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Contact area determination between structured surfaces and viscoelastic food materials

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ABSTRACT

Adhesion caused by intermolecular interaction between two systems can only occur at the contact points between the adhesive and adhered ("adhesive active regions"). The determination of the real contact area/points between viscoelastic food materials and solid surfaces would contribute to a prediction of their adhesion behavior. Therefore, two instrumental methods were developed to identify the contact area between viscoelastic food materials and solid surfaces as a function of the surface structure (static Color Print Method) and contact time (dynamic Imprint Method). The methods were validated using a wheat dough model and five structured surfaces: a strong reduction of the contact area between wheat dough and structured surfaces was identified compared to a smooth surface (e.g. 57% decrease for the nub structure). Additionally, adhesion measurements were implemented using a previous developed CTM (Contact Time Measuring) method. Correlation analysis revealed a strong linear relationship between the contact area and surface adhesion force (Color Print Method: $r = +0.93$; Imprint Method: $r = +0.97$). The adhesion distance and adhering dough residues showed a higher dependency on the type of structure. The developed methods contribute to elucidate the adhesive behaviour between a viscoelastic system and solid surfaces and thus the construction of optimized surfaces with specific structures for the food industry.

1. Introduction

During processing food products come into contact with a wide range of surfaces. Depending on the type of the food product, a high variety of processing surfaces are applied. An important requirement for this surfaces is often an anti-sticking effect in order to avoid adhering food residues on the surfaces to reduce disturbances during production (e.g. unnecessary downtimes due to time-consuming cleaning work on the machines) and to increase the hygienic level. The development of surfaces with specific properties plays a major role in the food industry. Several studies revealed the effect of the surface free energy of the contact partners (Avila-Sierra, Zhang, & Fryer, 2019; Bhandari & Howes, 2005; Detry, Sindic, & Deroanne, 2010; Ghorbel & Launay, 2014; Keijbets, Chen, Dickinson, & Vieira, 2009; Laukemper, Becker, & Jekle, 2021; Wagoner & Foegeding, 2018) as well as the surface structure and roughness of the processing surface (Ashokkumar & Adler-Nissen, 2011; Couch & Binding, 2002; Laukemper, Jekle, & Becker, 2019; Moeller & Nirschl, 2017) on the adhesion behaviour to food materials. A reduced adhesion of food to structured surfaces is often explained by the following theory: The contact points between food and structured surfaces and thus the contact area is reduced compared to the contact points of smooth contact partners, what leads to a reduced adhesion behavior (Gay, 2002; Ghorbel & Launey, 2014; Hui, Lin, & Baney, 2000; Laukemper et al., 2019; Moeller & Nirschl, 2017). Merely at these contact points, molecular interactions in the interface layer between the molecules of the adherend and the adhesive can occur (Baldan, 2012; Kinloch, 1987). Due to a lack of experimental methods to identify the "real" contact area, the relation between the contact area and the adhesion behaviour of structured processing surfaces and food materials has hardly been examined. Especially for viscoelastic food systems like wheat dough the identification of the contact area to the surface is challenging due to its dynamic (flowable) character: Depending on the composition of wheat dough and the structure of the processing surface, the material can flow into the valley of the surface

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and increase the contact area over time.

In bakeries dough adhesion can be adjusted through modifications of the dough composition, changes in process parameters like temperature or relative humidity or the application of dusting flour (Chen & Hoseney, 1995; Couch & Binding, 2002; Dhaliwal & MacRitchie, 1990; Ghorbel, Launay, & Heyd, 2003; Jekle & Becker, 2011; Laukemper et al., 2021; Yildiz, Meral & Dogan, 2012). However, these adjustments are limited due to influences on the end product quality. Understanding the behaviour of the contact area formation between viscoelastic food systems und processing surfaces as a function of the processing surface structure, food processing surfaces with application-specific adhesive properties could be developed.

In the non-food industry, different methods are applied to identify the contact area between two systems. In geophysics, the contact area between sliding surfaces (e.g. rocks) is obtained by using a microscope and transparent samples: contact points appear as bright spots of transmitted illumination against a darker background (Dieterich & Kilgore, 1994). Optical in-situ methods have also been developed for soft materials (Krick, Vail, Persson, & Sawyer, 2012; Sahli et al., 2018), whereby these methods can also only be implemented for transparent surfaces. Furthermore, the contact area of structured surfaces and soft materials is often calculated using numerical analysis (Carbone & Putignano, 2014; Hyun, Pei, Molinari, & Robbins, 2004; Yastrebov, Anciaux, & Molinari, 2015) or molecular dynamic simulation (Yang, Persson, Israelachvili, & Rosenberg, 2008). However, these methods are currently inapplicable for food industry relevant surfaces like structured conveyor belts and dynamic viscoelastic food systems. Therefore, this study aims to develop applicable experimental methods to determine the contact area between viscoelastic systems like wheat dough and surfaces depending on their geometry (macroscopic surface structure). Two methods have been developed in order to investigate the static (process surface structure) and dynamic (contact time of the adhesives) properties. The results of each method were compared and assessed of their applicability, reproducibility and expenditure. For this approach, specific surface geometries were constructed using 3D printing of the contact surfaces. Using the developed methods, the contact area between a wheat dough system and surfaces of five different surface geometries was examined. Additionally, the adhesion behavior of the wheat dough to the printed surfaces was analyzed using the (extended) Contact Time Measuring (CTM) method (Laukemper et al., 2019). Finally, correlation analyses ought to contribute to the elucidation of the relation between the adhesion and contact area of processing surfaces depending on the surface geometry.

2. Materials and methods

2.1. Materials

2.1.1. 3D printed surfaces

In addition to a smooth surface, 4 different geometries (ridged, waffle, nub and pyramid) were printed and used for method development, validation and adhesion measurements (3D printer Ultimaker S5, Ultimaker, Utrecht, Netherlands). Poli-Lactic Acid (PLA, Ultimaker, Utrecht, Netherlands) was used as printing material. The layer resolution of the applied 3D printer is in a range of 0.02–0.6 mm. To describe the surface roughness of the smooth surface the Keyence digital microscope VHX-950F (KEYENCE DEUTSCHLAND GmbH, Neu-Isenburg, Germany) was used. The measurements were carried out at three different locations of the sample. The roughness of the smooth surface is in a range of Ra = 3.05 ± 0.25 μm. The selection of the geometries is based on already existing surface structures of process belts in the food industry. Fig. 1 shows the designs and geometric data of the 3D printed structured surfaces. Each sample has a size of 20 × 20 mm..

2.1.2. Wheat dough composition

Wheat flour Type 550 was obtained from A. Rieper AG (Vintl, Italy). According to the methods of the American Association of Cereal Chemistry international (AACCi) and of the International Association for Cereal Science and Technology (ICC), 11.69 ± 0.09 g moisture per 100 g flour (AACCi 44–01), 12.30 ± 0.12 g protein content per 100 g dry flour (AACCi 46–16, N x 5.7), and 0.60 ± 0.04 g ash per 100 g dry flour (ICC 104/1) were determined. For sample preparation demineralized water was applied.

2.2. Dough preparation

In accordance to AACC method 54–21.02 a torque measuring z-kneader (doughLAB; Perten Instruments, Germany) was used to determine the optimum water absorption and kneading time. To reach 500 Farinograph Units the dough was prepared with 48.69 g wheat flour and 30.36 ml demineralized water and kneaded for 186 s at 63 rpm and a temperature of 30 °C. For the following analysis dough pieces were formed into smooth balls. The weight of the resulting balls was adapted to the respective method (contact area determination: 5 ± 0.5 g;

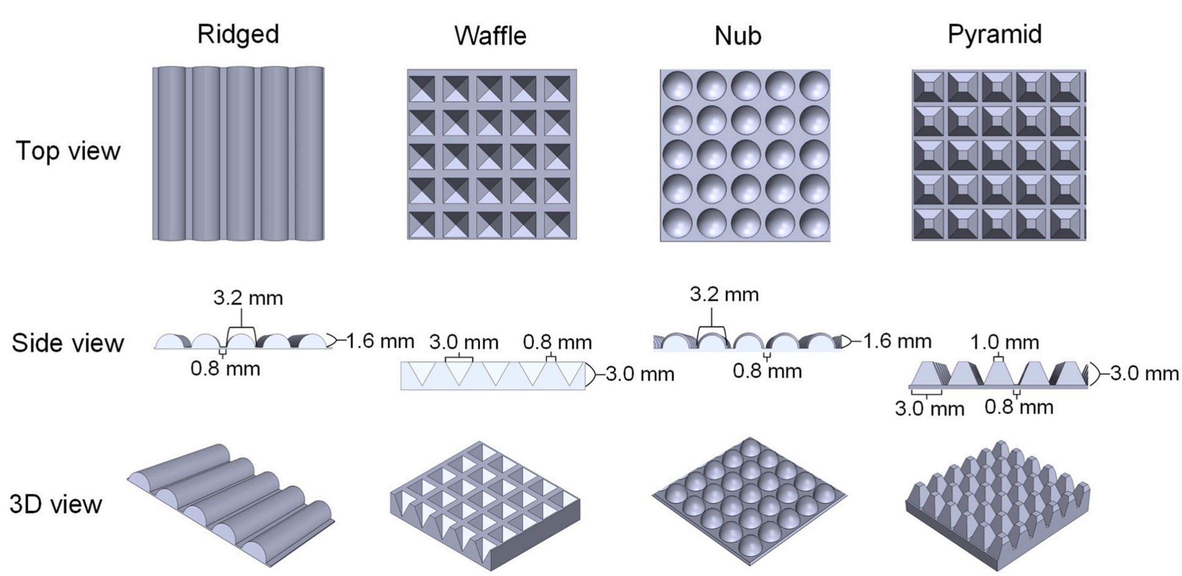

Fig. 1. Top, side and 3D view of the 3D printed structured surfaces including the geometric data.

stickiness measurement: 22 ± 1.0 g).

2.3. Macroscopic contact area determination

Currently there exists no method for identifying the "real" contact area between a viscoelastic food material and a solid (structured) surface. In the framework of this study two different methods for determining the contact area between dough and its processing surfaces were developed, validated and compared with each another.

2.3.1. Color print method (static method)

The development idea of the Color Print Method is based on "traditional fingerprinting technique". The challenge in developing this method was to identify a suitable coloring agent which enables a uniform distribution of the colorant on a (structured) surface, a correct transfer of the colorant to a dough surface when contacting and good adhesion of colorant on the dough surface. A schematic description of the finally developed Color Print Method is given in Fig. 2(A).

The surface sample to be examined was dusted in a closed area by a powder duster (Birchmeier, Stetten, Switzerland) with black patin powder based on 1% silicium oxide and 99% loess (Patin-A, Berlin, Germany) (Fig. 2(AI)). Surplus powder was removed from the surface to ensure a thin and even layer of dust. A dough sample (5 ± 0.5 g) with a „fresh cut" dough surface was placed on the dusted 3D printed surface and loaded with a standard weight for a uniform distribution and contact pressure (25 g, 5 s) (Fig. 2(AII)). At this point, the coloring agent was transferred at the real contact points from the surface to the dough. The dough was placed in a black-lined exposed photo box with an integrated camera (Basler, Ahrensburg, Germany), where a high-resolution image (2592 × 2048 pixel) was created of the dough surface and a 2 × 2 cm section was extracted for the contact area analysis. By means of matlab a black-and-white image was created, whereby the white area corresponds to the colored dough surface (Fig. 2(AIII)). The percentage of the white area and thus the real contact points between the dough and the printed surface were then calculated using matlab. Finally, the contact area was calculated in mm^2 (Fig. 2(AIV). In all experiments the surface and room temperature was kept constant at 20 °C.

The precision of the Color Print Method was analyzed by performing the entire experimental procedure (from sample preparation to evaluation) for 5 times on 5 different days (precision under intermediate conditions) applying a standard wheat dough and a PLA printed ridged structured surface. The relative standard deviation for this measurements is 9.9%, what shows a good reproducibility of the method.

2.3.2. Imprint Method (dynamic/time dependent method)

The requirement in developing this method was the observation of the dynamic flow behavior of the dough into the surface structures and thus the identification of the contact area after varying contact times. The development idea of the Imprint Method is based on "dental imprint technique" (impressions for dental protheses). The challenge in developing this method was to remove the dough from the surface without deformation to analyze the shape of the dough surface after contacting with a processing surface. A schematic description of the finally developed Imprint Method is given in Fig. 2(B).

A dough sample (5 ± 0.5 g) with a „fresh cut" dough surface was placed on the 3D printed surface and loaded with a standard weight for a uniform distribution and contact pressure (25 g, 5 s) (Fig. 2(BI)). The dough-on-surface sample was shock frozen in liquid nitrogen for 8 s (Fig. 2(BII)). The shock frozen dough was detached from the surface and immediately analyzed under a digital microscope (Keyence VHX 950-F, Neu-Isenburg, Germany) to receive a 3D profile of the dough surface (Fig. 2(BIII)). This step took place very quickly (≤30 s) in order to avoid the formation of condensation on the dough surface. With this 3D image a profile analyze was carried out: the identification of the maximum profile hight (difference between the lowest and highest point in the profile) which correspond to the maximum sinking depth of the dough into the surface (Fig. 2(BIV)). Based on the drawing of the respective 3D surface and the maximum profile height of the dough surface, the contact area per 400 mm^2 was determined with the help of solid work (Fig. 2 (BV)).

All experiments for the contact area determination were carried out in an open air condition at room temperature of 20 ± 1.5 °C and a relative humidity of approximately 50 percent. The surface temperature was also kept constant in all experiment at 20 °C (expect during and after shock freezing).

The precision of the Imprint Method was analyzed by performing the entire experimental procedure (from sample preparation to evaluation, 1 min contact time) for 5 times on 5 different days (precision under intermediate conditions) applying a standard wheat dough and a PLA printed ridged structured surface. The relative standard deviation for

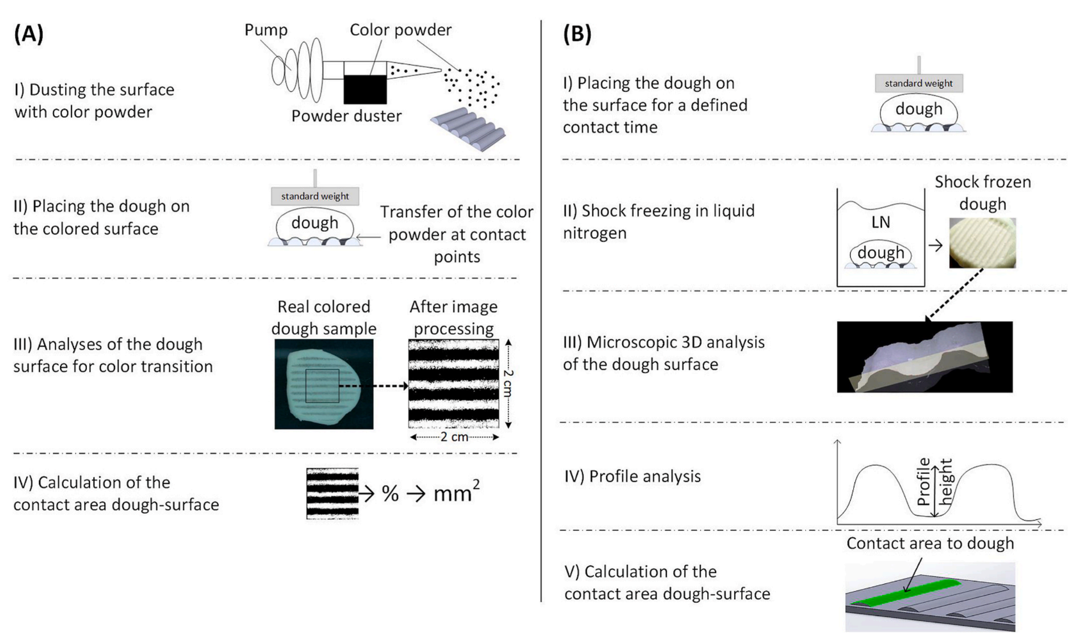

Fig. 2. Schematic description of the Color Print Method (A) and the Imprint Method (B). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

this measurements is 7.9%, what shows a good reproducibility of the method.

2.3.2.1. Applicability of the methods. The Color Print Method as well as the Imprint Method are both proved for macroscopic surface structures (>1 mm). The Imprint method is also suitable for the analysis of microscopic surface structures (<1 mm), though such surfaces have not been sufficiently investigated yet and are not part of this work.

2.4. Stickiness measurement

A previous developed Contact Time Measuring (CTM) method (Laukemper et al., 2019) was used for the investigation of the adhesion behaviour of dough to the printed surfaces. In this method, a CTM measuring cell for the Texture Profile Analyzer (TPA) is used. The CTM cell consists of a hollow cylinder with an opening at the bottom plate (d = 12 mm). This opening ensures a uniform contact to the sample material (PLA printed surface). The cylinder is placed on a desk with the sample contact material and connected to a Texture Profile Analyser (TPA) by a lever. The dough (22 ± 1.0 g) is placed into the cylinder and loaded with a standard weight for a uniform distribution. After a contact time of 1 min the cylinder is pulled upward by the TPA wherein the dough detaches from the material. In this study the surface adhesion force F_{max} (N), the adhesion distance (mm) and the work of adhesion (N. mm) were evaluated by the TPA. Additionally, the adhering dough residues (g) were determined after the measurement. Triplicate determinations of each surface material with 5 single measurements were performed. The measurements were carried out in an open air condition at room temperature of 20 ± 1.5 °C and a relative humidity of approximately 50 percent. The surface temperature was also kept constant in all experiment at 20 °C.

2.5. Statistical analysis

The statistical analysis was performed with the aid of Prism 6 (Version 6.01, GraphPad Software, Inc., La Jolla USA). Correlation analyses were used to investigate the relationship between variables. Consequently, correlations between the adhesive values and the contact area values were analyzed, whereby the correlation coefficient (r) represents strength and direction of a linear relationship. To detect significant differences between the samples a one-way ANOVA followed by Tukey-test ($p < 0.05$) was applied.

3. Results

3.1. Contact area determination between wheat dough and PLA printed structured surfaces using the color print method

In the Color Print Method the dough surface is colored at the contact points to the contact surface, which was colored before contacting. Fig. 3 (A) shows examples of the black-and-white images of the dough surfaces after contacting with the PLA printed surfaces of five different structures. Fig. 3(B) shows the results of the calculated contact area between the dough and the five different structured 3D printed surfaces per 400 mm^2 analyzed total area. A significant reduction of the contact area between dough and surface by structuring the surface could be identified for all structured surfaces in comparison to flat surfaces. Furthermore, significant differences in the contact area between the structured surfaces could be identified: e.g. a 46% reduction in the contact area through a waffle structure and even a significantly higher reduction in the contact area through a pyramid structure (79% compared to a smooth surface). The reduction of contact area by a waffle or ridged structure seems to be similar, the pyramid structure enables the highest reduction of the contact area. These results are obtained for a contact time of ≤1 min. As can be seen in Fig. 3(A) in the image of the smooth dough surface the overlying dough does not touch the surface completely: at the black areas the dough had no contact to the dough surface. That shows that the apparent visual contact area does not correspond to the real contact area between dough and their contact surface after a short contact time. Similar observations were made by Stadnyk, Piddubnyi, Krsnozhon, and Nataliia (2020), who investigated the effect of the roughness of rolls on the adhesion to dough. Due to the unevenness of both contact partners real contact area between the viscoelastic dough and a surface is also smaller than the geometric contact area (Ashokkumar & Adler-Nissen, 2011). Furthermore, the rheological properties affect the real contact area: firmer adhesive materials lead to isolated contact areas (Gay, 2002).

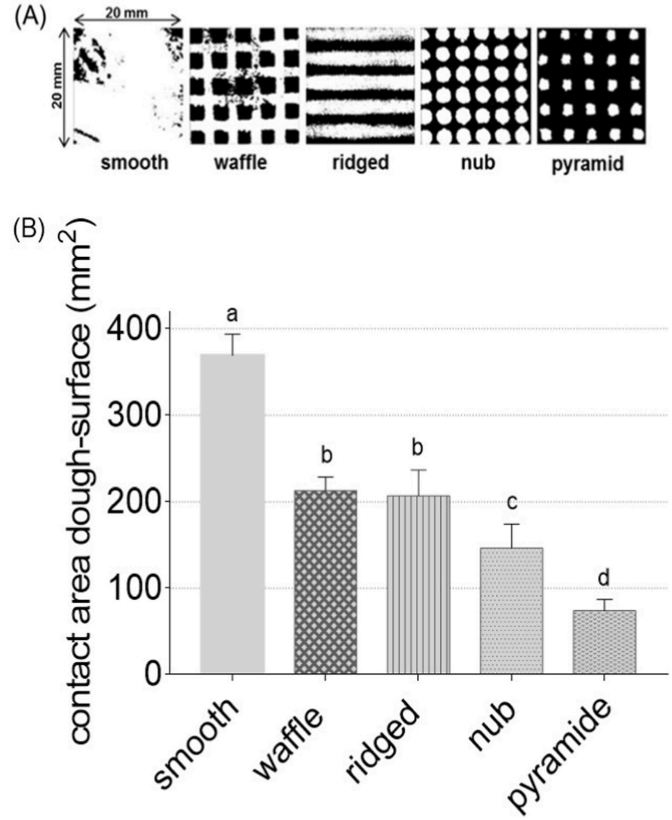

Fig. 3. Influence of surface geometry of PLA printed surfaces on the contact area to wheat flour dough analyzed with the help of a developed color print method. (A) Examples of the black-and-white images of the dough surfaces after contacting with the PLA printed surfaces for the determination of the contact area. (B) Results of the calculated contact area per 400 mm^2. Means with standard deviation (n = 10). The different letters indicate the significant differences between means (ANOVA, $p < 0.05$).

The results applying the Color Print Method shows a good reproducibility of the method as well as a low material and time expenditure. However, due to a very strong adhesion of the dough to the surfaces after a longer contact time, the method is just relevant to the investigation of short contact times (≤1 min) and limited to coarser surface structures. These limiting factors of the Color Print Method led to the development of another method, which allows the identification of the contact area after unlimited contact times for a high range of surfaces.

3.2. Contact area determination between wheat dough and PLA printed structured surfaces using the Imprint Method

To investigate the inflow behaviour of dough and thus the contact area between viscoelastic food materials and processing surfaces depending on the contact time and surface structure the Imprint Method was developed within this study. Fig. 4 (left) shows the results of the

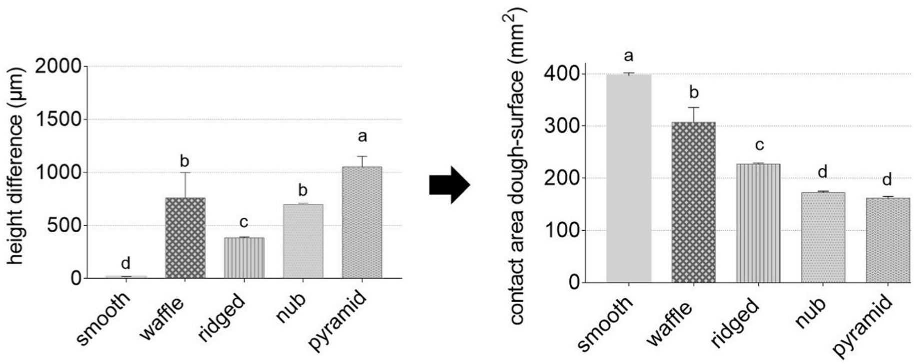

Fig. 4. Influence of surface geometry of 3D printed PLA surfaces on the profile height of the dough surface (left) and the contact area to wheat flour dough (right) analyzed with the help of a developed Imprint Method. Means with standard deviation (n = 6). The different letters indicate the significant differences between means (ANOVA, $p < 0.05$).

profile analysis of the dough surface after a short contact with the different structured surfaces. After a short contact time of the dough with the smooth surface, the dough shows the lowest profile height; the highest profile height of the dough results after the contact with a pyramid surface structure. In the next step the effect of the surface structure on the contact area between dough and surface was calculated with the help of the results of the profile height. The results are plotted in Fig. 4 (right): The lowest reduction in the contact area of 23% compared to a smooth surface could be achieved by a waffle structure, the highest reduction of 61% by the pyramid structure. Similar results were obtained when analysing the contact area using the Color Print Method (see Subsection 3.1). Comparing the results of both methods (see Figs. 3 and 4), the contact area results of the Imprint Method are overall a bit higher. This fact may result from an incorrect transformation of the coloring agent on the dough surface applying the Color Print Method. Furthermore, even a little inflow of the dough after a short contact time (≤1 min) is considered by applying the Imprint Method. For this reason, the Imprint Method enables more precise results and a wider range of applications: beside the determination of the contact area, the dynamic flow behavior of the dough can be identified depending on the surface geometry, the dough viscosity and the contact time between the adhesives. In addition, the Imprint Method is applicable for a high variation of surface structures including a fine structuring (e.g. structured industrial conveyor belts).

The developed methods enable the identification of the real contact area between a (structured) solid surface and a high variety of viscoelastic food materials for the first time. Applying these methods a strong reduction of the contact area between dough and a solid surface by structuring the surface could be proved. Furthermore, it could be shown, that the type of surface structure significantly influences the contact area to dough. In the next section, the effect of the same surface structures on the adhesion behaviour to dough was analyzed.

3.3. *Adhesion behaviour between wheat dough and PLA printed structured surfaces*

To investigate the adhesion behaviour between dough and the 5 different structured 3D printed surfaces, a previous developed CTM

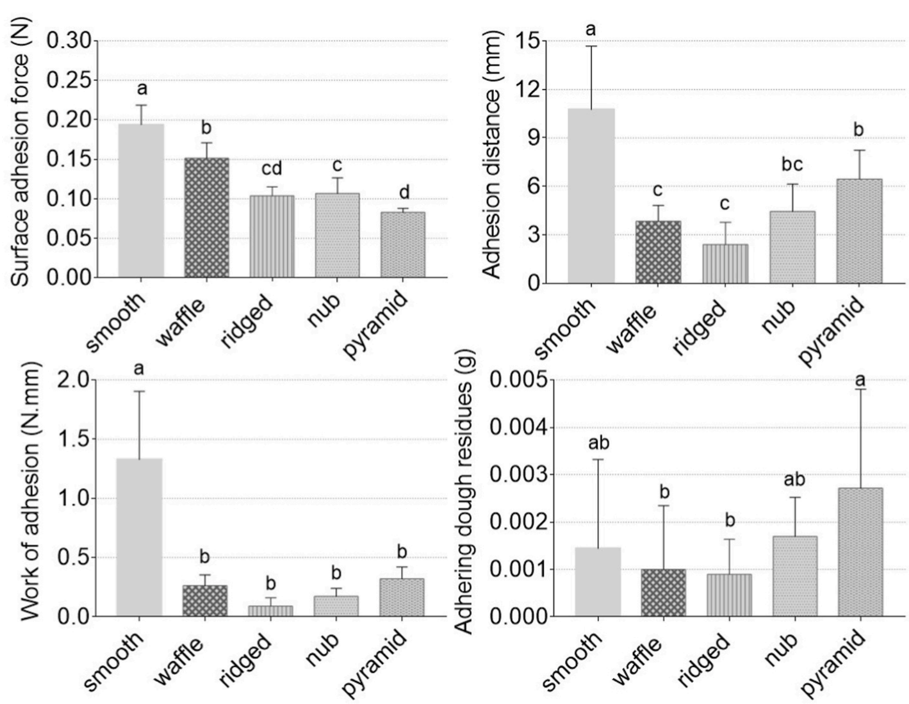

Fig. 5. Adhesion behavior between wheat dough and 5 different structured 3D printed PLA surfaces analyzed by the expanded CTM method. Means with standard deviation (n = 15).

method for dough stickiness measurements (Laukemper et al., 2019) was applied. As could be seen in Fig. 5, the surface adhesion force, the adhesion distance and thus the work of adhesion of wheat dough could be significantly reduced through all structured surfaces. For example, the surface adhesion force values could be reduced by 46% and the adhesion distance value by 77% when applying a surface with a ridged structure instead of a smooth structure. A reduction in the adhesion behaviour between dough and structured surfaces could also be identified in further and other studies (Ashokkumar & Adler-Nissen, 2011; Couch & Binding, 2002; Laukemper et al., 2019; Moeller & Nirschl, 2017). The type of surface structuring also significantly influences the adhesion behaviour. However, the type of structuring influences the various adhesion values differently: e.g. the surface adhesion force value decreases the most for the pyramid surface structure, whereat the adhesion distance value decreases the least for the pyramid surface structure. Here, the interlocking of dough in the pyramid surface structure could lead to high adhesion distance values. This seems to effect adhering dough residues on the surfaces: the pyramid structure shows the highest value. Overall, for all surfaces a cohesive failure was determined, although the amount was very low (see Fig. 5). The strength of the adhesive interaction between dough and the surfaces was comparable or stronger than the cohesive interaction within the dough. Just a few studies have been undertaken the effect of the composition or structure of the contact surface on adhering dough residues (Ghorbel & Launay, 2014). However, this value is very important as adhering dough residues can lead to microbial contamination of the processing surfaces and increased cleaning work (Beck, Jekle, Hofmann, & Becker, 2009; Laukemper et al., 2018). The results show the high importance of the different adhesion values when developing structured processing surfaces to reduce the adhesion to viscoelastic food systems: the possible interlocking of dough and adhering dough residues in certain surface structures must be taken into account.

The reduction of the adhesion of viscoelastic systems like wheat dough to structured surfaces is explained by several studies through a reduction in the contact area (Gay, 2002; Ghorbel & Launey, 2014; Hui et al., 2000; Laukemper et al., 2019; Moeller & Nirschl, 2017). However, there is no evidence of this claim so far. This relationship between the adhesion behaviour of wheat dough and (structured) surfaces is examined in the next section.

3.4. Correlation of contact area and adhesion behaviour between wheat dough and PLA printed structured surfaces

Plotting the surface adhesion force values against the contact area values, which were measured after a short contact time applying two different developed methods in the scope of this study, a strong positive correlation occurs: r = +0.930 for the results of the Color Print Method and r = +0.975 for the results of the Imprint Method (see Fig. 6). The results of both methods show an increase of the surface adhesion force with an increase of the contact area independent from the surface structure. However, just a moderate correlation between adhesion distance and contact area could be identified (see Table 1). The adhesion distance does not seem to depend on the contact area, but more on the type of surface structure. Some surface structures allow a reduction of the surface adhesion force due to a reduced contact area, however, lead to an interlocking of the dough in the structure of the surface. This leads to extended adhesion distance and adhering dough residues in spite of low surface adhesion force values and should be considered in the development of processing surfaces. Based on the results of this study, the pyramid structure enables a strong reduction in the contact area and thus of the surface adhesive force, however, leads to a long adhesion distance due to an interlocking of the dough in the structures and thus to adhering dough residues on the surface. Whereas the ridged structure of the examined surfaces in this study enables a strong reduction of the contact area and of all adhesion values compared to the smooth surface of this study and is therefore recommended for the application as a processing surface for viscoelastic food materials like wheat dough.

To sum up, the results of this study showed a significant correlation between the contact area of wheat dough and differently structured surfaces and the surface adhesion force after a short contact time ≤1 min. Thus, the structuring of processing surfaces enables a reduction of the surface adhesion force after a short contact time between two adhesives independent of the type of the surface structure. However, the structures must be designed in a way, that exclude the interlocking of dough and thus a long adhesion distance and adhering dough residues when removing it from the surfaces.

The developed methods of this study enables the identification of the contact area between viscoelastic food materials like wheat dough and (structured) solid surfaces and thus the development of surface structures of processing surfaces with a reduced adhesion behaviour.

Table 1
Results of the study of the linear correlation between the adhesion behavior (surface adhesion force, adhesion distance, work of adhesion) and the contact area between dough and 3D printed surfaces.

		Surface adhesion force (N) – contact area (mm^2)	Adhesion distance (mm) – contact area (mm^2)	Work of adhesion (N. mm) – contact area (mm^2)
Colour print method	Correlation coefficient r	+0.930	+0.553	+0.790
	Significance level	P < 0.05	NS	NS
Imprint method	Correlation coefficient r	+0.975	+0.588	+0.802
	Significance level	P < 0.01	NS	NS

NS: not significant (P > 0.05).

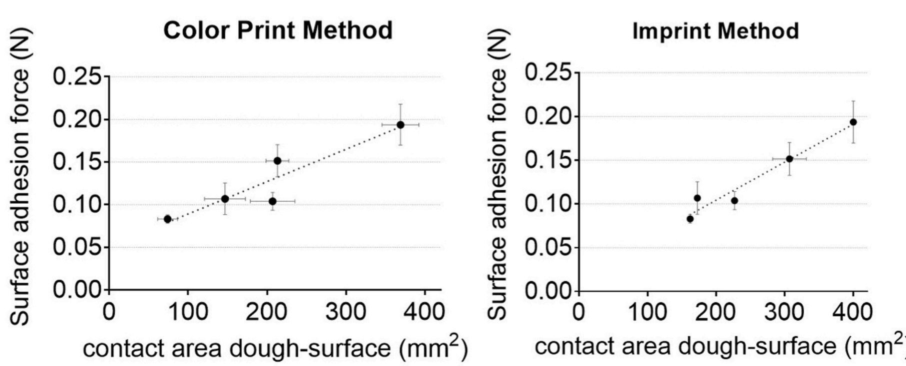

Fig. 6. Surface adhesion force (Fmax: peak separation force) of wheat dough measured with CTM method after 1 min contact time as a function of the dough-surface contact area determined via Color Print Method (left) and Imprint Method (right). Solid lines present linear correlations.

4. Conclusion

Adhesion between a solid surface and a viscoelastic food material can only occur at the contact area/points. This allows the adhesion behaviour to be adjusted by the contact area of both systems. In this study, two experimental methods have been developed to determine the so far unknown contact area between wheat dough and solid (structured) surfaces: a static Color Print Method and a dynamic Imprint Method. The methods were validated using 3D printed surfaces of five different structures. Subsequently, the relationship between the determined contact area and the adhesion behavior was investigated. Therefore, a previous developed CTM method was applied and expanded by an additionally examination of adhering dough residues.

Both methods enable a reproducible determination of the contact area between a wheat dough and a solid surface as a function of the surface geometry after a short contact time ($\leq$1 min). The Imprint method enables a more precise determination of the contact area as well as an additional analysis of the flow behavior of dough into the structure of the surface. Thus, the Imprint Method enables to get quantitative data about the flow behaviour of viscoelastic food materials depending on the material properties, the contact time between the adhesives and the surface structure of the adherend.

The results obtained by both developed methods showed a significant correlation between the contact area and the surface adhesion force: $r = +0.930$ for the results of the Color Print Method and $r = +0.975$ for the results of the Imprint Method. However, some structures can promote interlocking of dough and thus high adhesion distance values and a higher amount of adhering dough residues on the surfaces (e.g. pyramid structure). This fact must be considered when developing processing surfaces with specific structures. The ridged structure of the examined surfaces in this study enables a reduction of the contact area of 44% applying the Color Print method and of 42% applying the Imprint Method what leads to a reduction of all adhesion values: a reduction of 46% for the surface adhesion force, a reduction of 77% for the adhesion distance as well as a reduction of adhering dough residues of 37% compared to the smooth surface of this study. Within the structures examined as part of the study, the application of a processing surface with a ridged structure is recommended for viscoelastic food materials like wheat dough.

Through the possibility to identify the real contact area between a solid surface and a viscoelastic food material with the help of the methods developed within this work, surface structures which allow a small contact area to the adhesive can be identified. This allows the adhesion behaviour between the two contact partners to be controlled even after a long contact time.

Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

CRediT authorship contribution statement

Rita Laukemper: Conceptualization, Methodology, Writing – original draft, Visualization, Formal analysis. **Amelie Ochs:** Investigation, Formal analysis. **Kathrin Wohlmannstetter:** Investigation, Formal analysis. **Franziska Kugler:** Investigation, Formal analysis. **Thomas Becker:** Supervision. **Mario Jekle:** Supervision.

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