meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.523.053
ID: 133291017
https://doi.org/10.18485/meattech.2023.64.3.1

Original scientific paper

Evaluation of 3D laser imaging as a method for determination of different geometrical parameters of fermented sausages

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A R T I C L E I N F O

Keywords:
3D laser imaging
3D scanning
Volume
Surface
Shrinkage

A B S T R A C T

The aim of this study was to investigate the possibility of using 3D laser imaging in the analysis of geometrical parameters of fermented sausages during different stages of drying. Three samples of izletnička sausage ware taken for the analyses immediately after stuffing into casings and after 9, 18, 27 and 35 days of ripening. Volume of the sausage reduced significantly ($P < 0.05$) from the initial value of 377.93 cm^3 to 254.58 cm^3, while surface area reduced from 33.43 cm^2 to 27.06 cm^2. Weight loss showed strong negative correlations ($P < 0.01$) with both volume ($r = -0.99$) and surface area ($r = -0.82$), indicating the possibility of using 3D laser imaging in the estimation of weight loss. The relative error of volume estimation was between 1.9 % and 4.5 %. During the entire ripening period, a constant decrease in the volume to surface area ratio of izletnička sausage was observed. This decrease showed a strong negative correlation ($P < 0.01$; $r = -0.81$) with scores for wrinkly appearance obtained by a trained sensory panel. 3D laser imaging demonstrated a possibility for application in estimating the volume and surface area of fermented sausages.

1. Introduction

Food quality is specified by different regulations, and they mostly refer to chemical parameters that are determined using routine laboratory analyses (*Official Gazette of RS,* 2015). Apart from regulating chemical parameters of food, food quality regulations also refer to product color, texture and appearance, which are determined by sensory experts.

However, this type of quality determination depends on the subjective assessment of the sensory panellists, which could lead to a number of errors and false results. In addition, sensory analysis is laborious, time-consuming and limited by human factors. Therefore, development of fast, precise, accurate and automated methods for determination of sensory parameters is of interest to different parties involved, like producers, inspection bodies and laboratories.

In recent years, a great demand has arisen for additive free/clear label food (*Simunovic et al.,* 2020). In most cases, these products, often being of superior quality to those produced industrially, are produced by craft manufacturers. However, when using nothing but natural ingredients, it is difficult to achieve and maintain standardized production. Therefore, these products are usually more susceptible to quality defects, like rancidity, changes in color, texture and flavour and shorter shelf life. European regulations recognize some traditional

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Paper received November 11th 2023. Paper accepted November 22nd 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

food products and allow some exceptions in terms of compliance with hygienic requirements. According to *European Commission* (2004), food can be produced by traditional methods that have proven their safety, even if they do not comply with different food safety regulations. This is particularly important for small manufacturers of traditional products in Europe who cannot meet hygiene requirements for different reasons. These producers usually have financial difficulties meeting strict hygiene requirements. Additionally, full hygiene criteria compliance and abandoning the use of traditional materials could possibly affect specific sensory characteristics of the product.

In fermented sausage production, quality is usually determined by the use of higher quality ingredients, longer ripening period and higher meat to fat ratio in the sausage formulation. During the last decade, there has been a number of recommendations about dietary fat intake as a result of the negative health effects when such fat is consumed excessively (*Liu et al.*, 2017). This influenced the trend in consumption of low fat products and led to a number of fat-reduced products in the market. When it comes to fermented sausages, fat content was, in most cases, reduced by replacing part of the pork back fat with meat (*Gomez and Lorenzo,* 2013; *Lorenzo and Franco,* 2012). In addition to the increase in production price, fat reduction led to the formation of a wrinkly appearance or uneven surface of the sausage. The reason for this is to be found in the higher moisture content in meat compared to pork back fat, which consequently causes higher weight loss during drying than in the normal-fat sausages (*Mora-Gallego et al.*, 2014). However, there is no study focusing on the sensory acceptability of fermented sausages with different levels of wrinkly appearance.

Recent advancements in the field of three-dimensional (3D) laser imaging have created new possibilities in the analysis of various food products. The study of *Vaskoska et al.* (2020) showed that 3D laser imaging could be used to estimate the volume of pork cuboids. In addition, those authors showed the possibility of predicting cooking loss by using the volume reduction obtained by the 3D imaging before and after cooking. Traditionally, the volume of irregularly shaped objects is measured by the water displacement method. When it comes to food, the main disadvantage of this method is its destructiveness due to water absorption by the sample. However, this method is reliable, accurate and fast and can be used to determine the relative error of new methods for volume estimation (*Zhang et al*., 2019). The study of *Uyar and Erdogdu* (2009) showed the possibility of estimating volume and surface area of pears, strawberries, bananas, apples and eggs. In addition, in the study of *Zhang et al*. (2019), the volume of potatoes, carrots and ginger root was measured by both the 3D scanner and water displacement methods. The relative error of 3D estimated volume ranged between 2.6% and 5.4%. In the study of *Goni et al*. (2007), the relative error of volume estimation by 3D scanner for Granny Smith apple, red delicious apple and fresh meat was −1.25%, −1.01% and −0.95%, respectively. On the other hand, the surface area of irregularly shaped objects is traditionally measured by the tape method (*Banks,* 1985). This method involves covering the entire surface of an object using tape cut into small strips. Afterwards, the strips are removed and the surface area of all strips is measured manually or by an area meter. This method is prone to human error and is time-consuming (*Zhang et al.*, 2016). However, *Zhang et al.* (2016) proposed a method for measuring the surface area of an egg based on 3D laser imaging. The authors found that the method had high accuracy when they compared the results of 3D estimated surface area with results obtained by manual measurement of small pieces of broken egg shell.

Non-destructiveness is an important characteristic of analytical methods, perhaps especially for those that tend to be used for product analysis during different stages of production. 3D laser imaging is capable of measuring different geometrical characteristics of objects without destruction of product structure (*Uyar and Erdogdu,* 2009). In recent years, numerous research studies aimed at 3D scanning applications in different industries. The reasons for the recent increase in the popularity of 3D technology are in the more competitive price of commercial scanners and the advancements in the field of 3D processing software. In addition, these scanners do not require staff to be trained to a high level, while processing of 3D data is facilitated by the multiple software products available.

The aim of this study was to investigate the possibility of using 3D laser imaging in the analysis of the geometrical parameters of fermented sausages during different stages of ripening. In addition, volume to surface ratio, as a possible indicator of sausages' wrinkly appearance, was compared to sensory panel estimation of wrinkly appearance in order to evaluate the correlation between these two parameters. The authors identified a knowledge gap in the determination of fermented sausages' geometrical characteristics during ripening as a consequence of the destructiveness of methods we have used in the past.

2. Materials and Methods

2.1 Sausage preparation and sampling

One batch of approximately 20 kg of izletnička sausage was produced using fresh pork ham (85%) and pork back fat (15%). One part of the pork ham was ground through an 8 mm plate, while frozen (−18 °C) pork back fat and the rest of the pork ham were cut in a bowl cutter KU 130 AC (Laska, Traun, Austria) and then mixed with the ground ham and spices. The spices were the following: salt, white pepper, coriander, nutmeg; starter cultures were also added at this stage. Meat batter was stuffed into collagen casings (Ø 55 mm) in units of approximately 20 mm in length using a filling machine VF616 (Handtmann, Biberach an der Riss, Germany). Sausages were transferred to a traditional smoking chamber where they were cold smoked during four days using commercial beech chips as previously described by *Simunovic et al.* (2020). Afterwards, sausages were transferred to a ripening chamber with controlled conditions where they were kept for 36 days. Three sausages for analysis were taken immediately after stuffing into casings, and after 9, 18, 27 and 36 days of ripening. Before each stage of the analysis, the weight of the sausages was firstly measured in order to calculate weight loss, which was expressed as a percentage of the sample initial weight. The sausages were then used for 3D laser imaging and sensory analysis, and then after each stage of the analysis, the same sausages were immediately returned to the ripening chamber for further drying.

2.2 3D laser imaging

The 3D shape of the sausages (Figure 1) was obtained using an EinScan-SP (Shining 3D Tech., Hangzhou, China) scanner. Sausages were placed on a rotation table and scanned in a dark room as recommended by the manufacturer. In order to obtain 3D data of the downwards facing surface on which the sausage was laid, sausages were rotated by 90 degrees and scanned again. All sausages were scanned using texture mode while adjusting the brightness depending on the color of each sample. The duration of one scan was approximately 40 min. Meshing of 3D scans was performed using EXScan S_v3.0.0.1 (Shining 3D Tech., Hangzhou, China) software as described by *Simunovic et al.* (2022). Relative error (%) of 3D estimated volume was measured during each stage using the water displacement method.

Figure 1. 3D model of izletnička sausage

2.3 Sensory analysis

The sensory panel for descriptive sensory analysis consisted of four women and four men. Panellists were trained during a one-month period according to ISO 8586:2012 (*ISO*, 2012). Analysis was performed at the start and at each ripening stage, when panellists were asked to rate the wrinkly appearance of the sausages using a 5-point Likert scale (i.e. 1 – no wrinkly appearance, 5 – very wrinkly appearance). Before analysis, fermented sausages with different levels of wrinkly appearance were presented to panellists.

2.4 Statistical analysis

Pearson correlation coefficients, mean values and standard deviations were all obtained using SPSS package (SPSS 23.0, Chicago, IL, USA). For statistical analysis of the obtained data, one-way analysis of variance (ANOVA) was performed. Tukey's post hoc test was used for comparison of mean values of the analyzed parameters, with statistical significance being set at $p<0.05$.

3. Results and Discussion

The relative error of 3D volume measurements ranged from 1.9 % to 4.5 %, depending on the processing stage. These values are similar to those found by *Zhang et al.* (2019) and *Simunovic et al.* (2022), but higher than those reported by *Goni et al.* (2007). Generally, there are four main groups of characteristics that have been analyzed in fermented sausages: physico-chemical, textural, sensory and microbiological. All of these were extensively analyzed in many types of sausages in the past.

However, there is a lack of scientific data regarding geometrical parameters of sausages. Fermented sausages undergo relatively long ripening and drying processes. During this period, they can lose from 20 % to 55% of their initial weight (*Brankovic Lazic et al*., 2019; *Wen et al*., 2019), depending on temperature and relative humidity conditions, drying time and formulation. The decrease of sausage moisture content results in volume reduction and affects sausage appearance. At the moment, there are no peer-reviewed, published data regarding volume determination of fermented sausages.

During ripening, the volume of izletnička sausage reduced significantly ($P < 0.05$) from the initial value of 377.93 cm^3 to 254.58 cm^3 (Table 1). Volume reduction showed a very strong negative correlation ($P < 0.01$) with weight loss ($r = 0.99$).

From this it can be concluded that moisture evaporation, which naturally occurs during the drying process, influenced the reduction in volume of the sausages. To support this statement, the most intense reduction in both volume and weight loss was observed between days 9 and 18 of ripening. The strong correlation between weight loss and volume indicates that volume measurements by 3D laser imaging could be used to estimate the weight loss of the sausage, which is often used as an indicator for the end of the drying process. In addition, weight loss is an important economic parameter since it directly affects production yield. *Simunović et al*. (2020) reported the strong negative correlation between weight loss and moisture content of Njeguška sausage, which leads to an assumption that 3D laser imaging could also be used to estimate sausage moisture content. As moisture content is considered a quality parameter of dry fermented sausages according to Serbian regulation on the quality of ground meat, meat preparations and meat products (*Official Gazette of RS, 2015*), application of 3D laser imaging could be used as a tool in the analysis of moisture content. Traditionally, moisture content is determined by drying the sample for several hours at temperatures around 105 °C. The analytical method involves homogenization of the sample, drying and cooling until the sample reaches constant mass. This means that the sample can be dried several times, primarily depending on its moisture content but also on nutritional value, texture and other factors. Because of that, the method is very time-consuming and it requires use of an oven and an analytical balance. On the contrary, analysis by means of 3D laser imaging usually lasts from 20 to 80 minutes depending on the required quality of the scan. In the study of *Uyar and Erdogdu* (2009), the reported scanning time for peach samples was around 2 hours. The reasons for the lower scanning duration in our study could be in our use of a different scanner and the more advanced PC configuration nowadays. However, during the 3D scanning procedure, the presence of an operator is only needed for the rotation of the sample by 90°, as already explained in the previous section.

Application of 3D scanning technology in the food sector could be particularly important for the meat industry where 3D imaging could be used as a tool to determine the end of drying processes. Currently, food business operators are responsible for determining the end of a drying process, so this proposed method could potentially prevent the occurrence of human error. However, in order to apply this method in industry, it is necessary to develop mathematical models for different types of fermented sausages. Different sausage formulations, casings and ripening conditions affect different drying dynamics, which would consequently require different models, not only for different types of sausages but also for different processing plants and ripening

Table 1. Change in geometrical and sensory parameters of izletnička sausage during ripening

	Processing time (days)				
	0	9	18	27	36
Volume (cm^3)	377.93±2.50^a	334.25±2.02^b	289.43±1.58^c	273.29±0.94^d	254.58±2.29^e
Surface (cm^2)	33.43±0.56^a	30.64±1.51^b	28.94±0.47^{bc}	28.34±0.61^{bcd}	27.06±1.36^{cd}
Weight loss (%)		9.66±0.00	21.11±0.00	26.51±0.00	31.36±0.00
Volume/Surface ratio	11.31±0.15^a	10.93±0.60^{ab}	10.00±0.20^{bc}	9.65±0.24^c	9.42±0.54^c
Wrinkly appearance score	1.67±0.50^a	2.12±0.64^a	3.62±0.52^b	3.88±0.35^b	4.12±0.35^b

$^{a\text{-}e}$ Values in the same row followed by different letters are significantly different ($P<0.05$).
Data represent the mean ± standard deviation ($n = 3$)

chambers. Furthermore, these models could potentially be used to control the temperature and relative humidity conditions in ripening chambers, while on-line analysis could also be possible by installation of scanners directly in drying chambers.

The surface area of izletnička sausage reduced significantly during drying from the initial value of 33.43 cm^2 to 27.06 cm^2. As was the case with volume, surface area reduction showed a negative correlation ($P < 0.01$) with weight loss ($r = −0.82$). As we previously explained, manual surface area measurements of irregular objects are time-consuming and prone to human error. Because of that, these measurements are not performed routinely in laboratories in spite of the fact that surface area could potentially be used in evaluation of different quality parameters of food. However, because of the uneven surface of the sausages it was not possible to measure the surface area by the tape method. In the study of *Zhang et al.* (2016), the relative error for surface area estimation of an egg by 3D laser imaging was between 0.38 % and 0.95 %. In our study, at the end of the ripening, the weight loss of izletnička sausage was 31.36 %, and this was similar to the weight loss found in sausages with reduced salt content (*Corral et al*., 2016), but lower than weight losses found in Cinta Senese and Harbin dry sausages (*Aqualini et al*., 2018; *Wen et al*., 2019). Generally, sausages with high weight loss tend to acquire a wrinkly appearance, as is usually the case with sausages produced by traditional means. On the other hand, industrial sausages are usually produced with the addition of different plant proteins that have a role of binding the water molecules. This means that relatively few water molecules are capable of evaporating during drying, which results in less weight loss than in traditional sausages, and this is of great importance for the cost-effectiveness of production.

Fermented sausages are produced using two main ingredients, meat and back fat. In order to prepare the batter, these ingredients are comminuted or ground, mixed and filled into casings. Because of the higher moisture content of meat compared to back fat, in the parts where meat is on the surface of the sausage, small depressions are formed. In other words, more moisture evaporates from meat parts, which results in the formation of these depressions. The result is the formation of an uneven surface on the sausage. This is more obvious the longer the drying period. In the study of *Mora-Gallego et al*. (2014), three different types of fermented sausages were produced, each containing different amounts of pork back fat. Those authors concluded that the batch produced with the highest amount of back fat was rounder than other batches. In other words, the lower the content of fat in the sausage, the more uneven is the sausage surface. High fat content slows the drying rate during ripening, which results in a lower amount of wrinkles compared to those produced with lower fat content (*Wirth*, 1988). The longer the ripening period, the higher the weight loss, and consequently, the wrinklier the sausage appearance. In this study, our sensory panel rated the wrinkly appearance of izletnička sausage as highest at the end of the drying. Izletnička sausage is characterized by a low fat content, so high scores for wrinkly appearance at the end of the ripening were expected. Our results showed a strong correlation between surface area and volume during ripening ($P < 0.0$; $r = 0.92$). However, a strong correlation between these two parameters was expected. The total reduction in volume of izletnička sausage was 32.64 % and was higher than the reduction of sausage surface area, which was 19.05 % of its initial value. Results showed a constant decrease in volume to surface ratio during the entire ripening period. This reduction was strongly related to scores for wrinkly appearance obtained by sensory panel. More precisely, these two parameters showed a strong negative correlation ($P < 0.0$; $r = −0.81$), which indicates that volume to surface area ratio could potentially be used to estimate the wrinkly appearance of sausages. The volume to surface area ratio of izletnička sausage reduced from the initial value of 11.31 to 9.42 at the end of the ripening period. The lower this ratio is, the wrinklier is the appearance of the sausage. However, there is a need for more detailed research about the possibility of using volume to surface ratio for the estimation of wrinkly appearance of fermented sausage.

4. Conclusion

Relative errors of volume and surface area estimation gave promising results for the application of 3D laser imaging in the analysis of fermented sausages. Apart from being affordable and easy to use, this method is non-destructive, and because of that, it can be fully applicable in analysis during different stages of the fermented sausage production process. The strong correlation between sensory scores for wrinkly appearance and volume to surface ratio indicate that this ratio could be used in the future for determination of wrinkly appearance. However, further research regarding the application of 3D laser imaging in food analysis should be conducted. More precisely, future research should be focused on characterization of geometrical parameters of other fermented sausages and development of mathematical models for determination of different quality parameters. In addition, it is necessary to conduct a study on the sensory acceptability of fermented sausages with different levels of wrinkly appearance and to determine the optimal level for each type of the sausage. A limitation of this research is that surface area was not able to be measured experimentally due to the uneven surface of the sausage.

Procena metode 3D laserskog snimanja za potrebe određivanje različitih geometrijskih parametara fermentisanih kobasica

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INFORMACIJE O RADU

Ključne reči:
3d lasersko skeniranje
Zapremina
Površina
Naboranost

APSTRAKT

Cilj rada bio je da se istraži mogućnost primene 3D laserskog skeniranja u analzi geometrijskih parametara fermentisanih kobasica tokom različitih faza procesa sušenja. Tri uzorka izletničke kobasice su ispitivana odmah nakon punjenja u omotače, nakon 9, 18, 27 i 35 dana zrenja. Zapremina kobasice se statistički značajno ($P < 0,05$) smanjila sa početne vrednosti od 377,93 cm^3 na 254,58 cm^3. Sa druge strane, površina izletničke kobasice se statistički značajno ($P < 0,05$) smanjila sa 33,43 cm^2 to 27,06 cm^2. Kalo sušenja pokazalo je jaku negativnu korelaciju ($P < 0,01$) sa zampreminom ($r = -0,99$) i površinom kobasice ($r = -0,82$), ukazujući na mogućnost primene 3D laserskog skeniranja u proceni kala sušenja. Relativna greška procene zapremine bila je od 2,1 do 8,1 %. Tokom sušenja, primećen je konstantan pad odnosa zapremine i mase sa početne vrednosti od 11,31 do 9,42 na kraju procesa. Ovaj pad je pokazao jaku negativnu korelaciju sa ocenama za naboranost površine dobijenih od strane obučenog senzornog panela. 3D lasersko skeniranje pokazalo je mogućnost primene u proceni zapremine i površine fermentisanih kobasica.

Disclosure statement: No potential conflic of interest was reported by authors.

Funding: The study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract number 451-03-47/2023-01/200143) and Contract number — Grant No. 451-03-47/2023-01/200050 from 03.02.2023.

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