impingement oven, which reflects irradiation, compared to a conventional oven. Microwaving reduced baking time to half of the impingement oven baking time, but cakes had less volume and firmer structures compared to controls of similar colour. Increasing baking efficiency and better heat transfer to products reduces baking time and saves energy (Sablani et al., 1998). Cakes, bread and cookies were direct-gas and indirect-gas fired in convection ovens, where the process with high humidity showed lighter product colour, increased volume and reduced moisture loss. Humidity affects colour, baking speed, crust and crumb structure and final product moisture, but is often not measured in-situ. Ovens traditionally are time and temperature controlled, sometimes additionally by heat transfer and airflow speed control. Direct fired ovens come into contact with the baked product and build up water vapour; indirect-fired ovens do not. At high air flow the ovens heated faster than at low airflow. For the indirect-fired oven the cycle time was longer. The temperature of tunnel oven stabilised between 22 to 31 min depending on oven parameters (Xue et al., 2004; Xue et al., 2003), which is similar compared to waffle ovens that need approximately 30 min to reach baking temperature. Comparing different studies on baking ovens shows that ovens can be controlled by several variables and then should be adjusted to the product (Zareifard et al., 2009; Haas et al., 2006).

Although there are several influences on the baking process, the main influences on product quality are baking temperature and baking time. Slower baking with less temperature gives smoother colour distribution and provides less sticking products. Quicker and hotter baking leads to sticking, unequal baked crumb and non-homogenous surface colour distribution (Sablani et al., 1998). Browning reaction is different depending on baking temperature. Intensified reactions can lead to sticking waffles on baking plates (Ameur et al., 2007). A slight increase of temperature also increased the volume expansion. However, a strong increase in temperature leads to a decrease of volume and a darker surface colour with increased hardness (Marcotte, 2005).

1.5 Influence of the release agent

Release agents are used to prevent sticking of baked products such as waffle and wafers, on baking plates. Different thermally stable oils can be used for this aim. Thermally non-stable oil can be used for building a film on the baking plate, which carbonises over time. Thermally stable oils can be used for creating a release film, which is more stable and does not darken so fast, thus reduces cleaning intervals. Release agents are usually vegetable fat-based dispersions (e.g. heat stable palm fat, corn fat, shortenings, waxes, paraffins and sterols) with lecithin to prevent crystallisation. Optionally minor ingredients are emulsifiers (e.g. mono- and diglycerides), blocking agents (e.g. calcium carbonate, starches), release improvers (e.g. phosphates), homogenising solvents (e.g. propylene, sorbitol, glycerin), enzymes to prevent microbial growth (e.g. exo-amylase) and acids (e.g. sorbic acid, acetic acid, propionic acid). Essential oils (e.g. thyme oil, onion oil) can be used as preservative with flavouring effect for special applications (Meeker, 1994; Purves, 1987; Strouss, 1982; Clapp and Campell, 1990; De Levita et al., 2005; Feng and Stinson, 2006). Typically release agents are based on heat stable fats with lecithin mixtures, but they can also be acidic-based for combining cleaning and release in one (Oexmann, 2008). Available and common release agents, which are used in the bakery industry are “Dübör PR100” (waxes, vegetable oil and lecithin) and “Bandex“ (rapeseed oil-lecithin mixture), increasingly applied at the beginning of baking process. Different release agents show different release characteristics and different degrees of dirtiness. Wax and paraffin are not providing the best release characteristics (Haas et al., 1991).

Deposition of release agent by brushes is time consuming and may lead to contamination by losing hairs of the brush. Alternatively the release agent can be warmed up in a spray pistol. Spray pistols with movable head provide greater flexibility and reduce required release agent amount by approx. 80 % (Frisch, 1990). For waffle and wafer production release agents are either applied on the pre-heated warm baking plate, and then the baking plate is heated up until process temperature, or directly onto the baking plates at final baking temperature. More oil and release agents are needed in the start-up phase before batter deposition and after the first baked waffles. During baking very little release agent is needed when a self-fattening film from the waffle is built. If heating-up and cooling-down phases are often carried out, the baking plates require more release agent, which leads to faster dirt build-up on the plates, compared to continuous runs. Baking plates must be oil or release agent sprayed again after cleaning (Haas et al., 1991) to prevent corrosion of the baking surface (Dorfman, 2012).

2. Objectives

The **objective of this study** was to analyse the influence of batter ingredients on the quality (stability) and sticking behaviour of fresh egg waffles, further called waffles. The influence of different baking plate materials at different baking parameters (baking temperature and baking time) and with different release agents was studied. Common ingredients, which improve the release of the waffle from the ductile iron baking plate (mostly used as standard material for baking plates in waffle ovens) and ingredients, which deteriorate their release should be determined. All waffle trials were performed on equipment that is usually used in industrial baking. Analysed parameters were, 1st) the effect of starches from different sources (in detail the partial replacement (30%) of wheat flour by either lupine flour, rice flour or potato starch); 2nd) the effect of sugar source and sugar substitutes (crystal sugar, powdered sugar, sorbitol and glycerine); 3rd) the effect of different leavening agents (sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate, or mono calcium phosphate); 4th) the effect of different fat sources (rapeseed oil, cocos fat, butter or margarine); and 5th) the effect of water source (tap water 12 *dH and distilled water) on the quality (stability) of the waffle and on its release from the baking plates.

These effects of ingredients are published in the first two papers: 1. "Waffle production: Influence of batter ingredients on sticking of fresh egg waffles at baking plates – Part I: Effect of starch and sugar components", which is presented in chapter 3, and paper 2: "Waffle production: Influence of batter ingredients on sticking of waffles at baking plates – Part II: Effect of fat, leavening agent and water", which is presented in chapter 4.

In consequence, the standard baking plate material ductile iron was compared to alternative baking plate material grey iron and low-alloyed steel and the surface treatment TiN coating at moderate (140 °C bottom baking plate and 145 °C top baking plate for 110 s) and faster baking speed (160 °C bottom baking plate and 165 °C top baking plate for 90 s) with a waffle release-improving recipe and a waffle release-worsening recipe. The influence of release agents on the baking process was studied for the mentioned baking plate materials with the same recipes at common baking speed. Analysed release agents were "Bandex", a rapeseed oil-lecithin based mixture, "Dübör PR100", a wax-oil-lecithin mixture, and "Amarnakote C", an emulsifier-acid based cleaning and release agent mixture. These effects of baking plate material, baking parameter and release agent are published in the third paper: "Waffle production: Influence of baking plate material on sticking of waffles" and presented in chapter 5.

3. Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates – Part I:

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ORIGINAL RESEARCH

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Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates—Part I: effect of starch and sugar components

Regina Huber | **Regine Schoenlechner**

University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria

Correspondence
Regine Schoenlechner, University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria.
Email: regine.schoenlechner@boku.ac.at

Abstract

Fresh egg waffles are a sweet convenience product typically baked from eggs, water, sugar, flour, fat, leavening agents, emulsifiers, preservatives, and flavors. In industrial production, waffles are baked continuously in high amounts of up to 200 kg raw material per hour. Therefore, it is important that the waffles do not stick onto the baking plates, which can cause significant product loss and increased costs due to interruption of the baking process, required cleaning procedures, and restarting of the energy- consuming start- up phase. Sticking of waffles is greatly influenced not only by baking plate material, release agent, baking temperature, and time, but also by the batter ingredients. In this study, effects of different starches and sugar components were investigated. Within the selected starches, potato starch demonstrated the highest effects on increasing waffle stability and releasing properties compared to wheat and lupine flour (less than 7% sticking waffles). Rice flour performed worst, with almost 50% of sticking waffles. Most of these waffles were broken during take- off, due to their crumbly texture. Within the sugar components, glycerine was better suitable than sorbitol and crystal sugar was superior compared to powdered sugar. They required less take- off force. It could be demonstrated that waffles with increased stability and texture were those that showed the least number of sticking waffles, thus the main aim of batter ingredients was to improve waffle quality. Waffle quality was influenced by batter parameters, significant correlations could be found, for example, a positive correlation between pH- and L- value, negative correlations between pH- and a- value, or density and aw- value. This resulted in significant correlations with take- off- force, which was correlated with L*- and b*- value (negative) and positive to a*- value. Sticking behavior was strongly associated with b*- value (positive) and to a*- value (negative).

KEYWORDS

Fresh egg waffle, starch, sticking, sugar, waffle batter

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Regina Huber | Regine Schoenlechner

University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria

Correspondence
Regine Schoenlechner, University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria.
Email: regine.schoenlechner@boku.ac.at

Abstract

Fresh egg waffles are a sweet convenience product typically baked from eggs, water, sugar, flour, fat, leavening agents, emulsifiers, preservatives, and flavors. In industrial production, waffles are baked continuously in high amounts of up to 200 kg raw material per hour. Therefore, it is important that the waffles do not stick onto the baking plates, which can cause significant product loss and increased costs due to interruption of the baking process, required cleaning procedures, and restarting of the energy- consuming start- up phase. Sticking of waffles is greatly influenced not only by baking plate material, release agent, baking temperature, and time, but also by the batter ingredients. In this study, effects of different starches and sugar components were investigated. Within the selected starches, potato starch demonstrated the highest effects on increasing waffle stability and releasing properties compared to wheat and lupine flour (less than 7% sticking waffles). Rice flour performed worst, with almost 50% of sticking waffles. Most of these waffles were broken during take- off, due to their crumbly texture. Within the sugar components, glycerine was better suitable than sorbitol and crystal sugar was superior compared to powdered sugar. They required less take- off force. It could be demonstrated that waffles with increased stability and texture were those that showed the least number of sticking waffles, thus the main aim of batter ingredients was to improve waffle quality. Waffle quality was influenced by batter parameters, significant correlations could be found, for example, a positive correlation between pH- and L- value, negative correlations between pH- and a- value, or density and aw- value. This resulted in significant correlations with take- off- force, which was correlated with L*- and b*- value (negative) and positive to a*- value. Sticking behavior was strongly associated with b*- value (positive) and to a*- value (negative).

KEYWORDS

Fresh egg waffle, starch, sticking, sugar, waffle batter

1 | INTRODUCTION

Fresh egg waffles (subsequently called waffles throughout this manuscript) are a sweet convenience product with a soft texture, similar to a cake. Typical ingredients for waffles are eggs, water, sugar and sugar substitutes, flour and starch, fat, leavening agents, emulsifiers, preservatives, and flavors (Tiefenbacher, 2009). In industrial scale, waffles are baked at 140–180°C for 110 and 180 s, depending on thickness of waffle and batter type (Ashokkumar & Adler- Nissen, 2011; Tiefenbacher, 2003). Important is that the waffles are fully baked but not burnt, and that they do not stick onto the baking plates. If a waffle sticks to the baking plate, completely or partly (when it is torn during take- off due to insufficient waffle stability), it must be removed by hand and the baking plate must be cleaned. This interrupts continuous waffle baking in the industry, which can cause significant product loss and increased costs and thus has to be kept to an absolute minimum (Chavan, Sandeep, Basu, & Bhatt, 2016; Huang, Lindamood, & Hansen, 1988; Määttä et al., 2007; Piispanen et al., 2009). In order to decrease product loss or to prevent interruptions of industrial waffle baking, a good- quality waffle is characterized by high stability, that is, it is not torn during the needle take off, shows no holes or other irregularities, has an even color distribution, and does not stick to the baking plate during take- off. Waffles that are too soft or crumbly tend to tear, even if they do not stick to the baking plate.

Sticking of waffles is greatly influenced not only by baking plate material, release agent, baking temperature and time, room temperature, and humidity, but also by the batter ingredients like type of flour or starch, sugar, fat, emulsifiers, or leavening agents (Ashokkumar, Adler- Nissen, & Møller, 2012; Sadd, Hamlet, & Liang, 2008; Tiefenbacher & Dobrovics, 1999). In this study, the influence of the addition of starch from different sources to wheat flour as well as sugar and sugar substitutes were investigated. Starch and flour type greatly influence texture of the waffle as in any other bakery product (Huang, Lindamood, & Hansen, 1990; Maghaydah, Abdul- hussain, Ajo, Tawalbeh, & Elsahoryi, 2013; Onyango, Mutungi, Unbehend, & Lindhauer, 2011; Pérez, Matta, Osella, de la Torre, & Sánchez, 2013) and thus highly influences waffle stability. For waffles, wheat flour of fine granulation, low to medium protein content, and low water absorption capacity should be used. In contrast to bread flour, waffle quality cannot be predicted by classical rheological parameters like farinogramm or extensogramm. Starch in flour swells during mixing and gelatinizes during baking. Proteins build up a gluten network, which provides mechanical stability, but can make a batter unusable if a too strong network is formed, which increases batter viscosity. Important is thus the mixing step of the waffle batter, for example, high shear forces or high batter temperatures should be prevented (Tiefenbacher & Dobrovics, 1999; Tiefenbacher & Wrigley, 2004). Another possibility to dilute the amount of gluten is to add starch. Lupine and rice flour, corn, tapioca, potato, and wheat starch can be used for this aim to compensate high gluten content. They can increase the batter solids and final waffle stability, but they give also a drier structure and shorten the shelf life of waffles due to increased retrogradation

(Onyango et al., 2011; Tiefenbacher, 2009). Sugar and sugar substitutes are known to influence browning behavior due to Maillard reaction (Ameur, Mathieu, Lalanne, Trystram, & Birlouez- Aragon, 2007; Mohd Jusoh, Chin, Yusof, & Abdul Rahman, 2009; Pareyt et al., 2009; Purlis, 2010), which has effects on sticking behavior of waffles. Browning is intensified with increased sugar amount and increased pH, for example, by addition of sodium bicarbonate or ammonium bicarbonate. Additionally, dissolved sugar increases the surface tension, which results in a more liquid batter, and it can reduce starch swelling during mixing, thus change the amount of required water is necessary (Ameur et al., 2007; Purlis, 2010; Tiefenbacher, 2009). Sugar granulation is very important because it influences solubility in batter and finally waffle texture. Replacing sucrose by sugar substitutes changes batter characteristic and further process parameters. Glycerine has a similar sweetness to sucrose, but shows no browning reaction as well as sorbitol, which additionally is pH and heat stable.

The objective of this study was to analyze the influence of batter ingredients on the quality (stability) and sticking behavior of waffles. Up to now, there is no detailed scientific knowledge available on these phenomena, as waffles are highly under- researched in general. Analyzed ingredients for this part of the study were as follows; first, the effect of starches from different sources, in detail the partial replacement (30%) of wheat flour by either lupine flour, rice flour, or potato starch, and second, the effect of sugar source and sugar substitutes (crystal sugar, powdered sugar, sorbitol, and glycerine) on the quality (stability) of the waffle and on its release from the baking plates. All waffle trials were performed on pilot scale using equipment that is usually used in industrial baking.

2 | MATERIALS AND METHODS

2.1 | Materials

The following flour and starch ingredients were used for this study: wheat flour W480 (type “Allerfeinst”, Good Mills GmbH, Schwechat, Austria; protein content 11% dm, starch content 72% dm), toasted lupine flour (Frank Food Products, Twello, NL; protein content 39% dm, starch content 20% dm), rice flour (Rickmers Reismühle, Bremen, Germany; protein content 7.3% dm, starch content 76% dm), potato starch (Agrana GmbH, Gmünd, Austria; protein content 0.5% dm, starch content 80% dm). Rapid- visco- analyser (RVA 4500, Perten Instruments, Macquarie Park, Australia) viscosity profiles were determined for these flour and starches. Peak/final viscosities for wheat flour were 1496/1740, for potato starch 10961 (highest)/4199, for rice flour 2942/5581 (highest), and for lupine flour 69/23 (lowest for both). Further ingredients were eggs pasteurized (Landgold Fresh GmbH, Wien, Austria), tap water (12°dH, Leobendorf, Austria), sorbitol syrup (Sorbitex Ltd., Cincinnati, USA), glycerine syrup (type 1.23, Neuber’s Enkel, Vienna, Austria), sugar (type crystal, Agrana GmbH, Tulln, Austria), skimmed milk powder

(DMK GmbH, Zeven, Germany), sodium bicarbonate (Kotányi GmbH, Wolkersdorf, Austria), citric acid (Anna Gold GmbH, Vienna, Austria), a mixture of three different emulsifiers: sodium acid pyrophosphate (=SAPP40, Co. Levall, Antwerp, Belgium), monoglyceride ("Colco mono", Co. Aromatic, Stockholm, Sweden), and lecithin (from soy, liquid, "Lecisoya" F60IP, Werba GmbH, Vienna, Austria) and rapeseed oil (100% refined, Ölwert GmbH, Langenlois, Austria). "Bandex" (Co. Aromatic, Stockholm, Sweden) was applied as release agent on the baking plates. All raw materials were stored at a temperature of 8–10°C and taken out from the cooling room 15 min prior to batter preparation.

2.2 | Experimental design

The principal waffle recipe and its variations are given in Table 1. There is no standard recipe for fresh egg waffle. The recipe used for this study was based on a typical industrial- scale waffle recipe as used and applied by CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria. The used ingredients and their amounts were standardized in pre- trials (results not presented here).

In order to study the effect of different starches, 30% of the wheat flour was replaced by lupine flour, rice flour, or potato starch. The effect of sugar alcohols was studied by either adding the whole amount of sugar alcohols as glycerine or as sorbitol in comparison to their combined addition (control recipe). Additionally, the effect of sugar granulation was studied by either adding crystal sugar or powdered sugar (see Table 1).

TABLE 1 Experimental design—recipes of waffles investigated

Ingredients	Mixing sequence	Control [%]	Starch test[b]	Glycerine test	Sorbitol test
Wheat flour W480	3	22.40	15.68	22.40	22.40
Starch	3	0	6.72	0	0
Water 12°dH	1	7.96	7.96	7.96	7.96
Egg, fresh	1	24.89	24.89	24.89	24.89
Sorbitol syrup	1	4.98	4.98	7.47	0
Glycerine syrup	1	2.49	2.49	0	7.47
Sugar (crystal)[a]	2	15.93	15.93	15.93	15.93
Skimmed milk powder	2	1.00	1.00	1.00	1.00
Citric acid	2	0.05	0.05	0.05	0.05
Leavening Agent 1: sodium bicarbonate	2	0.29	0.29	0.29	0.29
Leavening Agent 2: SAPP40	3	0.40	0.40	0.40	0.40
Emulsifier 1: monoglyceride ColcoM	3	0.25	0.25	0.25	0.25
Emulsifier 2: lecithin liquid	4	0.50	0.50	0.50	0.50
Rapeseed oil	4	18.86	18.86	18.86	18.86
Sum	–	100.00	100.00	100.00	100.00

[a]in the trial with powdered sugar the full amount of crystal sugar was replaced by powdered sugar.
[b]Starch: lupine starch or rice flour or potato starch.

All these waffles were produced to best simulate industrial waffle production, using the same batter mixing machines, as well as baking plates (see section 2.3). From each recipe, 30 waffles were baked and evaluated, in order to obtain reliable results.

2.3 | Preparation of waffle batter

Preparation of batter was performed using a dissolver stirrer (IKA- Werke GmbH & CO. KG, Staufen, Germany) at medium speed of 800 rpm according to following common mixing sequence steps for waffles: step 1: Water and liquids (eggs, sorbitol, glycerine)—1 min; step 2: water soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent)—3 to 4 min; step 3: flour, starches, and pastes (flour, starch, monoglyceride, eventually second leavening agent)—3 to 4 min; step 4: fat and lecithin prewarmed to 40°C—1 to 2 min. The mixing of the waffle batter in this sequence is important to avoid too high shearing of the batter, which would result in increased gluten development, which is not desired for waffle production. The mixed batter was allowed to rest for 15–30 min prior to baking. Batter preparation was kept constant for all recipes. All batters were monitored for pH value, temperature, density, and viscosity, in order to detect eventual influences of the varied recipe parameters.

2.4 | Baking process for waffle production

Before baking, the baking tong "Turtle" (ductile iron baking plates, FHW Haas, Leobendorf, Austria) was preheated up to 140°C (bottom) and 145°C (top baking plate). Temperature of baking plates was monitored during the trials and found to be stable within a range of ±5°C. Before first batter disposition, a constant amount of the release agent (Bandex) was spread on both baking plates. For baking, a constant amount of 15 ml batter was deposited on the bottom baking plate, the baking plate was closed and the baking process started immediately (110 s). Then, the tong was opened and the waffle removed from the baking tong using a self- prepared vertical needle take- off (CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria), which is the usual process in industrial- scale waffle production.

After a cooling period of 30 min (time for moisture equilibration within the waffle), the waffle was characterized for weight, color, color spots, moisture content, and water activity as described in the following section. Additionally, after baking of all 30 waffles and complete cooling, the baking plate was characterized visually by a microscope and for surface roughness by a surface roughness analyser (Hommel Tester T100, Hommel Seitz, Viernheim, Germany) to ensure that the baking plate surface has not changed by the baking or cleaning process, which would have an influence on sticking behavior of the waffle. During this study, surface roughness was found to be constant. Between different recipes, cleaning was carried out by dry ice (frozen CO_2 pellets) in order to provide the same starting conditions for all recipes. In case a recipe produced many sticking waffles, an in- between cleaning step had to be done by brushing and applying new release agent. In the results section, information is given for which recipes this step had to be applied.

2.5 | Characterization of batter parameters (pH value, temperature, batter density, and viscosity)

The pH value of each batter was measured by a pH meter (Testo GmbH, Vienna, Austria). Optimum pH value for waffle batter lies in the range of pH 5.5 to pH 7.0. Density measurement was performed by filling a 100 ml cup with batter and recording its weight (g/100 ml). Density measurement of batter is a method to describe the aeration of a batter, the more a batter is aerated ("fluffy" batter), the lower is its density. Viscosity was measured by the so- called flow- cup method, which is best suitable to measure viscosity of waffle batters. The time the batter needed to flow through a 100 ml flow cup (Frikmar GmbH, Laatzen, Germany) with a 10- mm- diameter hole was recorded. An optimum viscosity value for waffles should be below 300 s. All these measurements were performed in triplicate and given as mean value.

2.6 | Characterization of waffles (baking loss, moisture content, water activity, color, and color distribution)

Baking loss gives information on the moisture loss during baking and was calculated for all 30 waffles according to following formula: *Baking loss*[%] = 1 - (*weight waffle*[*g*]/ *weight batter*[*g*])×100

For determination of the moisture content, the waffles were milled using a grinder (Co. DeLonghi, KG40, Neu- Isenburg, Germany) and then dried by an IR dryer (MA35, Co. Satorius, Göttingen, Germany). Water activity of the waffles was measured by a water activity analyser (Labmaster- aw, Novasin, Prague, Czech Republic). Both were determined in triplicate. Color (L*- , a*- , b*- values) of the waffles was measured at three points of each waffle (right top, center, left bottom) (Colorimeter Baking Meter BC- 10, Konika Minolta, Langenhagen, Germany). In total, nine values for each recipe were used to determine the mean value. Color distribution (homogenous vs. spotted color distribution) of each of the 30 waffles were rated visually to give a rough qualitative overview in addition to the determined L*- , a*- , b*- values.

2.7 | Determination of adhesion force and number of sticking waffles

On industrial scale, usually waffles are taken off from the baking plates vertically by needles. In order to best simulate this process, a so- called needle take- off was simulated by an in- house construction for pilot- scale production, which allowed measuring the force required to take off the waffle (see Fig. 1). After opening the baking tong, the arm with the needles was moved above the waffle, the needles were put into the waffle always at the same position, the scale was tared and then the needles were pulled up vertically by pneumatic force. The pneumatic pressure and the angle of the take- off arm was set constant and proofed by a barometer.

A hanging scale (HS 300± 0.1 g, Co. Dipse, Oldenburg, Germany) recorded the weight required to take- off the waffle from the baking tong, which was used to calculate the adhesion force by following formula:

$$\text{Adhesion force } [N = kg \times m/s^2] = \text{Waffle take-off weight } [g]/1000 \times 9.81\ [m/s^2].$$

Depending on the intensity of adhesion, the weight of the taken off waffle increased.

Number of sticking waffles was counted for all 30 waffles produced for one recipe and given as %. Torn waffles (not or only half taken off) were considered as sticking waffles.

FIGURE 1 Equipment for determination of waffle adhesion force

2.8 | Statistical evaluation

Results of waffles were evaluated statistically using Statgraphics Centurion XVI, Statpoint Technologies, Inc., Warrenton, USA) by one-factor analysis of variance (ANOVA) and Spearman rank correlation between each pair of variables. A *p*- value below .05 was considered as significant. Mean values were compared by Fisher's least significant difference (LSD) procedure.

TABLE 2 Batter characterization: pH, temperature, density, and viscosity (n = 3)

Batter characterization	pH	Temperature [°C]	Density [g/L]	Viscosity [s]
Effect of flour and starch				
Wheat flour ISTD	6.36 ± 0.01^{d}	26.2 ± 0.2^{b}	92.47 ± 0.42^{b}	120 ± 5^{c}
Lupine flour	6.13 ± 0.02^{a}	22.6 ± 0.1^{a}	86.29 ± 1.41^{a}	291 ± 10^{d}
Rice flour	6.31 ± 0.03^{c}	22.8 ± 0.2^{a}	86.089 ± 1.16^{a}	65 ± 7^{b}
Potato starch	6.22 ± 0.01^{b}	21.0 ± 0.1^{a}	92.94 ± 1.29^{b}	36 ± 1^{a}
p-value	.0000	.0000	.0001	.0000
Effect of sugar and substitutes				
Sorbitol syrup	6.51 ± 0.01^{c}	23.0 ± 0.1^{b}	89.25 ± 1.33^{a}	114 ± 4^{c}
Glycerine syrup	6.41 ± 0.02^{b}	23.8 ± 0.2^{c}	95.57 ± 0.98^{c}	64 ± 2^{a}
Sugar powdered	6.34 ± 0.01^{a}	21.7 ± 0.2^{a}	92.49 ± 1.44^{b}	84 ± 6^{b}
Sugar crystal ISTD	6.36 ± 0.01^{a}	26.2 ± 0.2^{d}	92.47 ± 0.42^{b}	120 ± 5^{c}
p-value	.0000	.0000	.0010	.0000

Note: Different superscript letters in the same column denote significant differences ($p<0.05$)

TABLE 3 Waffle characterization: color values (L*-, a*- and b*-values; n = 30)

	L*	a*	b*
Effect of flour and starch			
Wheat flour ISTD	46.31 ± 6.61^{ab}	16.58 ± 2.93^{a}	29.94 ± 2.56^{a}
Lupine flour	45.46 ± 5.11^{a}	18.83 ± 2.41^{b}	32.37 ± 3.38^{b}
Rice flour	49.25 ± 6.83^{b}	16.28 ± 3.73^{a}	32.63 ± 2.25^{b}
Potato starch	47.24 ± 6.18^{ab}	16.19 ± 2.50^{a}	30.88 ± 2.24^{a}
p-value	.1096	.0070	.0003
Effect of sugar and substitutes			
Sorbitol syrup	59.56 ± 7.37^{b}	11.78 ± 3.93^{b}	31.92 ± 2.57^{b}
Glycerine syrup	66.20 ± 5.08^{c}	8.80 ± 2.77^{a}	33.50 ± 2.75^{c}
Sugar powdered	63.74 ± 3.80^{c}	10.87 ± 2.66^{b}	33.56 ± 2.43^{c}
Sugar crystal ISTD	46.31 ± 6.61^{a}	16.58 ± 2.93^{c}	29.94 ± 2.56^{a}
p-value	.0000	.0000	.0000

Note: Different superscript letters in the same column denote significant differences ($p<0.05$)

3 | RESULTS AND DISCUSSION

All batter parameters determined are summarized in Table 2, waffle parameters in Tables 3 and 4 and Figure 2. Correlation analyses of the determined parameters are presented in Table 5.

3.1 | Effect of ingredients on batter parameters

In pre- trials (results not shown here), the control batter recipe was composed in a way that pH, density, and viscosity were within a recommended range for waffle batters. These recommended ranges are well experienced for industrial- scale waffle products by CFT- Haas GmbH (Leobendorf, Austria). Based on this recipe, the effect of varied ingredients was investigated and it was monitored if and in what range they changed these values. Severe changes of these parameters would already indicate their unsuitability for waffle production.

The pH value of the batters ranged from 6.1 to 6.5 and was not much influenced by the selected recipe components. From industrial trials (own experience, no data presented), it is known that high pH- values of batter can lead to increased sticking of the waffles. This is explained by the fact that at higher pH- values the browning reaction is intensified, which increases the amount of batter residues on the baking plates over time. In this performed trials, this phenomenon could not be detected.

Batter temperature ranged from 21.0 to 26.6°C, which was in the recommended range for waffle production. If the batter temperature ducible and too high batter deposit amounts and which could increase the number of sticking waffles. If the batter temperature is too high, the batter tends to form clumps, which leads to nonreproducible and too high batter deposit amounts and which could increase the number of sticking waffles.

Density and viscosity of batters are two parameters that have important effects on the fluidity properties of batters and later on waffle quality. Density of a waffle batter should be around 80–95 g/100 ml in order to show good fluidity behavior to fill the whole baking plate after application. A highly liquid dough causes higher waste of dough. Viscosity in liquids is usually influenced by density (the higher density the higher viscosity), but in batters, the effect of aeration on viscosity is much more relevant. The higher the aeration, the higher the batter viscosity, in practical terms spoken the batter gets stiffer (foam structure). Too stiff doughs again reduce or limit their fluidability and spreadability. Within a recipe, density and viscosity are negatively correlated and are influenced by aeration only—the higher the aeration, the lower the density and the higher viscosity. But density and viscosity (or foaming properties) are also strongly influenced by recipe ingredients and are thus only correlated within one recipe but not across different recipes. Some recipes show high density but low foamability after aeration or reverse. Principally, better aerated batters lead to softer waffles, but for sufficient spreadability, viscosity should remain below 5 min (as determined by the flow cup method). Softer waffles might have an influence on waffle stability, but not necessarily on sticking behavior.

Density and viscosity were significantly influenced by the addition of starch and sugar substitutes. Replacement of wheat flour by potato starch did not change density compared to wheat flour but decreased viscosity. Replacement by lupine flour decreased density, and increased viscosity strongly. This is most likely the result of the lupine protein, which is known to have good foaming ability (Maghaydah et al., 2013; Pareyt et al., 2009). Rice flour replacement decreased density and viscosity. Sole glycerine syrup addition showed higher density than sole sorbitol syrup or their combination, but sole glycerine syrup decreased viscosity. Between crystal and powdered sugar, there was no difference in density or viscosity. Some significant correlations between batter parameters and waffle parameters could be found, for example, positive correlation between pH- and L- value, negative correlations between pH- and a-value, or density and aw- value, but all association values were rather low, thus only indicating weak relationships. All recipes showed values for density and viscosity that were in an acceptable range for waffle batters and thus no significant effect of density or viscosity on sticking behavior or adhering force was detected. To conclude these results shortly, principally none of the selected ingredients had a negative influence on waffle batter properties. From this point of view, they were principally all suitable for waffle production.

FIGURE 2 Examples for waffles with good and bad quality (from left to right: wheat flour and glycerine (homogenous color distribution and totally filled waffle), rice flour (spotted and broken waffle), wheat flour (spotted, holes, crumble texture)

TABLE 4 Waffle characterization: baking loss, moisture content, aw- value, take- off force, and sticking of waffles

	Baking loss (*n* = 30) [%]	Moisture [%] (*n* = 3)	aW (*n* = 3)	Take- off Force (*n* = 30) [N]	Sticking (*n* = 1) [%]
Effect of flour and starch					
Wheat flour ISTD	25.41 ± 3.31[ab]	13.31 ± 0.94[a]	0.68 ± 0.03[a]	0.044 ± 0.015[b]	23.3 ± 43.0[a]
Lupine flour	24.47 ± 2.83[a]	14.38 ± 1.22[a]	0.70 ± 0.02[a]	0.032 ± 0.008[a]	6.7 ± 25.4[a]
Rice flour[#]	25.13 ± 2.62[ab]	14.11 ± 0.68[a]	0.70 ± 0.01[a]	0.031 ± 0.012[a]	46.7 ± 50.7[b]
Potato starch	26.50 ± 2.17[b]	13.90 ± 0.77[a]	0.69 ± 0.03[a]	0.027 ± 0.005[a]	6.7 ± 25.4[a]
*p-value**	.0425	.5660	.7919	.0000	.0001
Effect of sugar and substitutes					
Sorbitol syrup[#]	20.93 ± 3.87[a]	14.22 ± 1.87[a]	0.71 ± 0.02[b]	0.025 ± 0.008[b]	26.7 ± 45.0[b]
Glycerine syrup	22.65 ± 3.46[ab]	14.08[a]	0.63[a]	0.020 ± 0.004[a]	0.0 ± 0.0[a]
Sugar powdered	23.44 ± 4.27[b]	13.09 ± 0.40[a]	0.64 ± 0.02[a]	0.029 ± 0.007[b]	20.0 ± 40.7[b]
Sugar crystal ISTD	25.41 ± 3.31[c]	13.31 ± 0.94[a]	0.68 ± 0.03[ab]	0.044 ± 0.015[c]	23.3 ± 43.0[b]
p-value	.0001	.6766	.0286	.0000	.0289

[#]These recipes required an in- between cleaning step (brushing and additional application of releasing agent). Different superscript letters in the same column denote significant differences (p<0.05).

TABLE 5 Correlation analyses of determined batter and waffle parameters

	Temperature	Density	Viscosity	Moisture	aW- value	L*	a*	b*	Baking loss	Force	Sticking waffles
pH	0.5741*	0.3554	0.0033	−0.154	−0.0478	0.5057*	−0.6942*	0.2599	−0.5924*	−0.328	0.1364
Temperature		0.3823	0.5124*	−0.1406	−0.0636	0.1651	−0.2759	0.0514	−0.4559*	0.0182	−0.2273
Density			−0.3935	−0.1982	−0.4852*	0.5273*	−0.5705*	0.258	−0.0526	−0.4283	0.2636
Viscosity				−0.1596	0.1341	−0.2688	0.3054	−0.0864	−0.1994	0.4108	−0.036
Moisture					0.6387*	−0.1105	0.2564	−0.0852	0.007	−0.0246	−0.1
aW						−0.322	0.2958	−0.4009	0.0062	0.1135	−0.3545
L*							−0.8778*	0.5405*	−0.6452*	−0.5475*	0.5946
a*								−0.2454*	0.534*	0.5416*	−0.5946
b*									−0.4246*	−0.2341*	0.8469*
Baking loss										0.3582*	0.018
force											0.3424

*Significant at a *p*- value below .05.

3.2 | Effect of ingredients on general waffle quality

The investigated starches, sugar sources, or sugar substitutes influenced the appearance of the waffles. Visually, it could be observed that potato starch addition resulted in waffles of high stability with more homogenous color distribution than the waffles produced with wheat flour only or with replacement by lupine or rice flour. Glycerine syrup performed better than sorbitol syrup and crystal sugar better than powdered sugar with respect to stability and color distribution. During the production of the waffles with rice flour and the ones with sorbitol, in- between cleaning (by hand- brushing) and additional application of release agent was necessary. In comparison to the other flours used in this study, potato starch contained the highest amount of starch (80%) and showed the highest RVA values, which provides more elastic properties of the starch gelatinization itself compared to other tested starches and flours. Potato starch has an amorphous and more ordered structure (Stasiak, Rusinek, Molenda, Fornal, & Błaszczak, 2011). Lupine flour contained less starch (20%) but a protein that is known to have good foaming properties, thus it resulted in softer end- products, which might have been a disadvantage in waffle production. In a study on the effect of lupine flour on baking characteristics of gluten- free cookies, Maghaydah et al. (2013) demonstrated that addition of starch improved waffle stability in general and addition of lupine flour softened the texture.

Color is an important analysis for the bakery industry. Color determination is not directly influencing sticking behavior, but it gives some information on the state of the waffles. Color of the waffles was influenced by starch addition. Lupine flour resulted in darker waffles compared to rice flour. Lupine flour addition lead to higher a*- and b*- values. Regarding sugar components, waffles with glycerine syrup addition were less red, but more yellow compared to those with sorbitol syrup, and powdered sugar made the waffles less red and more yellow (lower a*- and higher b*- value) in comparison to crystal sugar. Obviously, powdered sugar decreased the production of Maillard products. It is known that darker color of waffles is usually caused by higher sugar amounts (increasing Maillard reaction) (Tiefenbacher, 2003; Ronda, Oliete, Gómez, Caballero, & Pando, 2011), but differences in color properties by the incorporation of crystalline or powdered sucrose are not known from other studies yet. Own experiences showed that crystalline and powdered sucrose show different sticking characteristics, which is assumed to occur due to the different dissolving behavior during batter preparation. Differences in color properties can be caused by protein content and type of protein, as Shevkani, Kaur, Kumar, and Singh (2015) has shown for muffins. Glycerine and sorbitol can influence the protein structure within a batter or dough. The water- retaining properties of sorbitol and glycerine lead to an increased moisture content of the waffles, which reduced the required take- off force (Demuth et al. 2015; Nezzal, Aerts, Verspaille, Henderickx, & Redl, 2009; Willart et al., 2005). Sugar sources can influence moisture content or water activity differently (Pareyt et al., 2009).

The aim of measuring moisture content was to follow waffle quality (Seog, Kim, & Lee, 2008). No differences were found between the starches or flours, but the different sugar sources influenced water activity. Glycerine syrup caused lower water activity in comparison to sorbitol syrup. Glycerine and sorbitol syrup act as moisture- binding agents, thus they principally can decrease water activity at same moisture content. There was no clear relationship of moisture or water activity to sticking behavior.

Baking loss was significantly influenced by starch and sugar addition; it was higher for potato starch compared to lupine flour, slightly higher for glycerine compared to sorbitol syrup (not significant) and for crystal sugar compared to powdered sugar, but differences were very low. Also, other researchers (Ashokkumar & Adler- Nissen, 2011; Ashokkumar et al., 2012) found that sticking of pancakes was influenced by moisture loss of the products. Color was significantly correlated with a lower baking loss (the darker, more red and less yellow the waffles the lower was baking loss), but association was low. Most likely the darkening effect occurred due to an intensified baking process, as other studies showed similarly for cakes or cookies (Ferng, Liou, Yeh, & Chen, 2016; Hesso et al., 2015; Pareyt et al., 2009; Purlis, 2010).

3.3 | Effect of ingredients on sticking behavior of waffles

Sticking behavior was determined by calculating the number of sticking waffles (% of 30 waffles) and measuring the take- off force. A waffle that was torn during take- off due to partially sticking increased the take- off weight.

The investigated ingredients showed significant influences on sticking behavior and take- off force. Within the starch group, rice flour caused the highest percentage of sticking waffles (46%), although take- off force was in the same range as lupine flour and potato starch and even lower compared to wheat starch (all 6.7%). As described before, rice flour resulted in very soft and inhomogeneous waffles, so almost every second one could not be removed, but the ones that were stable enough to be taken off, required only little force. Rice flour is known to give cakes a firmer structure, which was assumed to be due to its lower amylose content. This might also explain the dry, crumbly texture of the waffles, compared to the spongy- chewy texture of the waffles with potato starch. Glycerine syrup was again superior to sorbitol syrup or its combined addition, as well as crystal sugar compared to powdered sugar. They required less take- off force. Take- off force was significantly correlated with L*- and b*- value (negative, but weak association) and positive to a*- value. Sticking behavior showed strong associations to b*- value (positive correlation) and to a*- value (negative correlation). The lower the L*- and b*- value and the higher the a*- value (i.e., the waffle was darker, less yellow and more red), the higher was the take- off force and the lower was the sticking behavior of the waffle. A waffle that had a regular color (rather light, less red but more yellow, indicating also less spots) was more stable and less sticking and required significant lower take- off forces. An increase in baking loss seemed to increase take- off force, but the positive association was only weak.

From these determinations, it could be concluded that in order to obtain high waffle stability and lowest sticking tendency, baking loss should not be too high, batter temperature should be within an optimum range (20–28°C), color should be very regular and not too dark. To obtain these effects, it was shown that an increase in pH of the batter and addition of ingredients with increased water holding capacity to limit baking loss can play a positive role.

Also, in other studies, sticking or adhering behavior of food was influenced by adherence or cohesive forces and by stability of the sample. Liu, Christian, Zhang, and Fryer (2002) investigated the take- off for various foods like tomato or whey protein and found different adhesive forces of different foods, which suggests that different ingredients have an effect on adhesion or sticking behavior. Additionally, they observed that removing the food from a heated plate required increased force when the food broke during this procedure.

The results of this study have shown that take- off force and sticking of waffles were depending on recipe ingredients of flours, starches, sugar, and sugar substitutes. They influenced waffle stability. An unstable waffle can break and stick due to insufficient waffle structure or because of actual sticking and burning reactions. Increased adhesion force might lead to increased sticking behavior over long- term baking processes.

4. | Conclusion

In this study, effects of different starch sources and sugar components could be demonstrated: waffles with increased stability and texture (elastic, not too dry, and crumbly) were those that showed the least number of sticking waffles, thus the main aim of batter ingredients was to improve waffle quality (stability, texture) in order to decrease sticking and thus food waste.

Within the selected starches, potato starch demonstrated the highest effects on increasing waffle stability and releasing properties. Sticking number of waffles made from potato starch were comparable to waffles made from wheat flour and lupine flour, but the waffles from wheat flour and lupine flour were softer and crumblier. Take- off force was higher for these waffles, so in long- term trials they are more at risk to develop increased sticking behavior. For all starches investigated, rice flour addition performed worst, with almost 50% of sticking waffles. Most of these waffles were broken during take- off, due to their crumbly texture. Within the sugar components, glycerine was better suitable than sorbitol and crystal sugar was superior compared to powdered sugar. Glycerine in particular provided better texture, color distribution, and release characteristics of the waffles than sorbitol. For optimum waffle quality and enhanced production, the obtained results suggest developing waffle batters with a balanced addition of potato starch to wheat flour, to add glycerine instead of sorbitol and to incorporate ingredients with increased water holding capacity. A moderate baking process should be applied. Overall, the main aim was to achieve a stable waffle texture, which supports the waffle take- off during industrial baking.

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CONFLICT OF INTEREST

None declared.

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4. Waffle production: influence of batter ingredients on sticking of waffles at baking plates – Part II

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ORIGINAL RESEARCH

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Waffle production: influence of batter ingredients on sticking of waffles at baking plates—Part II: effect of fat, leavening agent, and water

Regina Huber | **Regine Schoenlechner**

Department of Food Sciences and

Technology, University of Natural Resources and Life Sciences, Vienna, Austria

Correspondence
Regine Schoenlechner, University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria.

Email: regine.schoenlechner@boku.ac.at

Abstract

Fresh egg waffles are continuously baked in tunnel baking ovens in industrial scale. Waffles that partly or fully stick to the baking plates cause significant product loss and increased costs. The aim of this study was, therefore, to investigate the effect of different recipe ingredients on the sticking behavior of waffles. In this second part, ingredients investigated were different leavening agents (sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate, or monocalcium phosphate), different fat sources (rapeseed oil, cocos fat, butter, or margarine), and different water sources (tap water 12°dH and distilled water). Within the different types of fats, solid fats with high amount of short- chain fatty acids (cocos fat or butter) decreased the number of sticking waffles compared to liquid oils (rapeseed oil). Regarding leavening agents, magnesium hydroxide carbonate and ammonium bicarbonate were superior to sodium acid pyrophosphate or monocalcium phosphate.

Between the two water sources, effects were small.

KEYWORDS

Fat, fresh egg waffle, leavening agents, sticking, waffle batter

1 | INTRODUCTION

Fresh egg waffles (subsequently called waffles) are made from high contents of eggs, sugar, and fat. They have a raised, cake- like texture and are baked in waffle irons. An industrial waffle oven produces up to 40,000 waffles per hour and only 1% of sticking waffles can make up to 72 kg waste per day (Tiefenbacher, 2009). Thus, sticking of waffles on baking plates must be prevented, but the reasons for sticking are not fully understood yet. Influencing factors on sticking of waffles are recipe ingredients, the baking process, baking plate material, release agent, and cleaning methods.

In this study the following influences of some batter ingredients were investigated: type of fat, leavening agents, and water hardness.

Fat and oils in waffle batters lead to softer texture of the waffle. Besides, fat provides a release film during baking. Disadvantageous effects are residues of fat waste on baking plates. Depending on the chain length and number of unsaturated fatty acids, fats show different stability. The more double bonds in fatty acids, the more thermal instable they are due to autoxidation. For waffles, stable fats with little amount of unsaturated fatty acids and iodine values below 85 should be used to minimize thermal fat degradation and increase shelf life. Required fat amount depends on the recipe and other batter ingredients and baking plate coating. Usual fat amounts of waffle batters are 18–29% (Tiefenbacher, 2009). According to Pareyt et al. (2009), fat might retard chemical leavening action and affect swelling of the cells during baking of cookies. Surface became uneven with decreasing fat levels. Lecithin (E322) is often used in waffle batters, where it acts as release improver and is therefore also an important ingredient in release agents. Additionally, lecithin improves the color distribution on the waffle surface. In waffles, liquid or powdered lecithin is usually used from 0.1% to 1.5% of flour (Tiefenbacher, Haas, & Haas, 1991).

Leavening agents are chemicals like sodium bicarbonate, sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate, and monocalcium phosphate, which lead to better steam release, softer, more porous, and lighter waffles (Tiefenbacher et al., 1991). Sodium bicarbonate (E500ii) increases the pH, which leads to more intensive browning and increases alkaline taste (Hesso et al., 2015). Ammonium bicarbonate (E503i) increases the pH as well, but pore size is more homogeneous, which makes the waffle softer and increases volume. It has a strong characteristic flavor and increases waste on baking plates. Ammonium bicarbonate is added at a maximum of 0.1% (Tiefenbacher, 2009). Sodium pyrophosphate (E450i) reacts with sodium bicarbonate and should be used in the ratio 1:0.73. Too much sodium pyrophosphate gives a metallic taste. Monocalcium phosphate (E341i) has a very fast leavening reaction compared to the other leavening agents and is used usually for American breakfast waffles (Miller, 2016). Magnesium hydroxide carbonate (E504) improves waffle release and can protect water from moisture migration.

Water temperature should be constant for batter preparation at about 20–30°C, because the warmer the water, the thicker gets the batter. Higher water hardness influences waffle texture and may require a reduced amount of leavening agents. But hard water increases baking plate residues. Soft water provides smoother waffle texture, which decreases waffle stability. Stable waffles can be taken off easier (Tiefenbacher, 2009). According to a study of Liu, Christian, Zhang, and Fryer (2002), water content influenced the adhesive strength of fouling from tomato paste. The adhesive strength of the tomato deposit could be reduced by hydration.

The objective of this study was to analyze the influence of batter ingredients on the quality (stability) and sticking behavior of waffles. Analyzed ingredients for this part of the study were: (1) the effect of different leavening agents (sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate, or monocalcium phosphate), (2) the effect of different fat sources (rapeseed oil, cocos fat, butter, or margarine), and (3) the effect of water source (tap water 12°dH and distilled water) on the quality (stability) of the waffle and on its release from the baking plates. All waffle trials were performed on pilot scale using equipment that is usually used in industrial baking.

2 | MATERIALS AND METHODS

2.1 | Materials

The following flour and starch ingredients were used for this study: wheat flour W480 (type "Allerfeinst," Good Mills GmbH, Schwechat, Austria; protein content 11% dm, starch content 72% dm), eggs pasteurized (Landgold Fresh GmbH, Wien, Austria), tap water (12°dH, Leobendorf, Austria), sorbitol syrup (Sorbitex Ltd., Cincinnati, OH, USA), glycerin syrup (type 1.23, Neuber's Enkel, Vienna, Austria), sugar (type crystal, Agrana GmbH, Tulln, Austria), skimmed milk powder (DMK GmbH, Zeven, Germany), citric acid (Anna Gold GmbH, Vienna, Austria), the emulsifiers monoglyceride ("Colco mono," Co.

Aromatic, Stockholm, Sweden), lecithin (from soy, liquid, "Lecisoya" F60IP, Werba GmbH, Vienna, Austria), the leavening agents ammonium bicarbonate (Anna Gold, Vienna, Austria), sodium acid pyrophosphate SAPP40 (Levall, Brenntag, Antwerp, Belgium), magnesium hydroxide carbonate (Neuber's Enkel, Vienna, Austria), monocalcium phosphate (Neuber's Enkel, Vienna, Austria), and the fats rapeseed oil (100% refined, Ölwert GmbH, Langenlois, Austria), margarine (Rama Original, vegetable fat, Unilever Austria, Vienna, Austria), butter (Spar, Salzburg, Austria), cocos fat partly hardened (Ceres, Wels, Austria). "Bandex" (Co. Aromatic, Stockholm, Sweden) was used as release agent applied on the baking plates. All raw materials were stored in cool place (8–10°C) and taken out from the cooling room 15 min prior to batter preparation.

2.2 | Experimental design

The principal waffle recipe and its variations are given in Table 1. There is no standard recipe for fresh egg waffles. The recipe used for this study was based on a typical industrial scale waffle recipe as used and applied by CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria. The used ingredients and their amounts were standardized in pretrials (results not presented here).

In order to study the effect of leavening agent, the full amount of SAPP40 was replaced by ammonium bicarbonate, magnesium hydroxide carbonate, or monocalcium phosphate. The effect of different fat sources was studied by replacing the full amount of rapeseed oil by cocos fat, butter, or margarine, the effect of water was studied by replacing the full amount of tap water (12°dH) by distilled water (see Table 1).

All these waffles were produced in the way industrial waffles are produced, using the same batter mixing machines and baking plates (see section 2.3). From each recipe, 30 waffles were baked and evaluated in order to obtain reliable results.

TABLE 1 Experimental design—principal recipe of waffles investigated

Ingredients	Mixing sequence	Principle recipe (%)
Wheat flour W480	3	22.40
Water 12°dH[c]	1	7.96
Egg, fresh	1	24.89
Sorbitol syrup	1	4.98
Glycerin syrup	1	2.49
Sugar crystal	2	15.93
Skimmed milk powder	2	1.00
Sodium bicarbonate	2	0.29
Citric acid	2	0.05
SAPP40[a]	3	0.4
Monoglyceride colco M	3	0.25
Lecithin liquid	4	0.50
Rapeseed oil[b]	4	18.86
Sum	-	100.00

[a]To investigate the effect of leavening agent, the full amount of SAPP40 was replaced by ammonium bicarbonate, magnesium hydroxide carbonate, or monocalcium phosphate.
[b]To investigate the effect of different fat sources, the full amount of rapeseed oil was replaced by cocos fat, butter, or margarine.
[c]To investigate the effect of water, the full amount of tap water (12°dH) was replaced by distilled water.

2.3 | Preparation of waffle batter

Preparation of batter was performed using a dissolver stirrer (IKA-Werke GmbH & Co., KG, Staufen, Germany) at medium speed of 800 rpm according to following common mixing sequence steps for waffles: Step 1—water and liquids (eggs, sorbitol, glycerin), 1 min; Step 2—water-soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent), 3–4 min; Step 3—flour, starches, and pastes (flour, starch, monoglyceride, eventually second leavening agent), 3–4 min; Step 4—fat and lecithin prewarmed to 40°C, 1–2 min. The mixing of the waffle batter in this sequence is important to avoid too high shearing of the batter, which would result in increased gluten development, which is not desired for waffle production. The mixed batter was allowed to rest for 15–30 min prior to baking. Batter preparation was kept constant for all recipes. All batters were monitored for pH value, temperature, density, and viscosity in order to detect eventual influences of the varied recipe parameters.

2.4 | Baking process for waffle production

Before baking, the baking tong "Turtle" (ductile iron baking plates, FHW Haas, Leobendorf, Austria) was preheated up to 140°C (bottom) and 145°C (top baking plate). Temperature of baking plates was monitored during the trials and found to be stable within a range of ±5°C. Before first batter disposition, a constant amount of the release agent (Bandex) was spread on both baking plates. For baking, a constant amount of 15 ml batter was deposited on the bottom baking plate, the baking plate was closed, and the baking process started immediately (110 s). The tong was then opened and the waffle removed from the baking tong using a self- prepared vertical needle take- off (CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria), which is the usual process in industrial scale waffle production.

After a cooling period of 30 min (time for moisture equilibration within the waffle), the waffle was characterized for weight, color, color spots, moisture content, and water activity as described in the following section. Additionally, after baking of all 30 waffles and complete cooling, the baking plate was characterized visually by a microscope and for surface roughness by a surface roughness analyzer (Hommel Tester T100, Hommel Seitz, Viernheim, Germany) to ensure that the baking plate surface has not changed by the baking or cleaning process, which would have an influence on sticking behavior of the waffle. During this study, surface roughness was found to be constant. Between different recipes cleaning was carried out by dry ice (frozen CO_2 pellets) in order to provide the same starting conditions for all recipes. In case a recipe produced many sticking waffles, an in- between cleaning step had to be done by brushing and applying new release agent. In the Results section, information is given for which recipes this step had to be applied.

2.5 | Characterization of batter parameters (pH value, temperature, batter density, and batter viscosity)

The methods for determination of the pH value, temperature, batter density, and batter viscosity are described in detail in the first part of this study (Huber & Schoenlechner, 2016). All these measurements were performed in triplicate and given as mean value.

2.6 | Characterization of waffles (baking loss, moisture content, water activity, color, and color distribution)

The method for measuring the baking loss, the moisture content, the water activity, the color, and the color distribution is the same procedure as in the first part of this study and described in detail previously (Huber & Schoenlechner, 2016). The baking loss was calculated from 30 measured waffles, as well as the moisture content, water activity, and color.

2.7 | Determination of adhesion force and number of sticking waffles

On industrial scale, usually waffles are taken off from the baking plates vertically by needles. In order to best simulate this process, a so- called needle take- off was simulated by an in- house construction for pilot scale production, which allowed measuring the force required to take off the waffle (see Fig. 1). After opening the baking tong, the arm with the needles was moved above the waffle, the needles were put into the waffle always at the same position, the scale was tared, and then the needles were pulled up vertically by pneumatic force. The pneumatic pressure and the angle of the take- off arm was set constant and proofed by a barometer. A hanging scale (HS 300± 0.1 g, Co. Dipse, Oldenburg, Germany) recorded the weight required to take- off the waffle from the baking tong, which was used to calculate the adhesion force by the following formula:

$$\text{Adhesion force } [N = kg \times m/s^2] = \text{Waffle take-off weight } [g]/1000 \times 9.81\ [m/s^2].$$

The weight of the waffles was included in this calculation, but all waffles were baked from exactly the same weight (weight of waffles after baking were controlled). Depending on the intensity of adhesion, the weight of the taken- off waffle increased.

Number of sticking waffles was counted for all 30 waffles produced for one recipe and given as %. Torn waffles (not or only half taken off) were considered as sticking waffles.

2.8 | Statistical evaluation

Results of waffles were evaluated statistically using Statgraphics Centurion XVI, Statpoint Technologies, Inc., Warrenton, VA, USA) by one- factor analysis of variance (ANOVA) and Spearman's rank correlation between each pair of variables. A $p < .05$ was considered as significant. Mean values were compared by Fisher's least significant difference (LSD) procedure.

3 | RESULTS AND DISCUSSION

All batter parameters determined are summarized in Table 2, and waffle parameters in Tables 3 and 4. All correlation values are presented in Table 5.

3.1 | Effect of ingredients on batter parameters

Based on pretrials and experience by CFT Haas GmbH (Leobendorf, Austria), the control batter was composed in a way that the pH, density, and viscosity are within a recommended range for batters. Based on this recipe, the effect of varied ingredients was investigated and it was monitored if and in what range they changed these values.

The pH value of the batters was between 6.3 and 7.2. In the group of leavening agents, highest pH value was achieved with ammonium bicarbonate, lowest with SAPP40. Fats also caused significant differences

in pH value, but differences were low. Water source had no effect on pH value. It is known that batter with higher pH values tend to increase the browning reaction of the batter, which can cause increased dough residues on the baking plate and subsequently increased number of sticking waffles. In industrial scale production (long- term baking), this phenomenon can often be observed, usually by the use of higher amounts of ammonium bicarbonate or older eggs (CFT own experience).

Batter temperature ranged from 20 to 28°C, and did not significantly influence sticking behavior.

Density showed little variation, ranging from 88 to 96per 100 ml, but it was significantly correlated with sticking behavior. The higher the density, the lower was the number of sticking waffles. Higher batter density was found by addition of ammonium bicarbonate or magnesium hydroxide carbonate and by addition of cocos fat or butter. The leavening reaction of ammonium bicarbonate and magnesium hydroxide carbonate seems to be less intensive than the addition of SAPP40. Less gaseous chemical reactions seem to act after mixing.

Viscosity showed higher variation from 32 to 149 s, yet it was not significantly correlated to the number of sticking waffles. Viscosity was lowest with ammonium bicarbonate or magnesium hydroxide carbonate and cocos fat or margarine, which is comparable to the relationship of density values.

Although these investigated parameters showed that principally all batter recipes were in a range that made them suitable for waffle production, it could be found that within the leavening agents, ammonium bicarbonate or magnesium hydroxide carbonate were somewhat superior. Within the fat sources, cocos fat, margarine, or butter seemed to better suitable for waffle production than rapeseed oil. This might be attributed to its physical parameters. Solid fats served better compared to liquid oils.

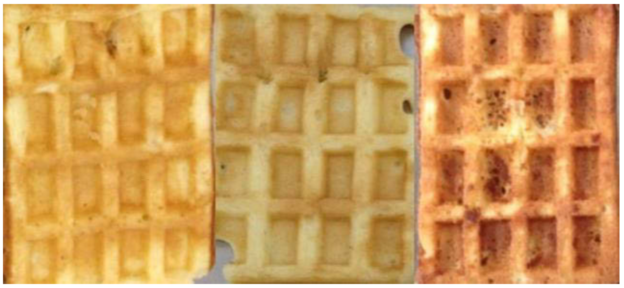

FIGURE 1 Waffles baked with palm fat (left), magnesium hydroxide carbonate (middle), and water of 12°dH (right)

TABLE 2 Batter characterization: pH, temperature, density, and viscosity

Batter characterization	**pH *n* = 3**	**Temperature (°C) *n* = 3**	**Density (g/L) *n* = 3**	**Viscosity (s) *n* = 3**
Effect of leavening agents				
Ammonium	7.21 ± 0.01[d]	23.23 ± 0.06[a]	96.25 ± 2.69[c]	32 ± 1[a]
Magnesium	6.84 ± 0.02[c]	26.67 ± 0.31[d]	94.02 ± 1.51[bc]	38 ± 0[bc]
MCP	6.44 ± 0.01[b]	24.33 ± 0.21[b]	88.32 ± 0.43[a]	240 ± 0[d]
SAPP40- Sodium ISTD	6.36 ± 0.01[a]	26.60 ± 0.20[c]	92.47 ± 0.42[b]	120 ± 4[c]
p- value	.0000	.0000	.0017	.0000
Effect of fat and lecithin				
Margarine 3	6.31 ± 0.01[a]	28.17 ± 0.15[d]	90.17 ± 1.24[a]	45 ± 1[a]
Cocos fat 4	6.41 ± 0.02[c]	20.03 ± 0.06[a]	95.95 ± 0.63[cd]	60 ± 2[b]
Butter 5	6.29 ± 0.01[a]	23.40 ± 0.26[b]	94.66 ± 0.78[c]	111 ± 8[c]
Rapseed oil ISTD 1	6.36 ± 0.01[b]	26.60 ± 0.20[c]	92.47 ± 0.42[b]	120 ± 4[cd]
p- value	.0000	.0000	.0000	.0000
Effect of water hardness				
Water distilled	6.38 ± 0.03[a]	21.17 ± 0.12[a]	93.79 ± 0.72[a]	149 ± 3[b]
Water 12°dH ISTD	6.36 ± 0.01[a]	26.60 ± 0.20[b]	92.47 ± 0.42[a]	120 ± 4[a]
p- value	.3276	.0000	.0520	.0010

Note: Different superscript letters in the same column denote significant differences ($p>0.05$).

TABLE 3 Waffle characterization: color values (L*- , a*- , b*- values)

Note: Different superscript letters in the same column denote significant differences (p>0.05).

	L *n* = 30	**a *n* = 30**	**b *n* = 30**
Effect of leavening agents			
Ammonium	62.22 ± 5.01^{b}	8.67 ± 2.06^{b}	33.01 ± 1.27^{b}
Magnesium	68.20 ± 3.06^{c}	7.04 ± 1.55^{a}	34.50 ± 1.62^{c}
MCP	70.92 ± 3.26^{d}	6.31 ± 2.31^{a}	32.37 ± 2.34^{b}
SAPP40- Sodium ISTD	46.31 ± 6.61^{a}	16.58 ± 2.93^{c}	29.94 ± 2.56^{a}
p- value	.0000	.0000	.0000
Effect of fat and lecithin			
Margarine	63.76 ± 5.26^{c}	11.92 ± 2.96^{b}	34.75 ± 2.08^{c}
Cocos fat	67.24 ± 4.25^{c}	9.10 ± 3.13^{a}	32.40 ± 1.98^{b}
Butter	68.02 ± 2.86^{b}	10.02 ± 2.05^{a}	35.26 ± 1.64^{c}
Rapseed oil ISTD	46.31 ± 6.61^{a}	16.58 ± 2.93^{c}	29.94 ± 2.56^{a}
p- value	.0000	.0000	.0000
Effect of water hardness			
Water distilled	62.30 ± 4.12^{b}	11.79 ± 2.29^{b}	33.44 ± 1.82^{b}
Water 12°dH ISTD	46.31 ± 6.61^{a}	16.58 ± 2.93^{a}	29.94 ± 2.56^{a}
p- value	.0000	.0000	.0000

TABLE 4 Waffle characterization: baking loss, moisture content, aw- value, take- off force, and sticking of waffles

	Baking loss (%) *n* = 30	Moisture (%) *n* = 3	aw *n* = 3	Force (N) *n* = 30	Sticking (%) *n* = 30
Effect of leavening agents					
Ammonium	21.38 ± 3.27[a]	12.86 ± 0.55[a]	0.69 ± 0.01[a]	0.022 ± 0.004[a]	0.0[a]
Magnesium	16.51 ± 2.20[c]	17.89 ± 1.08[b]	0.76 ± 0.03[b]	0.014 ± 0.003[b]	0.0[b]
MCP	18.38 ± 1.62[b]	16.71 ± 0.83[b]	0.75 ± 0.02[b]	0.020 ± 0.000[ab]	6.7[b]
SAPP40- Sodium ISTD	25.41 ± 3.31[d]	13.31 ± 0.94[a]	0.68 ± 0.03[a]	0.044 ± 0.015[c]	23.3[b]
p- value	.0000	.0002	.0041	.0000	.0010
Effect of fat sources					
Margarine	22.32 ± 3.09[b]	15.91 ± 0.86[bc]	0.71 ± 0.03[a]	0.035 ± 0.008[b]	3.3[a]
Cocos fat	19.93 ± 2.39[a]	15.02 ± 0.93[ab]	0.72 ± 0.02[ab]	0.022 ± 0.002[a]	0.0[a]
Butter	20.08 ± 1.24[a]	17.53 ± 0.97[c]	0.75 ± 0.01[b]	0.021 ± 0.005[a]	0.0[a]
Rapseed oil ISTD	25.41 ± 3.31[c]	13.31 ± 0.94[a]	0.68 ± 0.03[a]	0.044 ± 0.015[c]	23.3[b]
p- value	.0000	.0156	.0234	.0000	.0000
Effect of water hardness					
Water distilled	22.40 ± 2.14[a]	14.19 ± 1.29[a]	0.72 ± 0.02[a]	0.030 ± 0.007[a]	30.0[a]
Water 12°dH ISTD	25.41 ± 3.31[b]	13.31 ± 0.94[a]	0.68 ± 0.03[a]	0.044 ± 0.015[b]	23.3[a]
p- value	.0001	.3946	.0936	.0000	.5670

Note: Different superscript letters in the same column denote significant differences (p>0.05).

TABLE 5 Correlation analyses of determined batter and waffle parameters

	Temp.	density	viscosity	moisture	aw-value	L*	a*	b*	Baking loss	Sticking of waffles	Force
pH	−0.1214	0.1976	−0.2999	−0.1079	0.0605	0.3297	−0.6779*	−0.2357	−0.6828*	0.0001	−0.0242
Temperature		−0.705*	−0.28	0.2525	0.1862	0.0647	0.2153	0.3167	0.1519	0.0001	0.2333
Density			−0.3158	−0.1545	−0.2172	0.0311	−0.2455	−0.0257	−0.3657	0.0001	−0.3037
Viscosity				0.0174	0.0826	−0.2336	0.1891	−0.3024	0.3756	0.0001	0.3079
Moisture					0.8371*	0.4*	−0.1841	0.4706*	−0.1789	0.0001	−0.3838
aw						0.4656*	−0.3832	0.2415	−0.2483	0.0001	−0.6158*
L*							−0.8502*	0.1021	−0.7109*	−0.0113	−0.5956*
a*								0.1443*	0.745*	0.0130	0.6420*
b*									−0.1549*	−0.0783	−0.0875
Baking loss										0.0475	0.5558*
Sticking of waffles											−0.1679

*Significant correlation at α=0.05.

3.2 | Effect of ingredients on general waffle quality

All investigated recipe parameters influenced significantly color, moisture content, water activity, and baking loss.

Color was significantly brighter after the addition of ammonium bicarbonate, which was unexpected, and after the addition of monocalcium phosphate. Also, fat source influenced color; after the addition of rapeseed oil, waffles were significantly darker, those with butter and cocos fat were brighter and less red. Distilled water resulted in brighter, less red, but more yellow waffles than tap water with higher hardness. Baking loss was affected by the different leavening agents in the following order: ammonium bicarbonate > monocalcium phosphate > magnesium hydroxide carbonate > SAPP40, but these phenomena could not be explained. Margarine and rapeseed oil caused higher baking loss compared to butter and cocos fat. It seemed that fats containing more short- chain fatty acids retained water in the waffle better compared to fats containing higher amounts of long- chain fatty acids.

Moisture content and aw- value were higher in waffles with magnesium hydroxide carbonate and monocalcium phosphate and also fat source had significant effects on these parameters. Waffles with butter showed higher moisture content and aw- value compared to the other fat sources (except margarine for moisture content and cocos fat for aw-value). In contrast to the used fats and oils, butter contains much more water. Water hardness had no effects on batter moisture and its aw- value. Only little research was done so far to investigate the effect of different fat sources or leavening agents on color of the resulting bakery products, in contrast to the effect of different flours. Their contribution to browning due to Maillard reactions has been investigated by several researchers (Miller, 2016; Vetter, 2003). Also, influence of water hardness is not well understood for bakery products, but it is well known that it can change the quality of distillates like Whiskey for example (Bringhurst & Brosnan, 2014). The phenomenon of changing waffle cohesion was observed during previous tests with wafers. Wafers produced with distilled water were far more crumbly brittle than wafers produced with water of 12°dH water hardness (CFT own experience).

Several correlations between color values, moisture content, water activity, and baking loss could be detected. Darker waffles (lower L- value) was correlated with lower moisture content and lower aw-value, which can be explained by the relation that from a darker and more browned waffle more steam is evaporated off. This was also expressed in an increased baking loss value (significant correlation of L- value and baking loss).

3.3 | Effect of ingredients on sticking behavior of waffles

The results of sticking behavior were determined by calculating the number of sticking waffles (% of 30 waffles) and measuring the take- off force, which was recorded in order to have a tool to measure how easily the waffle could be removed from the baking plate or how much it adhered to it.

Take- off force and number of sticking waffles were significantly influenced by the studied ingredients. SAPP40 showed highest take- off force and higher number of sticking waffles compared to the other three leavening agents. Within the fat sources, cocos fat (see Fig. 1) and butter showed lowest take- off force and number of sticking waffles. These waffles showed the best stability and thus performed better during production. For bakery products the use of solid fats at room temperature (including more saturated fatty acids) is generally recommended, because they are more heat stable on the one hand, but also have different flow behavior compared to oils that contain more unsaturated fatty acids. Solid fats like cocos fat or butter show more elastic and pseudoplastic properties in contrast to oils (Palav, 2016; Schünemann & Treu, 2009), so type of fat/oil not only influences release behavior, but has also effects on the baking characteristics, product structure (Hadnađev, Hadnađev, Milica, Slađana, & Veljko, 2015; Sciarini, Van Bockstaele, Nusantoro, Pérez, & Dewettinck, 2013), and release characteristics. Fat–lecithin mixtures with saturated fatty acids are used as basis for release agents, where the same properties are usefully applied (Dorfman, 2012; Oexmann, 2008). The chain length and degree of saturation provides different adhesion behavior of the fat onto surfaces, which results in different contact angle values (Ashokkumar & Adler- Nissen, 2011).

Also, water source had an effect on sticking behavior; distilled water reduced take- off force, although this did not significantly influence the number of sticking waffles. Water of lower water hardness has a lower mineral content (Forghani, Joong- Hyun, & Deog- Hwan, 2015). According to Tiefenbacher (2009), the lower the mineral content in batters, the better is usually the release of the waffle and the less batter residue is left on the baking plates. But it has to be considered that waffle stability is also influenced by the mineral content of the batter, it decreases when the mineral content is too low. A balance of mineral content by using water of medium hardness seems to be required (see Fig. 1). Mineral content of the batter is not only a result of the used water but also of the used ingredients, for example, leavening agents are also a source of (different) minerals. In this study, magnesium hydroxide carbonate (see Fig. 1) and ammonium bicarbonate showed lowest number of sticking waffles and lower adherence forces. Magnesium hydroxide carbonate has been experienced to decrease sticking of wafers (Tiefenbacher, 2009) and thus seems to be better suitable for waffles. Ammonium bicarbonate is usually added in characteristic products only (e.g., ginger bread) because of its specific taste.

Take- off force was negatively correlated with aw- value, L*- value, and number of sticking waffles, and positively correlated with a*- value and baking loss, which themselves were influenced by the batter ingredients. In other words, the required take- off force decreased when the waffles were brighter and not burnt (increased L*- value), and when the aw- value was higher and the baking loss lower, indicating a stable, soft waffle. When a waffle was dark or burnt, also indicated by an increased baking loss and decreased moisture content or water activity, it required higher take- off force. This can lead to more sticking waffles in the end, although correlation between take- off force and number of sticking waffles was not significant for these trials.

For predicting the sticking or adhering behavior of waffles during industrial production, determination of moisture content, water activity, baking loss, or color values might be practicable parameters to allow a rough and quick estimation. This was also detected by other researchers, who used color measurements to predict baking state of crackers or moisture content (Broyart, Trystram, & Duquenoy, 1998) and temperature for regulating cake baking quality in tunnel ovens (Baik, Marcotte, & Castaigne, 2000; Sablani, Marcotte, Baik, & Castaigne, 1998; Zareifard, Boissonneault, & Marcotte, 2009).

4 | CONCLUSION

The results of this study showed that sticking behavior of waffles was influenced by different types of fats, leavening agents, and water hardness. Ingredients that decreased the number of sticking waffles and their adherence tendency were cocos fat, butter, margarine, ammonium bicarbonate, and magnesium hydroxide carbonate.

For the prediction of adherence or sticking behavior of waffles, the determination of take- off force, moisture content, water activity, baking loss, and color seemed to be promising and practicable parameters, which can be applied in laboratory as well as in industrial scale. Additionally, the determination of waffle texture is recommendable, as waffle stability was found to have a high influence. Besides these recipe parameters, the baking process is another important factor for waffle production. Contact time and temperature, as well as baking plate material and the type of release agent have to be considered in this respect.

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CONFLICT OF INTEREST

None declared.

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5. Waffle production: influence of baking plate material on sticking of waffles

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Waffle production: Influence of baking plate material on sticking of waffles

Regina Huber[1], Georg Kalss[2], Regine Schoenlechner[1**]

[1] University of Natural Resources and Life Sciences, Department of Food Science and Technology, Muthgasse 18, 1190 Vienna, Austria

[2] FHW Franz Haas Waffelmaschinen GmbH, Franz-Haas-Straße 1, 2100 Leobendorf, Austria

** corresponding author: University of Natural Resources and Life Sciences, Department of Food Science and Technology, Vienna, Austria, Muthgasse 18, 1190 Vienna, email: regine.schoenlechner@boku.ac.at

Abstract

Background of this study was to understand the factors that contribute to sticking of fresh egg waffles on baking plates. The aim of this study was to investigate the sticking (adhesion) behaviour of waffles on four different baking plate materials (ductile iron, grey iron, low alloyed steel and steel with titanium nitrite coating), at different baking parameters (temperature and time) and application of three different release agents (different fat compositions). Baking plates from ductile and grey iron showed lower release properties of waffles than the two steel baking plates. Baking parameters had to be high enough to allow rapid product crust formation but prevent burning, which again increases sticking behaviour. Release agents based on short-chain fatty acids with higher degree of saturation provided better release behaviour of waffles than those based on long-chain fatty acids or on emulsifier-acid combinations. Baking plates with

increased hardness, good heat storage capacity and smooth surface seemed to be best suitable. Further research on appropriate coating material might be promising for future.

Keywords: waffles, baking plates, sticking behaviour, adherence, release agents

Practical application

- Sticking of waffles is influenced by baking plate materials and process parameters.
- Baking plates should have sufficient hardness, heat storage capacity and smooth surface.
- Baking parameters should allow fast crust formation.
- Release agent should be based on short-chain saturated fatty acids

1. Introduction

Fresh egg waffles (subsequently called waffles) are a sweet convenience product that in industrial scale are baked in continuous waffle ovens. Sticking waffles are a great problem, because they have to be removed by hand and the baking plate needs to be cleaned, which interrupts continuous waffle baking and can cause significant product loss and increased costs (Määttä et al., 2007; Piispanen et al., 2009; Chavan et al., 2016). Sticking or adherence behaviour of waffles and bakery products is influenced by recipe ingredients (Chavan et al., 2016), baking plate materials (Reinhart and Haas, 2012), baking process parameters (time and temperature) (Ashokkumar and Adler-Nissin, 2011) and release agent (Tiefenbacher et al., 1991). For baking and frying equipment (e.g. pan or waffle ovens) several materials are available. Important for baking plates is that they show good heating capacity, thermal conductivity and mechanical strength (e.g. during industrial closing of the plates), as well as good release and cleaning properties. Most common used baking plate material is cast iron, which shows all of these characteristics except good release properties. Cast iron with lamellar graphite (“grey iron”) is corrosion resistant, but requires a lot of cleaning, while cast iron with spheroidal graphite (“ductile iron”) shows steel similar properties, but has low heat conductivity (Weißbach, 1994).

Experience in last time showed that alternative baking plate materials like e.g. stainless steel, which is mechanical robust, corrosion resistant, stable at all temperatures and easy to clean, and surface treatments might improve release properties (Reinhart et al., 2012). Coatings, such as Teflon, have been applied in the last decade to reduce adherence, but they do not show sufficient abrasion resistance as required for industrial application. Alternative coatings like nitridic-carbidic-oxidic diffusion surfaces and various titanium treatments might increase product release and abrasion resistance of the baking plate surface.

Additionally to baking plate material, baked products are affected by surface temperature of contact material, contact baking time and degree of baking (Ashokkumar and Adler-Nissin, 2011), which results in different qualities of the baked good (Sablani et al., 1998). It is assumed, that sticking is a function of temperature and moisture loss, and that contact time has no independent influence on sticking. Higher temperatures accelerate caramelisation, Maillard browning and protein denaturation, which are involved in forming an adhesive bonding between the pancake and the frying surface (Ashokkumar and Adler-Nissen, 2011).

Release agents are recommended to protect baking plates against corrosion (Dorfmann, 2012) and to improve release of the baked good (Oexmann, 2008). Several types of release agents are available on the market, and they differ greatly in their composition. Thermally stable oils can be applied as release agent, but also thermally non-stable oils, which form a film on the baking plate that carbonises over time (Tiefenbacher, 2009). Ideally during ongoing (long-term) baking very little release agent is further needed, as a self-fattening film from the bakery product is formed. Release agents are mostly vegetable fat based dispersions (e.g. heat stable palm fat, corn fat, shortenings, waxes, paraffins and sterols), often treated with lecithin to prevent crystallisation. Optional minor ingredients are emulsifiers (e.g. mono- and diglycerides), blocking agents (e.g. calcium carbonate, starches), release improvers (e.g. phosphates), homogenising solvents (e.g. propylene, sorbitol, glycerine), and enzymes (e.g. exo-amylase) or acids (e.g. sorbic acid, acetic acid, propionic acid) to prevent microbial growth.

The objective of this study was to investigate the effect of different baking plate materials, baking process parameters and release agents on the sticking behaviour of fresh egg waffles. Analysed baking plate materials were cast iron with lamellar graphite (“grey iron”), cast iron with spheroidal graphite (“ductile iron”), low alloyed steel and low alloyed steel with a TiN (titanium nitrite) coating. Two different baking regimes were studied: 1) 145 °C for 110 s vs. 2) 165 °C for 90 s using a waffle recipe which is known to have high sticking tendency, in order to better detect the effect of baking conditions under a stress situation. Release agents applied were: Bandex, Dübör PR100, or Amarnakote C (see Material and Methods for detailed description). All waffle trials were performed using equipment that is usually used in industrial baking.

2. Materials and Methods

2.1. Materials

The following baking plate materials were used for this study: ductile iron baking plate, grey iron baking plate, steel baking plate, (all three derived from FHW Haas, Leobendorf, Austria); steel baking plate with TiN (titanium nitrite coating) (Oerlikon AG, Pfäffikon, Switzerland) (see table 2 for detailed description). Cleaning was performed by dry ice and brushing. “Bandex” (Co. Aromatic, Stockholm, Sweden), “Amarnakote C” (Amarnakote, Delta, CO, USA) or “Dübör PR100” (Dübör Groneweg Gmbh und Co KG, Bad Salzuflen, Germany) was applied as release agent on the baking plates.

The following ingredients were used for this study: wheat flour W480 (type “Allerfeinst”, Vonwiller- Good Mills GmbH, Schwechat, Austria; protein content 11% dm, starch content 72% dm), rice flour (Rickmers Reismühle, Bremen, Germany; protein content 7.3% dm, starch content 76 % dm), potato starch (Agrana GmbH, Gmünd, Austria; protein content 0.5% dm, starch content 80 % dm). Rapid visco analyser (RVA 4500, Perten Instruments, Macquarie Park, Australia) profiles were determined for these flour and starches. Peak/final viscosities for wheat flour were 1496/1740, for potato starch 10961 (highest)/4199, for rice flour 2942/5581 (highest) and for lupine flour 69/23 (lowest for both). Further ingredients were eggs pasteurised (Landgold Fresh GmbH, Wien, Austria), tap water (12 °dH, Leobendorf, Austria), sorbitol syrup (Sorbitex Ltd., Cincinnati, USA), glycerine syrup (type 1.23, Neuber´s Enkel, Vienna, Austria), sugar (type crystal, Agrana GmbH, Tulln, Austria), skimmed milk powder (DMK GmbH, Zeven, Germany), sodium bicarbonate (Kotányi GmbH, Wolkersdorf, Austria), citric acid (Anna Gold GmbH, Vienna, Austria); the leavening agents ammonium bicarbonate (Anna Gold, Vienna, Austria), sodium bicarbonate (Kotányi, Wolkersdorf Weinviertel, Austria) and sodium acid pyrophosphate (=SAPP40, Co. Levall, Antwerp, Belgium); the emulsifiers monoglyceride ("Colco mono", Co. Aromatic, Stockholm, Sweden) and lecithin (from soy, liquid, "Lecisoya" F60IP, Werba GmbH, Vienna, Austria); further rapeseed oil (100 % refined, Ölwert GmbH, Langenlois, Austria) and cocos fat partly hardened (Ceres, Wels, Austria). All raw material were stored cool (8 °C to 10 °C) and taken out from the cooling room 15 min prior to batter preparation.

2.2. Production of Waffles

In order to investigate the described objectives, two different waffle recipes were used in this study, which are given in Table 1. As there is no standard recipe for fresh egg waffle, the recipes used for this study were based on a typical industrial scale waffle recipe as used and applied by CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria. The used ingredients and their amounts were standardised in pre-trials (not presented here), in order to find two recipes with different sticking behaviour - one that showed "good" release properties (called "optimum ingredients recipe"), and one that showed "bad" ones ("worst ingredients recipe"), which allowed to better visualise the effect of the investigated parameters. All waffles were produced using industrial equipment (e.g. batter mixing machine).

Preparation of batter was performed using a dissolver stirrer (IKA-Werke GmbH & CO. KG, Staufen, Germany) at medium speed of 800 rpm according to following common mixing sequence steps for waffles: step 1: Water and liquids (eggs, sorbitol, glycerine) - 1 min, step 2: water soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent) – 3 -4 min, step 3: flour, starches and pastes (flour, starch, monoglyceride, eventually second leavening agent) – 3 to 4 min, step 4: fat and lecithin pre-warmed to 40 °C – 1 to 2 min. The mixing of the waffle batter in this sequence is important to avoid to high shearing of the batter, which would result in increased gluten development, which is not desired for waffle production. The mixed batter was allowed to rest for 15-30 min prior to baking. Batter preparation was kept constant for all recipes. All batters were monitored for pH value, temperature, density and viscosity. From each recipe 30 waffles were baked and evaluated, in order to obtain reliable results.

2.3. Baking process and analysis parameter evaluation procedure

Before baking the baking tong "Turtle" (cast iron baking plates, FHW Haas, Leobendorf, Austria) was pre-heated up to 140 °C (bottom) and 145 °C (top baking plate) for moderate baking and up to 160 °C (bottom) and 165 °C (top baking plate) for fast baking. Before first batter disposition a constant amount of the release agent (Bandex, Dübör PR100 or Amarnakote C) was spread on both baking plates with a brush as a thin film on both baking plates. For baking a constant amount of 15 mL batter was deposited on the bottom baking plate, the baking plate was closed and the baking process started immediately (110 s for moderate baking and 90 s for fast baking). Then the tong was opened and the waffle removed from the baking tong using a self-prepared vertical needle take-off (CFT Haas Convenience Food Equipment GmbH, Leobendorf, Austria), which is the usual process in industrial scale waffle production.

After a cooling period of 30 min (time for moisture equilibration within the waffle), the waffle was characterised for weight, colour, colour spots, moisture content and water activity as described in the following section. Additionally, after baking of all 30 waffles and complete cooling, the baking plate was characterised visually by a microscope and for surface roughness. Between different trials cleaning was carried out by dry ice (frozen CO_2 pellets) in order to provide the same starting conditions for all recipes. Cleaning by dry ice was shown to deliver best results in pre-tests.

2.4. Characterisation of batter parameters (pH-value, temperature, batter density and viscosity)

The pH value of each batter was measured by a pH meter (Testo GmbH, Vienna, Austria). Optimum pH-value for waffle batter lies in the range of pH 5.5 to pH 7.0. Density measurement was performed by filling a 100 mL cup with batter and recording its weight (g/100 mL). Density of batter is a method to describe the aeration of a batter, the more a batter is aerated ("fluffy" batter), the lower is its density. Density measurement was performed by filling a 100 mL cup with batter and recording its weight. Viscosity was measured by the so-called flow-cup method, which is best suitable to measure viscosity of waffle batters. The time the batter needed to flow through a 100 mL flow cup (Frikmar GmbH, Laatzen, Germany) with a 10 mm diameter hole was recorded. An optimum viscosity value for waffles should be below 300 s. All these measurements were performed in triplicate and given as mean value.

2.5. Characterisation of waffles (baking loss, moisture content, water activity, colour and colour distribution)

Baking loss gives information on the moisture loss during baking and was calculated for all 30 waffles according to following formula: *Baking loss [%] = 1 – (weight waffle [g] / weight batter [g]) * 100.*

For determination of the moisture content the waffles were milled using a grinder (Co. DeLonghi, KG40, Neu-Isenburg, Germany) and then dried by an IR dryer (MA35, Co. Satorius, Göttingen, Germany). Water activity of the waffles was measured by a water activity analyser (Labmaster-aw, Novasin, Prague, Czech Republic). Both were determined in triplicate. Colour (L*-, a*-, b*-values) of the waffles was measured at three points of each waffle (right top, centre, left bottom) (Colorimeter Baking Meter BC-10, Konika Minolta, Langenhagen, Germany). In total 9 values for each recipe were used to determine the mean value. Colour distribution (homogenous vs. spotted colour distribution) of each of the 30 waffles were rated visually to give a rough qualitative overview in addition to the determined L*-, a*-, b*-values.

2.6. Characterisation of baking plates (temperature, surface roughness, microscopic image)

During (before and after) baking the baking plates were monitored for temperature and surface roughness. Temperature of the baking plate was measured at beginning and during the baking trials by a contact surface thermometer (Testo GmbH, Vienna, Austria) from the hot baking plates in order to lie within a range of +/- 2.5 °C for the desired temperature, because temperature differences of only 5 °C cause already differences in waffle colour and quality. Surface roughness was monitored by a surface roughness analyser (Hommel Tester T100, Hommel Seitz, Viernheim, Germany) from the cooled baking plate after the baking process (before cleaning) and again after the cleaning process before new release agent was applied to ensure that the baking plate surface has not changed by the baking or cleaning process and to provide the same starting conditions for all experimental trials. Measurement point was always at the same baking plate pyramid of the top baking plate (right column, second row, see fig. 1: each waffle baking plate has 16 pyramidsrectangular elevations on the baking mould, which give the characteristic waffle look and support the evaporation of steam during baking). From the baking plate a picture was taken with a camera. For further detail the surface was analysed by microscopes from the same baking plate pyramide that was measured for surface roughness, a microscopic image was taken by a stereo microscope (6.5 x and 50 x magnification; Stemi 2000-C, Zeiss, Oberkochen, Germany).

2.7. Determination of adhesion force and number of sticking waffles

On industrial scale, usually waffles are taken off from the baking plates vertically by needles. In order to best simulate this process, a so-called needle take-off was simulated by an in-house construction for pilot scale production, which allowed measuring the force required to take off the waffle. After opening the baking tong the arm with the needles was moved to a fixed position above the waffle, the needles were put into the waffle always at the same position, the scale was tared and then the needles were pulled up vertically by pneumatic force. A hanging scale (HS 300 +/- 0.1 g, Co. Dipse, Oldenburg, Germany) recorded the weight for take-off, which was used to calculate the adhesion force by following formula:

*Adhesion force [N = kg * m / s^2] = Waffle take-off weight [g] / 1000 * 9.81 [m/s^2].*

The weight of the waffles was included in this calculation, but all waffles were baked from exactly the same weight (weight of waffles after baking were controlled). Depending on the intensity of adhesion the weight of the torn off waffle increased by increasing sticking behaviour. Number of sticking waffles was counted for all 30 waffles produced for one recipe and given as %. Torn waffles (not or only half taken off) were considered as sticking waffles.

2.8. Statistical evaluation

Results of waffles were evaluated using Statgraphics Centurion XVI, Statpoint Technologies, Inc., Warrenton, USA) by One-Factor ANOVA and mean values were compared by Fisher's least significant difference (LSD) procedure. A p-value below 0.05 was considered as significant.

3. Results and Discussion

In table 3 the results for the baking trials on different baking plate materials (for both recipes) and different baking regimes (for the recipe with worst ingredients) are summarised. Table 4 summarises the results for the application of different release agents.

Characterisation of batter was performed in order to monitor their properties (pH, temperature, density and viscosity of batter) and to eventually explain the obtained results for waffle characteristics. The data measured, proved that all batters were principally lying within the typical range of waffle batters. Minor differences between the two recipes (optimum – worst ingredients) were visible as expected; viscosity of the batter from optimum ingredients was lower than from worst ingredients, pH-value was slightly higher. The recipe with optimum ingredients was composed to have a higher stability. Higher RVA values of the more ordered structure of potato starch, which was used in the optimised recipe (Stasiak et al., 2011), has an important influence on stability. In comparison, the recipe with worst ingredients contained rice flour with lower RVA values and showed less stability.

3.1. Influence of baking plate material and baking regime (baking temperature and time)

Colour of waffles was significantly influenced by baking plates, but differences between the samples were low. Waffles baked on grey iron or ductile iron were usually darker compared to those baked on low alloyed steel or steel with titanium coating. This was true for both recipes.

Baking loss, moisture content and aw-value were only little influenced by the different baking plates, within the waffles produced from the optimum ingredients, the waffles baked on plates from steel with titanium coating showed significant lower baking loss, moisture content and aw-value were higher compared to the baking plates. For the worst ingredient recipe this was only true for baking loss of waffles baked on TiN coated steel baking plates compared to waffles baked on grey iron. Most important were the results for adherence force and number of sticking waffles, which both showed significant differences between the different baking plates. In the trials using the worst ingredients recipe (and moderate speed), lowest adherence force, which indicates easier waffle release (although not always related with number of sticking waffles) was found for the baking plate from grey iron and the plates from steel - titanium nitrite coating even improved this one slightly. Number of sticking waffles was lower for these baking plates, compared to the one from ductile iron. When using a recipe with optimum ingredients, which was used to verify if these results are also true for "best conditions", results could partly confirm the before obtained results. Again both steel baking plates seemed to be superior, but for this recipe ductile iron served better than grey iron with respect to adherence force and number of sticking waffles.

After the baking tests baking plates from grey iron were the dirtiest ones (containing the highest amount of waffle residues), which was also determined in other studies by Reinhart et al. (2012). Waffle waste on TiN coating and steel was slightly brownish and only slightly adhered to the baking plate. Waffle waste on ductile iron and grey iron baking plates was burnt and stuck strongly to the baking plate. Both steel baking plates thus remained cleaner (see Fig 1 and Fig. 2). This, as well as the observed adherence decreasing effect of steel backing plates, can probably be attributed to its smoother surface (steel baking plate) and higher material stability (both steel baking plates show lower tendency to generate cracks) compared to grey iron or ductile iron.

Baking regime – combined effect of baking temperature and speed – is known to greatly influence waffle quality in general and is also likely to influence sticking behaviour of the product. Main reasons for this effect are assumed in the rate and speed of drying the product, thus forming a type of crust, which then can be taken off easier. Waffles (produced from worst ingredient recipe) baked at faster baking speed (higher temperature, but shorter time), were found to be significantly drier compared to those baked at slower speed: baking loss was higher, moisture content and aw-value were lower. In consequence these waffles required less take off force and number of sticking waffles was significantly lower. During these trials with 30 waffles none of the fast baked waffles was sticking. One fact that could be observed though is that at higher baking speed more waffle batter residues remained on the baking plates (increased dirt). Experience from long-term trials (during applied industrial baking tests) has shown that more dirt on baking plates can lead to more sticking waffles after some time. This effect has to be considered for industrial application when setting baking temperature and time. It could be worth to investigate if falling temperatures (hotter at the beginning and lower at the end) could be applicable, as this would maybe accelerate fast "crust" formation at the beginning and ensure fully baked waffles without leaving batter residues on the plates.

An explanation for the better release of waffles from grey iron or steel might be the heat storage capacity of the baking plates. Grey iron and steel have better volumetric heat capacity compared to ductile iron (see table 1), thus they are less susceptible against temperature fluctuations within the baking oven and keep contact baking temperature more constant. This effect might have contributed to the better release of waffles from these baking plates baked at suboptimal conditions - worst ingredient recipe, which is more at risk to produce high number of sticking waffles, and moderate baking regime, where temperature fluctuations exert more severe effects.

To conclude these results shortly, baking plates with increased hardness, good heat storage capacity and a (stable) smooth surface seemed to be better suitable for waffle production. Coating of the plates might even improve the release behaviour of waffles, although TiN coating that was investigated in this study delivered no significant effects. Still further research in this direction might be promising.

3.2. Influence of release agent

For this study three types of release agents were chosen, which represent the typical types available: *Bandex*, containing thermal stable fats and mainly short-chain saturated fatty acids, *Dübor PR100*, containing mainly long-chain saturated fatty acids, and *Amarnakote C*, a release agent based on a combination of emulsifier and acid, which combines cleaning and release application in one. All trials were performed from batters of the worst ingredients at moderate baking conditions (suboptimal conditions where more sticking waffles are expected). Obtained results are summarised in table 4.

Within the three tested release agents, *Bandex* showed significantly better release properties of waffles compared to *Dübör PR100* and even more to *Amarnakote C.* Number of sticking waffles was significantly lower for all baking plates. Additionally the amount of batter residues that remained on the baking plates increased strongly in the same order. Adherence force of waffles produced with application of *Bandex* was lower for some baking plates, although results here were not as clear as for number of sticking waffles. After application of *Amarnakote C* or *Dübör PR100* more than 50 % of the waffles could not be taken off the baking plates (except for *Dübör PR100* on grey iron baking plate, here 30 %), in some cases even none of the waffles could be removed, in particular after *Amarnakote C* application.

These results demonstrated that release agent based on higher saturated short-chain fatty acids provided the best waffle release and least waffle residues, compared to long-chain saturated fatty acids based release agents. Thus, not only heat stability of fats alone is important for successful release (Oexmann 2008), but also chain length of fatty acids. Similar results were also found in a study of Tiefenbacher et al. (1991), who used waxes. It seemed that fats containing more short chain fatty acids retained water in the waffle better in comparison to fats containing higher amounts of long chain fatty acids. This might provide a better release film due to altered contact angles on the surface material (Ashokkumar and Adler-Nissen, 2011; Palav, 2016; Schünemann and Treu, 2009). Release agents based on emulsifier-acid-combinations (like *Amarnakote C*) showed no suitability for this application - waffles could not be removed, additionally it lead to increased batter-films on the baking plates, which in the long-term worsens waffle release even further.

4. Conclusion

This study has shown that sticking of waffles on baking plates is highly influenced by the baking plate material, the baking regime (baking temperature and time), as well as the release agent. Independent from each other following results could be concluded: Baking plates with increased hardness, good heat storage capacity and a (stable) smooth surface provided better release of waffles and caused less waffle residues. Among the baking plates investigated, best release results were found for steel baking plates, grey iron and ductile iron only seem to be limited suitable. Their poor mechanical stability (formation of cracks) allow their use mainly for short-term baking trials (e.g. household), but not for long-term industrial applications.

Baking temperature and time has to be chosen carefully, it should be high enough to allow rapid products crust formation, but not too high to enhance burning, which leaves increased amounts of waffle residues on the plates. Falling temperature regimes (hotter at the beginning and lower at the end), which is often applied for bread baking, could be a possible strategy also for waffle.

Release agents, which are based on short-chain saturated fatty acids, provide better release of waffles and leave less dirty baking plates than release agents with long-chain saturated fatty acids. Release agents based on emulsifier-acid-combinations are not suitable for this type of application.

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Tab.1: Experimental design – recipes of waffles investigated

Ingredients	**Mixing sequence**	**Optimised [%]**	**Worst [%]**
Wheat Flour W480	3	15.77	15.77
Potato starch	3	6.73	-
Rice flour	3	-	6.73
Water 12°dH	1	8.00	8.00
Egg, fresh	1	25.01	25.01
Sorbitol sirup	1	-	7.54
Glycerin sirup	1	7.54	-
Sugar crystal	2	16.01	16.01
Skimmed Milk Powder	2	1.00	1.00
Sodium-Bicarbonat	2	0.29	0.29
Citric acid	2	0.05	0.05
SAPP40	3	-	0.40
Ammonium bicarbonate	3	0.40	-
Monoglycerid ColcoM	3	0.25	0.25
Palm fat Ceres	4	18.95	-
Rapeseed oil	4	-	18.95
Sum	-	**100.00**	**100.00**

Table 2: Physical properties of the used baking plate materials

Materials characterisation	**grey iron**	**ductile iron**	**steel**	**steel with TiN coating**
Surface hardness	180 - 230 HB	130 - 180 HB	163 HB	2300 HV0.05
Surface roughness R_a [µm]	0.85	0.96	0.59	0.98
Tensile strength [N/mm²]	250 - 350	> 400	585	585
Yield strength [N/mm²]	165 to 228 (0.1% elongation)	> 250 (0.2% elongation)	450	450
Breaking elongation [%]	0.3 - 0.8	> 15	12	12
Young´s Modulus [GN/m²]	103 - 118	169	206	206
Thermal expansion [µm / m K]	13.0 (20°C - 400°C)	12.5 (20°C - 400°C)	13.7 (0°C -400°C)	13.7 (0°C -400°C)
Thermal conductivity [W/m K]	46.5 (at 300°C)	36.2 (at 300°C)	51.9	51.9
Diffusivity [m / s²]	1.2×10^{-5}	9.9×10^{-6}	1.4×10^{-5}	1.4×10^{-5}
Thermal capacity [J / kg K]	535 (20°C - 600°C)	515 (20°C - 500°C)	486 (above 100°C)	486 (above 100°C)
Density [kg / m³]	7200	7100	7870	7870
Volumetric heat capacity [J /m³ K]	3.85×10^6	3.66×10^6	3.82×10^6	3.82×10^6
Citation	DIN EN 1561	DIN EN 1563	www.matweb.com	www.oerlikon.c om

Table 3: Effect of baking plate materials and baking speed (release agent *Bandex* for all trials)

	Batter characterisation				Waffle characterisation							
	pH n=3	**Temperature [°C]** n=3	**Density [g/l]** n=3	**Viscosity [s]** n=3	**L** n=30	**a** n=30	**b** n=30	**Baking loss [%]** n=30	**Moisture [%]** n=3	**aW** n=3	**Force [N]** n=30	**Sticking [%]** n=1
Optimum ingredients – moderate speed												
Steel with TiN coating	7.15 ± 0.02^{b}	31.33 ± 2.08^{c}	97.58 ± 2.46^{a}	14 ± 1^{a}	64.45 ± 8.36^{d}	6.32 ± 3.70^{a}	28.99 ± 6.31^{a}	19.52± 5.84^{a}	16.28 ± 0.78^{c}	0.65 ± 0.02^{c}	0.021 ± 0.007^{ab}	10.0
Low alloyed steel	7.20 ± 0.03^{b}	22.87 ± 0.06^{a}	98.70 ± 0.58^{a}	30 ± 2^{d}	59.26 ± 5.89^{c}	9.94 ± 2.79^{b}	31.50 ± 1.79^{b}	24.54 ± 2.88^{b}	14.71 ± 1.30^{bc}	0.63 ± 0.02^{bc}	0.020 ± 0.008^{a}	0.0
Ductile iron	6.94 ± 0.00^{a}	29.93 ± 0.31^{c}	98.27 ± 0.31^{a}	19 ± 1^{b}	55.76 ± 5.15^{b}	11.10 ± 2.61^{b}	29.94 ± 2.27^{ab}	24.06 ± 4.15^{b}	12.82 ± 1.94^{ab}	0.59 ± 0.04^{b}	0.025 ± 0.010^{b}	3.3
Grey iron	7.20 ± 0.07^{b}	25.03 ± 0.38^{b}	99.07 ± 0.55^{a}	22 ± 1^{c}	47.22 ± 4.61^{d}	13.91 ± 2.13^{c}	28.86 ± 2.09^{a}	24.75 ± 2.11^{b}	11.19 ± 0.35^{a}	0.55 ± 0.01^{a}	0.045 ± 0.014^{c}	20.0
p-value [1]	*0.0001*	*0.0000*	*0.5703*	*0.0000*	*0.0000*	*0.0000*	*0.0209*	*0.0000*	*0.0051*	*0.0022*	*0.0000*	
Worst ingredients – moderate speed												
Steel with TiN coating	6.44 ± 0.00^{d}	17.23 ± 0.06^{a}	98.99 ± 1.18^{b}	37 ± 2^{a}	64.10 ± 5.11^{b}	8.64 ± 1.90^{b}	33.55 ± 2.47^{b}	23.33 ± 2.41^{a}	10.77 ± 3.73^{a}	0.64 ± 0.03^{a}	0.032 ± 0.011^{b}	43.3
Low alloyed steel	6.26 ± 0.01^{b}	19.40 ± 0.20^{c}	94.42 ± 1.84^{a}	66 ± 2^{c}	71.96 ± 4.28^{c}	4.93 ± 2.17^{a}	31.37 ± 3.23^{a}	23.43 ± 2.16^{a}	14.88 ± 0.72^{b}	0.69 ± 0.01^{b}	0.029 ± 0.011^{ab}	43.3
Ductile iron	6.18 ± 0.01^{a}	17.53 ± 0.15^{a}	94.90 ± 1.65^{a}	70 ± 1^{d}	57.94 ± 7.21^{a}	11.99 ± 3.44^{d}	31.90 ± 0.00^{a}	23.43 ± 2.07^{a}	12.57 ± 1.22^{ab}	0.64 ± 0.03^{a}	0.039 ± 0.014^{c}	53.3
Grey iron	6.41 ± 0.02^{c}	18.93 ± 0.21^{b}	92.43 ± 0.39^{a}	55 ± 2^{b}	63.68 ± 6.42^{b}	10.39 ± 3.09^{c}	34.09 ± 3.09^{b}	25.64 ± 2.63^{b}	13.54 ± 1.14^{ab}	0.68 ± 0.02^{ab}	0.025 ± 0.007^{a}	0.0
p-value [2]	*0.0000*	*0.0000*	*0.0026*	*0.0000*	*0.0000*	*0.0000*	*0.0001*	*0.0002*	*0.1796*	*0.0574*	*0.0000*	
Worst ingredients – fast speed												
Steel with TiN coating	6.34 ±0.01^{ab}	21.67 ± 0.58^{c}	63.28 ± 2.75^{a}	56 ± 6^{a}	49.36 ± 8.82^{a}	14.49 ± 2.88^{a}	29.48 ± 3.33^{a}	27.48 ± 2.13^{a}	10.35 ± 0.47^{a}	0.59 ± 0.03^{a}	0.014 ± 0.002^{a}	0.0
Low alloyed steel	6.37 ± 0.06^{b}	19.23 ± 0.06^{a}	89.90 ± 2.27^{b}	71 ±17^{a}	55.60 ± 6.97^{b}	14.37 ± 3.11^{a}	31.70 ± 2.24^{c}	26.04 ± 1.51^{a}	10.87 ± 0.78^{a}	0.59 ± 0.02^{a}	0.022 ± 0.004^{c}	0.0
Ductile iron	6.37 ± 0.06^{b}	20.30 ± 0.00^{b}	96.67 ± 0.51^{c}	64 ± 1^{a}	51.23 ± 8.65^{ab}	14.52 ± 4.13^{a}	30.11 ± 3.21^{ab}	26.50 ± 5.18^{a}	11.76 ± 1.40^{a}	0.63 ± 0.03^{a}	0.016 ± 0.004^{b}	0.0
Grey iron	6.27 ± 0.06^{a}	19.43 ± 0.06^{a}	94.82 ± 1.21^{c}	60 ±10^{a}	53.10 ± 8.37^{ab}	14.65 ± 3.34^{a}	30.91 ± 2.79^{abc}	26.74 ± 2.30^{a}	10.83 ± 1.52^{a}	0.61 ± 0.05^{a}	0.016 ± 0.004^{b}	0.0
p-value [3]	*0.1193*	*0.0000*	*0.0000*	*0.4066*	*0.0387*	*0.9575*	*0.0139*	*0.2645*	*0.5226*	*0.4679*	*0.0000*	-
Effect of BP materials *p-value* [4]	*0.6689*	*0.3645*	*0.0834*	*0.1694*	*0.0000*	*0.0000*	*0.0400*	*0.7928*	*0.8624*	*0.9875*	*0.0000*	*0.0015*
Effect of baking speed *p-value* [5]	*0.7893*	*0.0001*	*0.0412*	*0.2473*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0150*	*0.0002*	*0.0000*	*0.0000*

[1] comparison of baking plates with optimised recipe, and moderate baking speed

[2] comparison of baking plates with worst recipe and moderate baking speed

[3] comparison of baking plates with worst recipe and fast baking speed

[4] comparison of baking plates (independent of recipe and baking speed, calculated from all tests to compare effects of baking plate material.

[5] comparison of baking speed (independent of baking plate, calculated from all tests with worst ingredients

Table 4: Effect of release agents (worst recipe and moderate baking speed)

	Batter characterisation				Waffle characterisation							
	pH n=3	**Temperature [°C]** n=3	**Density [g/l]** n=3	**Viscosity [s]** n=3	**L** n=30	**a** n=30	**b** n=30	**Baking loss [%]** n=30	**Moisture [%]** n=3	**aW** n=3	**Force [N]** n=30	**Sticking [%]** n=1
Baking plate: Steel with TiN coating												
Bandex	7.15 ± 0.02^{c}	31.33 ± 2.08^{c}	97.59 ± 2.46^{ab}	14 ± 1^{a}	64.45 ± 8.46^{a}	6.31 ± 3.70^{a}	28.99 ± 6.31^{a}	19.52 ± 5.84^{a}	16.28 ± 0.78^{a}	0.65 ± 0.02^{a}	0.032 ± 0.011^{b}	10.0
Dübör PR100	5.80 ± 0.00^{a}	23.03 ± 0.06^{b}	100.00 ± 0.62^{b}	45 ± 2^{c}	63.41 ± 7.53^{a}	8.32 ± 3.44^{b}	29.71 ± 4.06^{a}	25.40 ± 5.69^{b}	13.41 ± 2.42^{a}	0.68 ± 0.06^{a}	0.023 ± 0.02^{a}	80.0
Amarnakote C	6.14 ± 0.01^{b}	17.77 ± 0.06^{a}	94.23 ± 1.73^{a}	35 ± 1^{b}	60.92 ± 7.01^{a}	9.61 ± 2.47^{b}	32.42 ± 3.73^{b}	25.00 ± 4.81^{b}	13.84 ± 0.29^{a}	0.68 ± 0.02^{a}	0.002 ± 0.006^{b}	86.7
p-value	*0.0000*	*0.0000*	*0.0202*	*0.0000*	*0.1915*	*0.0007*	*0.0185*	*0.0001*	*0.1090*	*0.5596*	*0.0000*	*0.0000*
Baking plate: Low alloyed steel												
Bandex	7.20 ± 0.03^{b}	22.87 ± 0.06^{b}	98.70 ± 0.59^{b}	30 ± 2^{a}	59.26 ± 5.88^{a}	9.94 ± 2.79^{b}	31.50 ± 1.79^{a}	24.54 ± 2.88^{a}	14.71 ± 1.30^{a}	0.63 ± 0.02^{a}	0.019 ± 0.008^{a}	0.0
Dübör PR100	6.30 ± 0.00^{a}	23.90 ± 0.00^{c}	97.00 ± 0.10^{a}	45 ± 2^{b}	66.20 ± 3.66^{b}	10.03 ± 2.85^{b}	34.06 ± 3.38^{b}	22.86 ± 2.17^{a}	12.74 ± 1.10^{a}	0.67 ± 0.02^{b}	0.037 ± 0.020^{b}	56.7
Amarnakote C	6.27 ± 0.03^{a}	19.40 ± 0.00^{a}	94.37 ± 1.17^{a}	43 ± 1^{b}	67.58 ± 7.49^{b}	6.98 ± 3.26^{a}	30.80 ± 3.86^{a}	23.87 ± 6.1^{a}	14.53 ± 0.85^{a}	0.67 ± 0.02^{b}	0.026 ± 0.020^{a}	100.0
p-value	*0.0000*	*0.0000*	*0.0224*	*0.0000*	*0.0000*	*0.0001*	*0.0003*	*0.2943*	*0.1280*	*0.0108*	*0.0011*	*0.0000*
Baking plate: Ductile iron												
Bandex	6.94 ± 0.01^{c}	29.93 ± 0.31^{c}	98.27 ± 0.31^{a}	19 ± 1^{a}	55.76 ± 5.15^{a}	11.10 ± 2.61^{c}	29.94 ± 2.28^{a}	24.06 ± 4.15^{a}	12.82 ± 1.94^{a}	0.59 ± 0.04^{a}	0.025 ± 0.010^{a}	3.3
Dübör PR100	6.37 ± 0.01^{b}	27.07 ± 0.06^{b}	97.48 ± 1.48^{a}	30 ± 1^{b}	62.51 ± 5.17^{b}	9.67 ± 2.61^{b}	33.17 ± 2.58^{b}	22.30 ± 4.04^{a}	16.09 ± 0.88^{b}	0.72 ± 0.01^{b}	0.065 ± 0.020^{c}	70.0
Amarnakote C	6.31 ± 0.01^{a}	22.50 ± 0.00^{a}	101.54 ± 1.74^{b}	39 ± 2^{c}	64.51 ± 5.10^{b}	8.00 ± 2.71^{a}	32.48 ± 3.60^{b}	24.22 ± 3.13^{a}	14.46 ± 1.09^{ab}	0.68 ± 0.01^{b}	0.036 ± 0.022^{b}	86.7
p-value	*0.0000*	*0.0000*	*0.0211*	*0.0000*	*0.0000*	*0.0001*	*0.0001*	*0.1024*	*0.0722*	*0.0010*	*0.0000*	*0.0000*
Baking plate: Grey iron												
Bandex	7.20 ± 0.07^{b}	25.03 ± 0.38^{b}	99.07 ± 0.55^{b}	22 ± 1^{a}	47.22 ± 4.61^{a}	13.91 ± 2.13^{c}	28.86 ± 2.09^{a}	24.75 ± 2.11^{b}	11.19 ± 0.35^{a}	0.55 ± 0.01^{a}	0.045 ± 0.014^{ab}	20.0
Dübör PR100	6.41 ± 0.02^{a}	26.03 ± 0.06^{c}	99.14 ± 0.80^{b}	35 ± 1^{b}	61.55 ± 5.03^{b}	10.34 ± 2.38^{b}	32.65 ± 3.06^{b}	23.37 ± 2.00^{ab}	13.95 ± 0.96^{b}	0.69 ± 0.03^{b}	0.037 ±0.016^{a}	30.0
Amarnakote C	6.38 ± 0.02^{a}	17.93 ± 0.06^{a}	97.08 ± 1.36^{a}	40 ± 2^{c}	64.80 ± 4.86^{c}	8.85 ± 2.71^{a}	32.40 ± 3.05^{b}	22.24 ± 4.42^{b}	16.75 ± 0.51^{c}	0.74 ± 0.01^{c}	0.051 ± 0.019^{b}	73.3
p-value	*0.0000*	*0.0000*	*0.0662*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.080*	*0.0002*	*0.0000*	*0.0054*	*0.0000*
p-value [1]	*0.3396*	*0.0000*	*0.0124*	*0.0000*	*0.3980*	*0.0139*	*0.2707*	*0.6191*	*0.0519*	*0.0129*	*0.0001*	*0.0000*

[1] Comparison of all release agents, independent of baking plates (calculated from all tests)

Fig. 1: Baking plates (after baking of waffles from worst ingredient at moderate speed, using *Bandex* as release agent). From left to right: steel with TiN coating, low alloyed steel, ductile iron, grey iron; – after baking (top row) and after cleaning (bottom row).

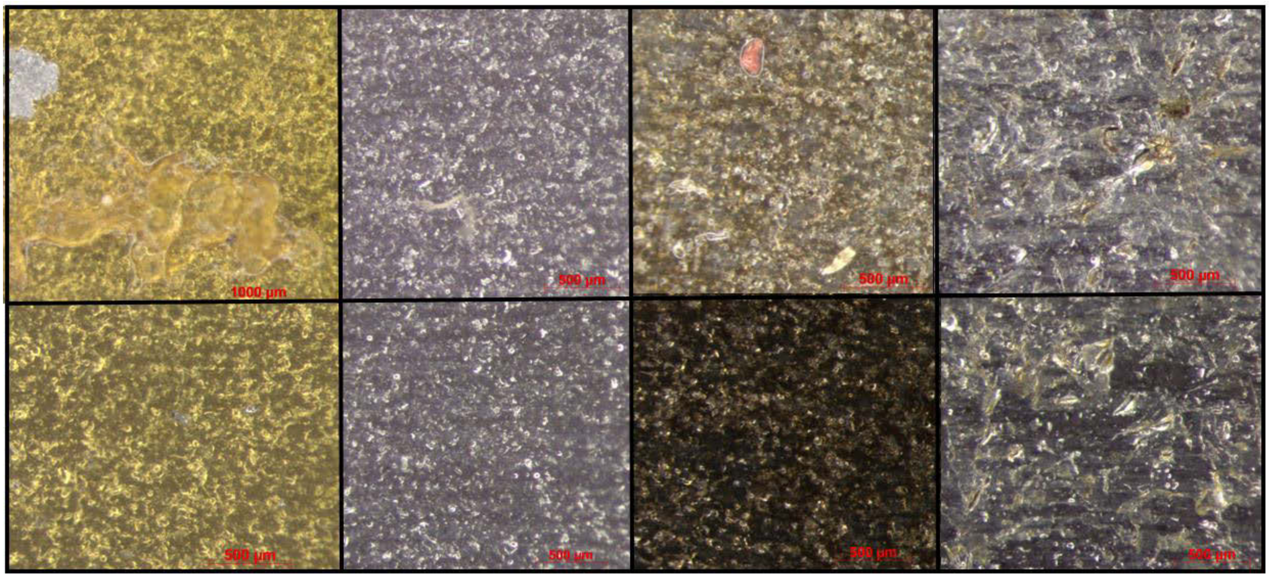

Fig. 2: Microscopic image of baking plates (after baking of waffles from worst ingredient at moderate speed, using *Bandex* as release agent). From left to right: steel with TiN coating, low alloyed steel, ductile iron, grey iron; – after baking (top row) and after subsequent cleaning (bottom row)

6. Conclusion

6.1 Waffle production and important sticking influences

A homogeneously **waffle** appearance and stable, soft waffle texture indicates a successful baking process, including waffle take-off. A good waffle quality is influenced by its ingredients (eggs, water, sugar and sugar substitutes, flour and starch, fat, leavening agents, emulsifiers, preservatives and flavours). A qualitative waffle is finally required for selling the waffles to the customers.

Sticking of waffles to the baking plates was significantly influenced by batter ingredients, baking parameter, baking plate material and coating, and release agents. Waffle release should be improved during needle take-off to avoid dirt on the baking plates by adhering waffle waste. A crumble (influenced by ingredients) or burnt (influenced by baking parameters) waffle tended to stick on the baking plate.

This **study aimed** to investigate sticking (adhesion) behaviour of different fresh egg waffle ingredients on ductile iron baking plates and alternative baking plate materials and coatings with different baking parameters, tested with different release agent types. Background of this study was to understand the factors that contribute to the sticking of waffles to different baking plate materials to reduce the number of sticking waffles and thus decrease waffle waste, cleaning intervals and required processing time and resources.

The **waffle production process** involved the batter preparation, the baking process and the packaging of the waffle. The batter preparation was performed according to standard procedures by using a dissolver stirrer and a common mixing sequence: step 1: water and liquids (eggs, sorbitol, glycerin) - 1 min, step 2: water soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent) – 3 to 4 min, step 3: flour, starches and pastes (flour, starch, monoglyceride, eventually second leavening agent) – 3 to 4 min, step 4: fat and lecithin pre-warmed to 40 °C – 1 to 2 min. After 15 to 30 min batter resting time the pH value, the temperature, the density and the viscosity were measured. Then 15 mL of the batter was deposited onto the baking plate. The pre-heated baking plate (140 °C bottom and 145 °C top baking plate at medium baking speed with 110 s; and 160 °C bottom and 165 °C top baking plate at fast baking speed with 90 s) was immediately closed after batter deposition and the waffle was baked. Afterwards the baking tong was opened and the waffle was taken out by a needle take-off, which is the common procedure in industrial waffle production. After 30 min cooling down the waffle properties (baking loss, L*, a*, b* colour values, moisture content and water activity) were measured at room temperature. The baking plate surface roughness was measured after each baking test and a microscopic image was taken to verify that the surface was not changed by the baking tests or the cleaning procedure using dry ice. The surface roughness did not change, but this gave no indication for surfaces changes, as found later. The reproducibility of the tests was verified for the grey iron baking plates. The results of this reproducibility tests can be used as indicator for baking behaviour characteristics, where the best release improving combinations can be analysed. For all baking tests the conditions were kept constant, except the investigated factors – which were ingredients, baking plate material, baking speed (a baking temperature and baking time combination) and release agent type. The influence factors have been changed separately at each baking test, and are discussed further.

6.2 Influence of the ingredients

The **influence** of the individually investigated **ingredients** on sticking behaviour (see first and second paper) later verified by two recipes: 1st) an optimised, release increasing recipe and 2nd) a worst, release decreasing recipe. Results showed that the number of sticking waffles was lower with the optimised recipe, compared to the worst recipe independent of the baking plate material (ductile iron, low alloyed steel, TiN coating), except grey iron. Grey iron showed fewer sticking waffles with the worst recipe due to the better volumetric heat capacity. Between the number of sticking waffles and take-off force there was a relationship, mostly take-off force decreased and when less waffles stuck. For baking plates with TiN coating or from steel take-off force was lower although waffles showed higher sticking behaviour. The reason for this might have been the influence of the waffle texture. If a waffle has a spongy-chewy texture (like tests with potato starch), the cohesion within the waffle is better and the release is possible although it is sticking slightly to the baking plate. If a waffle has a crumble texture (like tests with sorbitol), the waffle breaks or crumbles easier although the release behaviour would be better. The worst case is, that a waffle is crumble and additionally sticks to the baking plate (like tests with rice flour). The best case is that the waffle has a good texture and additionally does not stick to the baking plate (like tests with glycerine). This relationship was observed, but not measured and should be further analysed by a comparison of take-off force and waffle texture. Waffles should show a high waffle stability and low sticking tendencies, which could be achieved with ingredients with water retention tendencies (like moisture binding agents and short-chain fatty acids), a lower protein content, a higher starch content, starch types with higher RVA values, a slightly lower mineral content, and short chain, saturated fatty acids, which provide a better flow behaviour of the batter as well. In conclusion, release improving ingredients are glycerine, potato starch, cocos fat, butter, margarine, ammonium bicarbonate and magnesium hydroxide carbonate, and water with low water hardness. Sticking increasing ingredients are sorbitol, rice flour, lupine flour, rapeseed oil, water with higher water hardness, and sodium acidy pyrophosphate, which have been confirmed in the optimised and worst recipe. Influence of ingredients was independent from baking temperature and baking time, baking plate material and release agent, although some baking plate materials equilibrate sticking increasing influences better than others.

6.3 Influence of the baking plate material

The **influence of the baking plate materials** ductile iron, as standard material, low alloyed steel and grey iron as basic material alternative and titanium nitrite coating were analysed with the sticking decreasing recipe and the sticking increasing recipe at moderate and fast baking speed and with different release agent types (“Bandex“, “Dübör PR100”, “Amarnakote C”). Comparing the results of all baking plate materials, grey iron surprisingly provided only few adhering waffles, but showed higher required take-off force. It is assumed that due to the good volumetric heat capacity of grey iron the influence of adherence increasing ingredients is equilibrated compared to steel and ductile iron. Sticking number of waffles are higher with increasing required take-off force at both recipes at each baking plate material. The TiN coating and the basic material low alloyed steel showed similar sticking effects. The smooth surface of low alloyed steel might have a release improving effect. After each baking test a cleaning step with dry ice pellets at 6 bar was performed. The TiN coating started to crack and break off in microscopic dimensions from the basic material. Grey iron showed graphite break-out. Because this happened after the last baking test, this had no influence on these baking results. For long term ply adhesion of the coating the pre-treatment of the coating process should be developed further, and the cleaning procedure with dry ice pellets should be improved to a more gentle procedure by using dry ice pellets with smaller diameter at 12 bar. In conclusion, the TiN coating shows slightly waffle release improving properties – independent from recipe, release agent and baking speed – compared to the other basic baking plate materials. Alternative coatings, applied on a stable and smooth basic baking plate material with high volumetric heat capacity could improve waffle release.

6.4 Influence of the baking process

The **influence of the baking speed** (consisted of baking temperature and baking time) was studied with the worst recipe on the mentioned baking plate materials (ductile iron, grey iron, low alloyed steel, TiN coating) using the release agent “Bandex”. Waffles did stick more at moderate baking speed than at faster baking speed as results surprisingly showed for TiN coating, steel and ductile iron baking plates. There was no difference between different baking speeds for grey iron; no waffles did stick at these tests. Usually it is recommended to bake waffles at moderate baking speed and temperature, because over longer time release is improved due to less browning. It was observed that there is a relationship between sticking number of waffles and waffle dirt on the baking moulds. More waffle waste leads to more sticking waffles over longer time, which was not significantly detected in this short term test, but should be considered. The take-off force decreases significantly with higher baking loss and lower water activity and moisture content. Waffles, that are darker and browner, show a significant lower moisture content and lower water activity. Therefore waffle release is improved when waffles are baked ideally and if waffle colour is brighter. A higher baking temperature could be used to bake waffles out, but not over longer time, because then waffle waste and subsequently number of sticking waffles might increase. Baking hotter at the beginning to build up a thin waffle crust, followed by decreasing baking temperature to bake out the waffle crumb would maybe improve waffle release, like it is applied in bread production as well (so called "temperature decreasing baking process"). To analyse this phenomenon in more detail long term oven tests with an infrared camera might be a possibility. In conclusion, faster baking speed improves release of waffles for short term processes, but moderate baking is recommended for longer continuous industrial baking tests in combination with a slight temperature decrease at the end of the waffle baking process. This would provide a better product quality and less dirt on the baking plates, which improves waffle release over longer time.

6.5 Influence of the release agent

From the **influence parameter release agents** "Bandex", "Dübör PR100" and "Amarnakote C" were tested at the different baking plate materials (ductile iron, grey iron, low alloyed steel and TiN coating) with the worst recipe at moderate baking speed. Fewest waffles did stick with release agent "Bandex"at all baking plate materials. Far more waffles did stick with "Dübör PR100" and the most waffles did stick with "Amarnakote C". Concluding that, release agents with short-chain, saturated fatty acids improve release of waffles („Bandex"), as it was observed in ingredients tests as well. Release agents with long-chain, saturated fatty acids do not decrease the sticking behaviour ("Dübör PR100"), where the improvement of release was little, as it was mentioned in other studies with waxes as well. Release agents on emulsifier-acid-basis ("Amarnakote C", which is a 2 in 1 combination of release agent and cleaner) are not suitable for baking waffles, because, as it was shown, this type of release agent does not improve the release. In conclusion, release agents with short-chain saturated fatty acids are recommended for baking waffles.

6.6 Poster "Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates"

The Poster was presented at the ÖGE-Jahrestagung from the "Österreichische Gesellschaft für Ernährung", the yearly conference of the Austrian Nutrition Society from 24th to 25th of November 2016.

Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates

Regina Huber*, Regine Schönlechner
Universität für Bodenkultur, Institut für Lebensmitteltechnologie
CFT Haas Convenience Food Equipment GmbH
**regina.v.huber@aon.at*

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1. Industrial production of fresh egg waffles

Fresh egg waffles are continuously baked in industrial tunnel baking ovens in high amounts of up to 200 kg raw material per hour. Waffles, like all other baked products, that partly stick to the baking plates cause significant product loss and increased costs due to required cleaning procedures and restarting phase [1]. Sticking of waffles is influenced by:

- ***batter ingredients***
- ***baking plate material***
- ***baking temperature and time***
- ***release agent***

The aim of this study was to understand the factors that contribute to sticking of fresh egg waffles on baking plates.
The effect of different recipe ingredients (starches and sugar components, leavening agents, fat and water sources) on the sticking (adhesion) behaviour of waffles on the baking plate material ductile iron were investigated at moderate baking temperature and time with common release agent "Bandex".

2. Why is sticking so important?

- up to 4800 kg batter per 24 h day
- < 1 % baking waste O.K. = 288 kg baking waste per week
- lots of various ressources (1,15 bill. food wasted global)

3. Waffle production and analysis methods

Preparation of batter was performed using a dissolver stirrer (IKA) at medium speed of 800 rpm according to common mixing sequence for waffles: step 1: Water and liquids (eggs, sorbitol, glycerine)—1 min; step 2: water soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent)—3 to 4 min; step 3: flour, starches, and pastes (flour, starch, monoglyceride, eventually second leavening agent)—3 to 4 min; step 4: fat and lecithin prewarmed to 40°C—1 to 2 min. The mixed batter was allowed to rest for 15–30 min prior to baking and pH, temperature, viscosity and density were measured. The principal waffle recipe and its variations are given in Table 1.

The baking tong "Turtle" (ductile iron baking plates, FHW Haas, Picture 1) was pre-heated up to 140°C (bottom) and 145°C (top baking plate). Before first batter disposition, a constant amount of the release agent (Bandex) was spread on baking plates. 15 ml batter was deposited on the baking plate, which was closed and the baking process started immediately (110 s). The tong was opened and the waffle removed from the baking tong using a self-prepared vertical needle take-off (CFT Haas), which is the usual process in industrial waffle production. The take-off force was detected.

Pic. 1: Needle take-off

After a cooling period of 30 min (time for moisture equilibration within the waffle), the waffle was characterized for weight, color, color spots, moisture content and water activity. Additionally, after baking of all 30 waffles and complete cooling, the baking plate was characterized visually by a microscope and by a surface roughness analyser (Hommel Tester T100) to ensure that the baking plate surface has not changed. During this study, surface roughness was found to be constant. Between different recipes, cleaning was carried out by dry ice (frozen CO_2 pellets) to provide the same starting conditions for all recipes.

[1] ASHOKKUMAR, S., J. ADLER-NISSEN and P. MOLLER. Factors affecting the wettability of different surface materials with vegetable oil at high temperatures and its relation to cleanability. Applied Surface Science 2012; 263, 86-94

Ingredients	Mixing sequence	ISTD* [%]
Wheat Flour W480	3	22.40
Potato starch	3	
Rice flour	3	
Water 12°dH	1	7.96
Egg, fresh	1	24.89
Sorbitol sirup	1	4.98
Glycerin sirup	1	2.49
Sucrose crystal or powdered	2	15.93
Skimmed milk powder	2	1.00
Sodium bicarbonate	2	0.29
Citric acid	2	0.05
SAPP40	3	0.40
Ammonium bicarbonate	3	
Monoglyceride ColcoM	3	0.25
Lecithin liquid	4	0.50
Rapeseed oil	4	18.86
Cocos fat	4	
Sum	**-**	**100.00**

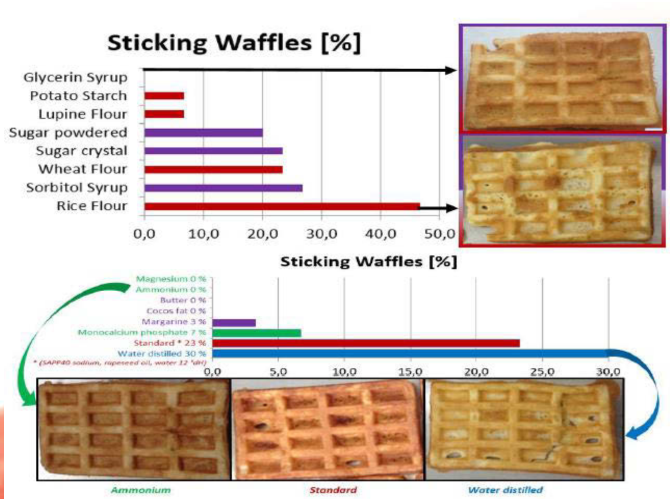
Tab. 1: Recipes: *ingredients tests by substitution

4. Results of release improving ingredients

Potato starch demonstrated the highest effects on increasing waffle stability and releasing properties compared to wheat and lupine flour. Rice flour performed worst, with almost 50% of sticking waffles. Starch tightens the waffle stability in contrast to protein and amylose softens and dries the waffle structure. ***Glycerine*** was better suitable than sorbitol and crystal sugar, which was superior compared to powdered sugar. Waffles with bright colour tend to stick less due to homogeneously baking process. Solid fats with high amount of short-chain fatty acids (***cocos fat, butter or margarine***) decreased the number of sticking waffles compared to liquid oils (rapeseed oil). Regarding leavening agents, ***magnesium hydroxide carbonate and ammonium bicarbonate*** were superior to sodium acid pyrophosphate or mono calcium phosphate. Between the two water sources effects were small. It could be demonstrated that waffles with increased stability and texture were those that showed the least number of sticking waffles, as given in Picture 2 and 3.

5. Conlusion

- ***Improved waffle stability***
  (starch stabilises, protein softens, amylose tightens)
- ***Water retaining ingredients***
  (moisture binding agents, short-chain satturated fats)
- More research on other ingredient groups for ***bakery products*** to improve baking processes



Pic. 2 & 3: Results of sticking waffles and waffle appearance

6.7 Concluding summary

Concluding all these results, the influence of ingredients, baking plate material, baking speed (a combination of baking temperature and baking time) and release agent on waffle release are independent from each other. The list of waffle release improving ingredients (glycerin; potato starch; saturated fats from cocos fat, butter and margarine; ammonium bicarbonate and magnesium hydroxide carbonate; and water with low water hardness) should be expanded by other starches, sugars and sugar substitutes, fats and leavening agents, and further by other main ingredient groups, such as emulsifiers, preservatives and eggs. In parallel the recipe could be optimised to achieve a spongy-chewy texture with good cohesion of the waffle to improve take-off quality. The relationship between waffle texture and cohesion should be analysed in more detail. Additionally other release agents with short-chain saturated fatty acids could be searched for. Coatings with far more release improving characteristics should be studied. Pre-treatments for coatings should be adopted. For coatings the food regulatory should be proofed. Baking tests on industrial scale at moderate and fast baking speed are recommended to proof the release decreasing behaviour of listed ingredients, baking plate materials and release agents. Baking with slightly decreasing temperature to the end of the waffle baking process could be tested to improve waffle quality and waffle release. An in-situ monitoring system to predict sticking waffles by waffle product quality and release behaviour could be a possible future development to improve the continuous industrial baking process. A combination of waffle colour (e.g. by L*a*b*), temperature profiles of waffles and baking plates (e.g. by temperature sensors), the degree of dirt on the baking plates and waffles moisture content (e.g. in-situ near infrared spectroscopy), linked to take-off force (e.g. by sensors in the needle take-off drum), in combination with batter data (e.g. pH value, temperature, viscosity and density) – which all show significant correlations to sticking behaviour– could be used to optimise waffle production.

7. Abstract

Fresh egg waffles are continuously baked in tunnel baking ovens in industrial scale in high amounts of up to 200 kg raw material per hour. Waffles that partly or fully stick to the baking plates cause significant product loss and increased costs due to interruption of the baking process, required cleaning procedures and restarting of the energy consuming start-up phase. Sticking of waffles is greatly influenced by baking plate material, release agent, baking temperature and time, and by the batter ingredients. The aim of this study was to understand the factors that contribute to sticking of fresh egg waffles on baking plates. The effect of different recipe ingredients (starches and sugar components, leavening agents, fat sources and water sources), on the sticking (adhesion) behaviour of waffles on four different baking plate materials (ductile iron, grey iron, low alloyed steel and steel with titanium nitrite coating), at different baking parameters (temperature and time) and application of three different release agents (different fat compositions) were investigated. Potato starch demonstrated the highest effects on increasing waffle stability and releasing properties compared to wheat and lupine flour. Rice flour performed worst, with almost 50% of sticking waffles. Starch tightens the waffle stability in contrast to protein and amylose softens and dries the waffle structure. Glycerine was better suitable than sorbitol and crystal sugar, which was superior compared to powdered sugar. Waffles with bright colour tend to stick less due to homogeneously baking process. Solid fats with high amount of short-chain fatty acids (cocos fat, butter or margarine) decreased the number of sticking waffles compared to liquid oils (rapeseed oil). Regarding leavening agents, magnesium hydroxide carbonate and ammonium bicarbonate were superior to sodium acid pyrophosphate, or mono calcium phosphate. Between the two water sources effects were small. Baking plates from ductile and grey iron showed lower release properties of waffles than the two steel baking plates. Baking parameters had to be high enough to allow rapid product crust formation but prevent burning, which again increases sticking behaviour. Release agents based on short-chain fatty acids with higher degree of saturation provided better release behaviour of waffles than those based on long-chain fatty acids or on emulsifier-acid combinations. It could be demonstrated that waffles with increased stability and texture were those that showed the least number of sticking waffles. Baking plates with increased hardness, good heat storage capacity and smooth surface seemed to be best suitable. Further research on appropriate coating material might be promising for future.

8. Zusammenfassung

Frischeiwaffeln werden in Industrieöfen in sehr hohen Mengen von bis zu 200 kg Rohmaterial pro Stunde gebacken. Klebende oder teils anhaftende Waffeln können zu hohen Kosten auf Grund eines Produktionsstillstandes und in weiterer Folge zu hohen Produktverlusten, erforderlichen Reinigungen und neuerlichen, energieverbrauchenden Anheizphasen führen. Das Anklebeverhalten von Waffeln wird durch das Backplattenmaterial, die Trennmittel, Backtemperatur und –zeit, sowie die Rohmaterialzutaten selbst maßgelblich beeinflusst. Ziel dieser Studie war die Einflüsse des Klebens von Waffeln an Backplattenmaterialien zu verstehen. Es wurde der Einfluss von unterschiedlichen Zutaten (Stärke- und Zuckerkomponenten, Triebmittel, Fette und Wasser) auf das Klebeverhalten der Waffeln an vier unterschiedlichen Backplattenmaterialien (Sphäroguss, Grauguss, niedrig legierter Stahl und Stahl mit einer Titaniumnitritbeschichtung) bei unterschiedlichen Backparametern (Temperatur und Zeit) unter Anwendung von unterschiedlichen Trennmitteln (mit unterschiedlicher Fettzusammensetzung) untersucht. Kartoffelstärke zeigte die besten Ergebnisse mit den stabilsten Waffeln und ausgezeichneten Ablöseeigenschaften, im Vergleich zu Weizen- und Lupinenmehl. Reismehl zeigte die schlechtesten Ergebnisse mit mehr als 50 % klebenden Waffeln. Stärke stärkt die Waffelstabilität, im Vergleich zu Protein und Amylose, welche die Waffeltextur erweichen und austrocknen. Glycerin brachte eindeutig bessere Ergebnisse hervor als Sorbitol oder Kristallzucker, welcher noch besser war als Staubzucker. Eine helle Waffelfarbe führt auf Grund eines homogeneren Backprozesses zu weniger Ankleben. Feste Fette mit hohen Anteilen an kurzkettigen Fettsäuren (Kokosfett, Butter oder Margarine) reduzieren die Anzahl an anklebenden Waffeln im Vergleich zu flüssigen Ölen (Rapsöl). Bei den Triebmitteln zeigten Magnesiumhydroxidkarbonat und Ammoniumbikarbonat sehr gute Ablöseresultate im Vergleich zu Natriumpyrophosphat oder Monocalciumphosphat. Wasser mit unterschiedlichen Härtegraden zeigten geringere Unterschiede. Backplatten aus Sphäroguss und Grauguss bieten den Waffeln schlechteres Ablöseverhalten als beide Backplattentypen aus Stahl. Bei den Backparametern ist eine Temperatur-Zeit-Kombination mit höherem Anheizen erforderlich, um eine Krustenbildung zu ermöglichen, die jedoch noch nicht zum Verbrennen führt, welche wiederum das Ankleben erhöht. Trennmittel mit kurzkettigen, gesättigten Fettsäuren verbessern das Ablöseverhalten im Vergleich zu jenen mit langkettigen Fettsäuren oder Emulgator-Säure-Basis. Es konnte gezeigt werden, dass Waffeln mit hoher Texturstabilität zu reduziertem Ankleben führen. Backplatten mit erhöhter Härte, hoher Wärmespeicherkapazität und einer glatten Oberfläche dürften am besten geeignet sein. Fortführende Forschungen zu Backplattenmaterialbeschichtungen sind für die Zukunft vielversprechend.

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Curriculum Vitae Regina Huber, MSc.

Personal information:

Nationality: Österreich

Date of birth, place: 05.11.1987, Wien

Gender: female

Work experience:

- Sales Development & Marketing; analytical instrument configurations, price list configurations, turnover controlling, writing of scientific articles and press release, publication library, conference organization and poster presentation, website creation, organization and moderation of AAC Education courses (Academy for Analytical Chemistry); in Korneuburg, called "Shimadzu Handelsges.m.b.H." since November 2015

- Consulting for baking plate contact materials and recipe development; statistical evaluation and interpretation of research data about adherence of bakery products (SEM, HSI-NIR, contact angle); in Leobendorf, called "CFT Haas Food Equipment GmbH" in November 2015 to February 2016

- Food technologist; Product development for waffles, wafers and convenience food (water activity, moisture content, L*a*b*, infrared camera, surface roughness, incident and transmitted light microscopy, rheometer, texture analyzer, density), upscale to industrial scale in Austria and international, material research, quality control (GMP), safety-at-work practitioner; in Leobendorf, called "CFT Haas Food Equipment GmbH – Department Technology, Research and Development" in September 2012 to October 2015

- Method development in protein research (DSC, CD, API formulation), research associate; first aider; in Vienna, called "Baxter Innovations GmbH – Global Preclinical R&D Hemophilia BioSciences – Pharmaceutical Sciences, Formulation Design & Devices" in September 2011 – September 2012

- Master thesis (Analysis of the Microchemical Composition of Fish Hard Parts Using Laser Ablation ICP-MS) in the field of mass spectroscopy in Vienna, called "University of Natural Resources and Life Sciences, Vienna, Department of Chemistry H771, VIRIS Laboratory" in January – May 2011

- Quality control (HACCP, IFS) and ethanol analysis (according to USP: GC, UV/VIS) in Spillern, called "AustrAlco – Österreichische Agrar Alkohol Handelgesellschaft m.b.H." in July and August 2008; Bachelor thesis (Pt-Co Farbzahlmessung ethanolischer Lösungen) in February – August 2009

- Deployment in wafer technology in Leobendorf, called "Haas Waffelmaschinen und Keksanlagen GmbH" in August 2007

- Pharmaceutical laboratory (KF titration, particle size analysis, water hardness) in Leobendorf, called "Kwizda Agro" in July 2004 and July 2005

Regina Huber, MSc. | Wiener Straße 67d 2104 Spillern – Austria | 0043 (0) 664 4240749 regina.v.huber@aon.at

Education and training:

2013 – 2016:	University of Natural Resources and Life Sciences, Vienna – Department of Food Science and Technology – Institute of Food Technology – PhD program
2009 – 2011:	University of Applied Science Wiener Neustadt – Master degree programme "Biotechnical Process" (elective courses: "Quality in Food and Feed", "Environmental Technology and Monitoring")
2007 – 2009:	University of Applied Science Wiener Neustadt – Bachelor degree programme "Biotechnical Process" (elective courses: „Bio Plastic")
2002 – 2007:	Secondary College for Food Technology and Meat Processing – Department Hygiene (Examination project: "Produktspezifikation einer Kaiserblutwurst nach analytischen und mikrobiologischen Kriterien")
1998 – 2002:	Grammar school (Latin)

Personal skills and competences:

Language:	Mother tongue: German; Other languages: English (Independent User).
Computer skills:	MS Office (Word, Excel, Power Point); Sharepoint LDMS; ERPsystems: SAP, CRM, BW; StatGraphics, SPSS; Website software Drupal.
Presentation skills:	Winner of ORF eins NEWTON Science Slam, IFA Tulln.
Organizational skills:	Organization of exhibitions and AAC education courses; design and experimental set-up for bakery product development; class representative and school representative in Secondary College.
Social competences:	I am a good team player and a co-operative, self-motivated and friendly person. I am in the "Gesunde Gemeinde Spillern" program (Pilates) and in the ballet group "Beweg-dich-beweg-es". I was a member of SC Malibu (trainer for dancing and gymnastics for children and senior citizen), Beachvolleyball Club I. BVV04 Spillern, Gitti City show dancing group, Union Handball Club Stockerau, Scouts, Wiener Synchronschwimmverein and ATUS Korneuburg – Rythmische Gymnastik.
Driving licence:	I am a holder of an Austrian drivers licence, category A motorbikes and B vehicles; and a holder of an Austrian motorboat license, category under 10 meters on the Danube and sea, and BFA Yacht Master Sailing license.

4. Waffle production: influence of batter ingredients on sticking of waffles at baking plates – Part II

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ORIGINAL RESEARCH

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Waffle production: influence of batter ingredients on sticking of waffles at baking plates—Part II: effect of fat, leavening agent, and water

Regina Huber | **Regine Schoenlechner**

Department of Food Sciences and

Technology, University of Natural Resources and Life Sciences, Vienna, Austria

Correspondence
Regine Schoenlechner, University of Natural Resources and Life Sciences, Department of Food Sciences and Technology, Vienna, Austria.

Email: regine.schoenlechner@boku.ac.at

Abstract
Fresh egg waffles are continuously baked in tunnel baking ovens in industrial scale. Waffles that partly or fully stick to the baking plates cause significant product loss and increased costs. The aim of this study was, therefore, to investigate the effect of different recipe ingredients on the sticking behavior of waffles. In this second part, ingredients investigated were different leavening agents (sodium acid pyrophosphate, ammonium bicarbonate, magnesium hydroxide carbonate, or monocalcium phosphate), different fat sources (rapeseed oil, cocos fat, butter, or margarine), and different water sources (tap water 12°dH and distilled water). Within the different types of fats, solid fats with high amount of short- chain fatty acids (cocos fat or butter) decreased the number of sticking waffles compared to liquid oils (rapeseed oil). Regarding leavening agents, magnesium hydroxide carbonate and ammonium bicarbonate were superior to sodium acid pyrophosphate or monocalcium phosphate.
Between the two water sources, effects were small.

KEYWORDS
Fat, fresh egg waffle, leavening agents, sticking, waffle batter

Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates

Regina Huber*, Regine Schönlechner
Universität für Bodenkultur, Institut für Lebensmitteltechnologie
CFT Haas Convenience Food Equipment GmbH
**regina.v.huber@aon.at*

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

1. Industrial production of fresh egg waffles

Fresh egg waffles are continuously baked in industrial tunnel baking ovens in high amounts of up to 200 kg raw material per hour. Waffles, like all other baked products, that partly stick to the baking plates cause significant product loss and increased costs due to required cleaning procedures and restarting phase [1]. Sticking of waffles is influenced by:

- ***batter ingredients***
- ***baking plate material***
- ***baking temperature and time***
- ***release agent***

The aim of this study was to understand the factors that contribute to sticking of fresh egg waffles on baking plates.
The effect of different recipe ingredients (starches and sugar components, leavening agents, fat and water sources) on the sticking (adhesion) behaviour of waffles on the baking plate material ductile iron were investigated at moderate baking temperature and time with common release agent "Bandex".

2. Why is sticking so important?

- up to 4800 kg batter per 24 h day
- < 1 % baking waste O.K. = 288 kg baking waste per week
- lots of various ressources (1,15 bill. food wasted global)

3. Waffle production and analysis methods

Preparation of batter was performed using a dissolver stirrer (IKA) at medium speed of 800 rpm according to common mixing sequence for waffles: step 1: Water and liquids (eggs, sorbitol, glycerine)—1 min; step 2: water soluble powders (sugar, skimmed milk powder, citric acid, first leavening agent)—3 to 4 min; step 3: flour, starches, and pastes (flour, starch, monoglyceride, eventually second leavening agent)—3 to 4 min; step 4: fat and lecithin prewarmed to 40°C—1 to 2 min. The mixed batter was allowed to rest for 15–30 min prior to baking and pH, temperature, viscosity and density were measured. The principal waffle recipe and its variations are given in Table 1.

The baking tong "Turtle" (ductile iron baking plates, FHW Haas, Picture 1) was pre-heated up to 140°C (bottom) and 145°C (top baking plate). Before first batter disposition, a constant amount of the release agent (Bandex) was spread on baking plates. 15 ml batter was deposited on the baking plate, which was closed and the baking process started immediately (110 s). The tong was opened and the waffle removed from the baking tong using a self-prepared vertical needle take-off (CFT Haas), which is the usual process in industrial waffle production. The take-off force was detected.

Pic. 1: Needle take-off

After a cooling period of 30 min (time for moisture equilibration within the waffle), the waffle was characterized for weight, color, color spots, moisture content and water activity. Additionally, after baking of all 30 waffles and complete cooling, the baking plate was characterized visually by a microscope and by a surface roughness analyser (Hommel Tester T100) to ensure that the baking plate surface has not changed. During this study, surface roughness was found to be constant. Between different recipes, cleaning was carried out by dry ice (frozen CO_2 pellets) to provide the same starting conditions for all recipes.

[1] ASHOKKUMAR, S., J. ADLER-NISSEN and P. MOLLER. Factors affecting the wettability of different surface materials with vegetable oil at high temperatures and its relation to cleanability. Applied Surface Science 2012; 263, 86-94

Ingredients	Mixing sequence	ISTD* [%]
Wheat Flour W480	3	22.40
Potato starch	3	
Rice flour	3	
Water 12°dH	1	7.96
Egg, fresh	1	24.89
Sorbitol sirup	1	4.98
Glycerin sirup	1	2.49
Sucrose crystal or powdered	2	15.93
Skimmed milk powder	2	1.00
Sodium bicarbonate	2	0.29
Citric acid	2	0.05
SAPP40	3	0.40
Ammonium bicarbonate	3	
Monoglyceride ColcoM	3	0.25
Lecithin liquid	4	0.50
Rapeseed oil	4	18.86
Cocos fat	4	
Sum	-	**100.00**

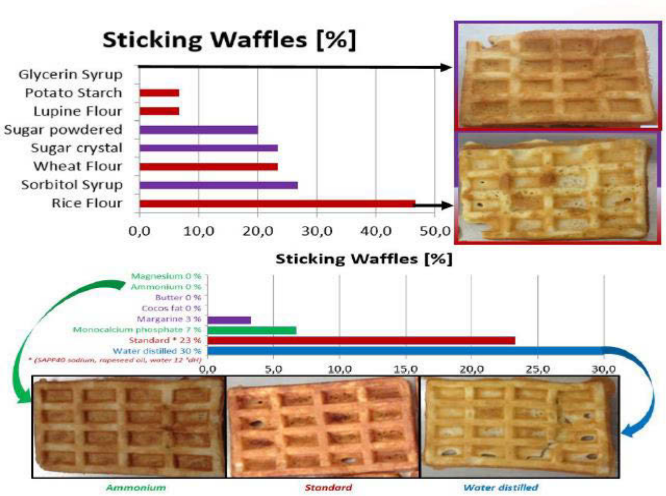
Tab. 1: Recipes: *ingredients tests by substitution

4. Results of release improving ingredients

Potato starch demonstrated the highest effects on increasing waffle stability and releasing properties compared to wheat and lupine flour. Rice flour performed worst, with almost 50% of sticking waffles. Starch tightens the waffle stability in contrast to protein and amylose softens and dries the waffle structure. ***Glycerine*** was better suitable than sorbitol and crystal sugar, which was superior compared to powdered sugar. Waffles with bright colour tend to stick less due to homogeneously baking process. Solid fats with high amount of short-chain fatty acids (***cocos fat, butter or margarine***) decreased the number of sticking waffles compared to liquid oils (rapeseed oil). Regarding leavening agents, ***magnesium hydroxide carbonate and ammonium bicarbonate*** were superior to sodium acid pyrophosphate or mono calcium phosphate. Between the two water sources effects were small. It could be demonstrated that waffles with increased stability and texture were those that showed the least number of sticking waffles, as given in Picture 2 and 3.

5. Conlusion

- ***Improved waffle stability***
  (starch stabilises, protein softens, amylose tightens)
- ***Water retaining ingredients***
  (moisture binding agents, short-chain satturated fats)
- More research on other ingredient groups for ***bakery products*** to improve baking processes



Pic. 2 & 3: Results of sticking waffles and waffle appearance