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ENTWICKLUNG UND IMPLEMENTIERUNG EINES FUZZY-SYSTEMS ZUR PROZESSREGELUNG DES AUSWALZVORGANGS VON WEIZENTEIGEN

DEVELOPMENT AND IMPLEMENTATION OF A FUZZY SYSTEM FOR PROCESS CONTROL OF THE SHEETING PROCESS OF WHEAT DOUGH

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Key words: rolling of wheat dough, rheological characteristics, detection of surface cracks, image processing, Fuzzy System

Abstract

One of the prime challenges faced by small scale industries using wheat for its products is to control the dough sheeting process. The focus of the presented research is to establish a Fuzzy Logic-based process control strategy for efficient sheeting of wheat dough. Fuzzy control systems are a development of Fuzzy Logic that allows for extremely precise control of robotic systems. It accounts for ambiguities in the data by giving it a level of confidence rather than declaring the data simply true or false. Two variations of Fuzzy Control Systems were implemented. Variation 1 via image processing (online) enables the system to analyze crack formation on the dough surface during the dough sheeting process. Variation 2 along with the online information also takes inputs from rheological measurements (offline) and evaluates the load bearing capacity of the dough. The rules for these two variations are based upon the findings of the image processing and rheological measurements. Apart from crack formation on the surface of the dough, both variations can also assess an additional input parameter, the thickness of the dough and two output parameters, the addition of flour and the change in the distance between the rolls.
Two different types of flours were used to prepare the doughs: Brema flour and Keks flour. Various compositions of wheat dough were used such as mixtures with and without yeast, mixtures with ordinary tap and oxygen enriched water, mixtures to which cysteine was added. Therefore the addition of redox-active or inhibitory substances (oxygen enriched water or L-cysteine) affects the adhesive proteins, thus the rheological behavior and machinability of the dough. The developed Fuzzy-based Rolling System (program) can regulate between a fast and a slow, a harsh and a gentle Sheeting Program as quickly as possible, without compromising the dough quality. When the two Fuzzy Control Systems are integrated into a running process, it can be noticed that both systems generate the same outputs that is the quality of the dough. If the dough is of lower quality the Fuzzy Control System considers the reviews from rheological measurements, reacts more defensively and rolls the dough more gently. Stickiness of the dough is compensated by the Sprinkling of flour. Overall the presented research reveals that both the time and the energy efficiency can be increased by the implementation of a Fuzzy Control System in the dough sheeting process as each individual batch of dough can be rolled effectively in fewer steps.

Introduction

Wheat, one of most widely cultivated crop, is unique among cereal and other proteinaceous plant in its ability to form a dough with viscoelastic properties ideally suited to making bread, biscuits, pasta, and cereal products [1, 2]. According to a study by the IFEU Institute, a power of 1.5 kilowatt hours is necessary to produce an average loaf of bread. It is both for grain cultivation and further processing into flour along with the baked loaf taken into account as well as the transportation to the consumers. This ecological accounting also reveals that with respect to economical energy consumption large bakeries can work much more efficiently than medium or small scale bakeries [3, 4]. Therefore importance is precisely in the area of small and medium-sized enterprises to make the production process more efficient in order to be more competitive. In the presented paper optimization of the sheeting process is of prime focus. It is primarily based on the manipulation of rheological dough characteristics for improved processability. Dough rheology plays an important role in determining the processing behavior and final quality of baked products; hence, it is not surprising that dough rheology also has an impact on dough sheeting processes [5]. Sheeting of dough between rollers is an important processing step in the production of a wide range of bakery products, including pastries, biscuits, cookies, crackers, pizza, noodles, bread and some pasta. Doughs are sheeted to form them into an appropriate shape for subsequent processing; however, sheeting can also afford other additional benefits [6].

By employing the findings, rolling process can be effectively designed by an adaptive process control and implemented in contrast to the previously fixed controls. For operational use, meaning not only to reduce energy costs but also to save time by quick and gentle rolling process in combination with reduced flour addition can be achieved. Since the aim of the presented work is to establish a Fuzzy system for efficient rolling processes of wheat doughs, focus is also on identifying the rheological properties of dough mixtures with (ciabatta) and without (puff pastry) the addition of yeast. In order to assess the dough processability additives such as oxygen enriched water and cysteine are used. The rheological properties can be affected both negatively and positively by the addition of cysteine or oxygen enriched water. The interpretation of rheological oscillation and rotation measurements is intended to draw conclusions on the dough processability.

Another key aspect is the representation of automated data acquisition and analysis from a CCD camera. Furthermore doughs are rated online (good, acceptable, not acceptable) by the digital image processing techniques, making it possible to integrate a Fuzzy System in an online process control of the rolling process of wheat doughs. The recordings quantify the cracks that develop on the dough surface during the rolling process thus providing information about the load on the surface of the dough. The probability of formation of cracks depends on the particular texture and rheological properties of the dough, so that it represents the constantly varying dough size. The findings are subsequently implemented as input variables in the Fuzzy System. The outputs of the Fuzzy System are mainly the control variables such as the addition of flour, which helps to reduce the stickiness of dough and the distance between the rollers (next rolling step) which increases the efficiency of dough processing.

Materials and methods

The basis of Fuzzy Systems is the integrated expert knowledge. Thereby for every rheological measurement carried out, parameters for input variables have to be defined. On the other hand the rheological data is associated with the results of the camera measurements. Thus two variations of a Fuzzy System are developed.

Dough preparation

For the rheological measurements different types of wheat dough were prepared based on the statistical planning of experiments. The different influencing parameters which cause a variation in the dough are use of different recipes:

- With and without the addition of yeast.
- Addition of cysteine
- Use of oxygen enriched water or tap water
- Use of different types of flour- Brema flour- wheat flour type 550 (from Bremen Roland mill Erling GmbH and Co KG, Bremen) and Keks flour- wheat flour type 550 (from Bremen Roland mill Erling GmbH and Co KG, Bremen)

The production of ciabatta and puff pastry is carried out according to a specially developed standard recipe (Tab.1).

Tab.1. Standard recipe for puff pastry and Ciabatta

Ingredients	Ciabatta	Puff pastry
Flour	100%	100%
Water	50%	50%
Sugar	9,6%	2%
Salt	1,3%	2%
Fat	-	5%
Oil	2%	-
Yeast	6,5%	-

The ingredients are mixed in the spiral kneader WP 50 eco from Kemper (Rietberg, Germany). In every batch 15kg of dough is mixed. The necessary ingredients for the dough such as water and fat were added at the temperature of 4°C so that the dough had a final temperature of 25°C after kneading. The kneading took place in two steps: initial two minutes slow mixing and then for the next six minutes the mixing is fast. Dough with yeast is rested for 1 hour to allow fermentation of yeast whereas the dough without yeast can be used for the measurements after 15 minutes of resting time.

Dough sheeting process

Fig. 1: Dough Sheeting Machine from Rondo Compas 3000, Burgdorf, Switzerland

The wheat dough is sheeted using Dough Sheeting Machine Compas 3000, from RONDO Burgdorf AG (Burgdorf, Switzerland) (Fig. 1). Sheeting implies rolling the dough between 2 rollers and repetition of the same with reduced spacing between the rollers in order to get a smooth crack free dough surface. For the presented research work 15-kg of dough was kneaded and portioned into 2.5 kg batches. Two programs were used for sheeting the wheat dough (Tab. 2). Program 1 with eight steps corresponds to be slow and gentle similar to the one often used in small bakeries which rolls the dough in a gentle manner using small increments of gaps between the rollers with the least possible stress reduction. The rolling gaps are defined in the following 8 steps: 45 mm, 35 mm, 25 mm, 15 mm, 10 mm, 8 mm, 6 mm and 5 mm. Program 2 reduces the rolling gaps to five steps from 45 mm to 5 mm (45 mm, 30 mm, 15 mm, 5 mm and another 5 mm) and is comparatively faster due to the lesser number of rolling steps. In this case, the dough experiences a significantly greater stress.

Tab. 2. Representation of the rolling programs

Sheeting programs	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Program 1	45mm	35mm	25mm	15mm	10mm	8mm	6mm	5mm
Program 2	45mm	30mm	15mm	5mm	5mm			

Dough sheeting profile

The Fuzzy System should give as an output for every dough being rolled a suitable rolling profile with belt speed of the Sheeting Machine being 26. 4 cm/s. The first rolling step of 45 mm as well as the final thickness of 5 mm is achieved by default. The intermediate rolling steps are oriented between a gentle (R1) and a consistently stressful program (R2) and is based on the nature of the dough. R1 includes eight steps; R2 however has only four steps (Fig. 2). This also means that the dough will be more stressed compared to R1 with greater compression and thus experiences greater shear forces. The shear forces increase particularly at low dough thickness and large reduction of the roll gap (Tab. 3).

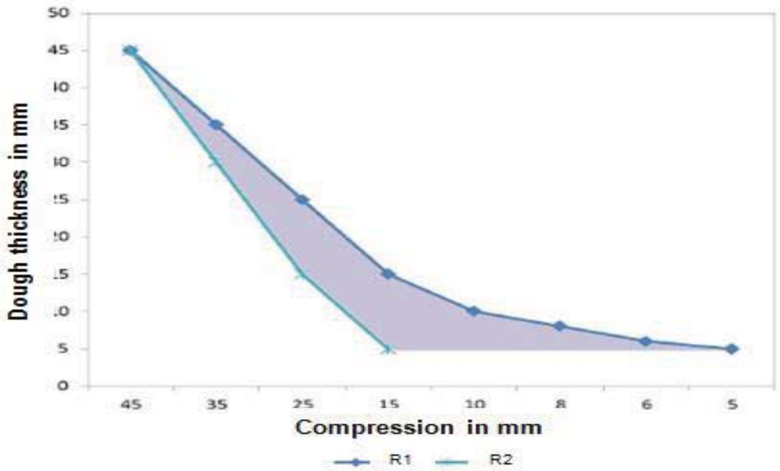

Fig. 2. Range of possible rolling profile between a gentle rolling program (R1) and a consistently stressful rolling program (R2)

Tab. 3. Shear rate comparisons between the rolling programs R1 an R2

Sheeting program	1	2	3	4	5	6	7	8
Program 1	45mm	35mm	25mm	15mm	10mm	8mm	6mm	5mm
Shear rate in 1/s	5.88	7.55	10.58	17.63	26.44	33.05	44.07	52.88
Program 2	45mm	30mm	15mm	5mm	5mm			
Shear rate in 1/s	5.88	8.81	17.63	52.88	52.88			

The term "processability" is a possibility to assess to which extent the dough can with stand the stress. If the dough is easy to work with then it can withstand high force. Therefore it is not sticky and does not tear. However if the dough shows more area of cracks and sticks to the rollers then it is difficult to process. In the bakeries stickiness of the dough is compensated by the sprinkling of flour. How much flour has to be added in each case depends on experience and differs for 2.5 kg dough with less stickiness from a half (about 30 g) to a whole hand full of flour (75 g). If this is not sufficient, several times flour will be sprinkled over the dough (about 113g). Consequently, as output variables for the fuzzy system, the next rolling stage and the addition of flour is specified. The objective is to achieve a rolling profile with few rolling steps, without damaging the dough, until the final thickness of 5mm is attained. Flour can be added only when the dough is rolled without any tear and without being stuck to the rolls after the first rolling step.

Rheological measurements

To determine the rheological properties of the wheat dough oscillation measurements were carried out to accommodate loss modulus and storage modulus. On the other hand rotation measurements were carried out to determine viscosity with respect to time.
For the rheological measurements with a plate plate rheometer from Anton Paar MCR 301 (Ostfildern-Scharnhausen, Germany), dough samples of about 100 g were rolled to a thickness of 1.5 mm with the Dough Rolling Machine. Then a sample with a diameter of 14 mm was used for the measurements in the rheometer. Instead of flat polished measuring plates it uses a toothed plate having a diameter of 25 mm. To prevent drying of the sample, a cover over the parallel-plate system and polymer crystals were used (Fig. 3).

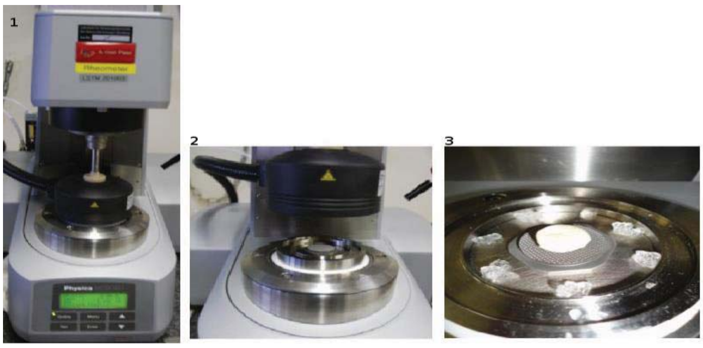

Fig. 3. Set up for the rheological measurements. 1. Rheometer: MCR 301 Anton Paar, Ostfildern-Scharnhausen, Germany, 2. Temperature control, 3. Dough sample on the measurement plate

Oscillation measurements

For the amplitude sweeps there are 21 measurement points with measuring point duration of 2 seconds and a constant angular frequency of 5 s^{-1} and a logarithmic decade to 5 Pts. / Dec and increasing deformation of 0.01 - 100%. Further amplitude sweeps were carried out with 23 measuring points with a deformation of 0.01 - 300%. For the frequency sweep deformation remains constant at 10%, and the angular frequency decreases from 100 rad / s at 21 measured points to one second at 0.01 rad / s.

Rotation measurements

The parameters for the rotation measurements are similar to that of oscillation measurements. The specifications on the rheometer are a constant shear rate of 0.5, 1 and 2 rad / s and the recording of 50 measuring points.

Camera measurements

To determine the formation of cracks on the dough surface, the dough was rolled in a sheeting machine with the mentioned 2 different rolling programs. For recording image data a charge-coupled device (CCD) camera is attached on one side of the rolling machine above the dough conveyor belt. By means of this camera, online measurement data is collected. The control of the camera is via Matlab software. To make sure that in every rolling step the entire dough is imaged, six images are taken. The next step is segmentation of the dough surface using masking and boundary tracing followed by background elimination. Finally from the number of pixels on the cracks, ratio of cracks in relation to the entire dough area is calculated which is referred to as crack ratio (Fig. 4).

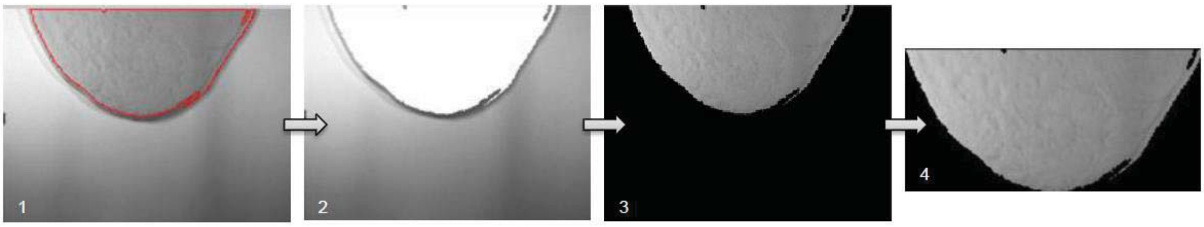

Fig. 4. Illustrative representation of image processing algorithm 1. Detection of dough border, 2. Masking the surface of the dough, 3. Background masking, 4. Cropping of the image

Structure of the Fuzzy Systems

In the present work, two variations of a Fuzzy System are developed. Both variations have the dough thickness and the crack formation as input parameters and the next rolling step along with the addition of flour as output parameters. They differ in that second variation where rheological data and the camera measurements are taken as input parameters. However in Variation 1 rheological data is not taken into account (Fig. 5). They are programmed using the software Matlab (Fuzzy Logic Toolbox). To visualize the Fuzzy System created in the Editor, Fis-Editor integrated in Simulink is used.

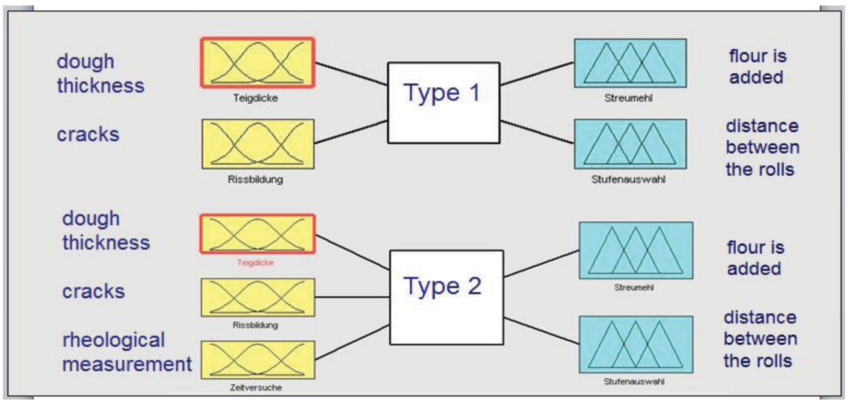

Fig. 5. Representation of the input and output parameters of the Fuzzy System

Results and discussions

Evaluation of rheological measurements

Rheological measurements of dough made with yeast, 0.01% cysteine and Keks flour show similar results to that of the dough without yeast, oxygen enriched water and Keks flour. All measurements are in the range of high values of both loss and storage modulus. Both doughs exhibit maximum viscosity in the experiments carried out with respect to time. Effect of cysteine in a low concentration on the dough structure cannot be clarified since the values of loss modulus and storage modulus along with the viscosity hardly differ and also in the dough with cysteine and tap water only slight differences are noticeable. The addition of oxygen enriched water in yeast doughs shows minimum values of the rheological modulus in oscillation measurements; in contrast dough without yeast does not. Thus, no final evaluation is possible at this point.

Evaluation of camera measurements

With the help of online camera measurements the dough quality was predicted. For a good dough surface the crack ratio is less than 0.12 and for an extremely cracked surface the value is greater than 0.45. In between these two values there are three more areas of dough surface namely very low, slight, and medium crack formation (Tab. 4).

Tab. 4. Boundary determination for crack values

Negligible	< 0.12
very low	0.12 – 0.20
Slight	0.20 – 0.32
Medium	0.32 – 0.45
High	> 0.45

Analysis and assessment of the rolling profile variants of the Fuzzy Systems

Finally, two doughs- dough from Keks flour and tap water without yeast and dough from Brema flour with oxygenated water and yeast (puff pastry and ciabatta) were rolled using both variations of the Fuzzy System. The rolling profile for dough without yeast in both the variations was the same. The dough rolling process starts with 45mm followed by 30mm, 15mm and finally ends with 5mm (Fig. 6).

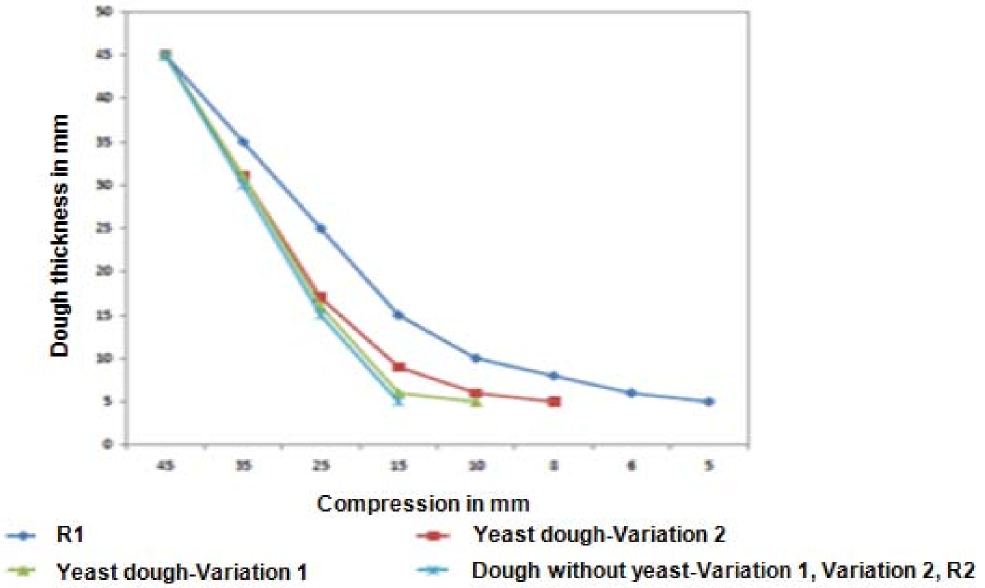

Fig. 6. Representation of the rolling profile of wheat dough with and without yeast using Fuzzy System- Variation 1 and Variation 2 using both gentle and harsh rolling programs. Puff pastry shows in both variations same rolling profile. Yeast dough is rolled more strongly with Variation 1 compared to variation 2.

By different crack ratios in individual steps the difference between both the variations of the developed Fuzzy System can be recognized. By the inlet thickness of 45mm shows both doughs similar crack ratio, 0.44. Since this is a high value, dough is rolled carefully, resulting in a crack ratio of 0.29. Variation 2 takes in to account the rheological data and rolls the dough in steps leading to lesser crack ratio until the final thickness is reached. In Variation 2, the rolling gap is strongly reduced showing the crack ratio of 0.44. From this point Variation 1 reacts with a small reduction in the dough thickness (8 mm), leading to a lower value of the surface crack ratio (0.29). In the final rolling step crack ratio of 0.1 is reached which signifies the resulting smooth texture on the dough surface (Fig. 7).

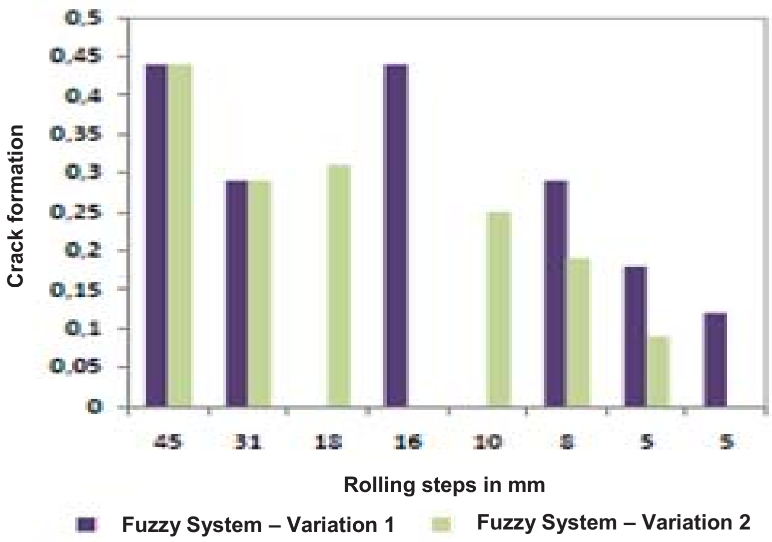

Fig. 7. Rolling of dough with yeast using Fuzzy System

Since the rolling profile of the two variations of the Fuzzy System results in a smooth final surface, optimization of the rolling process is possible from both the Fuzzy Systems. The introduction of a further input variable such as in Variation 2 shows that an even more sensitive process control can be achieved. The acquired data pool allows no jumps between strong and lower reduction in the roll gaps and thus there is no significant increase in the crack ratio during the rolling process. For Variation1 a further input in the form of a memory function, can be inserted so that the surface crack ratio is stored and taken into account. As a result more sensitive processing of dough becomes possible with Variation 1.

Summary

To optimize the rolling process it is important to focus on the production of good quality dough. It appears promising to investigate the rheological properties of dough along with the effects of additives such as cysteine or oxygenated water to comprehensively assess the dough. These findings can then be employed in the kneading process, in which the first step of dough structure builds up. By means of Fuzzy System, quick and efficient rolling of dough is achieved from good processable dough finally resulting in a potentially high quality product for the ongoing process in production of various dough products.

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