INFLUENCE OF FILLING CONDITIONS ON PRODUCT QUALITY AND OPERATING PARAMETERS IN FERMENTED COARSE MEAT EMULSIONS PRODUCED BY CONTINUOUS HIGH SHEAR GRINDING AND VACUUM FILLING

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Abstract— The influence of filling conditions of high shear grinders on structure, physicochemical properties and sensory of fermented salami was evaluated. Coarse meat emulsions (65% pork, 35% pork belly) were manufactured by passing mixtures through perforated knife-plate assemblies at different temperatures. Casings were filled by vacuum stuffing and fermented for 21 days at 24-14°C and 94-74% RH. Changes in pH, weight, water activity and texture, were determined. Fat particles size and spatial distribution were obtained by image analysis. Sensory analysis of products was conducted by a trained panel. Similar high quality products could be obtained without the need to use frozen meat. Coarse meat emulsions (aka salami) filled at bulk mass temperatures of 0 and +2°C had excellent sensory scores based on their product appearance, fat particle size distribution and number of pores. The quality was comparable with that of control-batches filled at -2.8°C. At raw material temperatures above 0°C, only minimal temperature increases of 1-1.4°C occurred after the filling process. The warmer raw material dramatically decreased the power consumption and reduced the acting torque by 40%. Swirling and delays during fermentation were not observed. Results showed that the combination of continuous filling and shear grinding has a substantial potential to reduce process time, energy costs while maintaining a high quality of the produced product.

Keywords: Coarse meat emulsion, fermented salami, high shear grinding, vacuum filling, product quality

I. INTRODUCTION

High shear grinders consisting of knife and perforated plate assemblies have increasingly replaced bowl choppers to produce coarse fermented meat emulsions (aka salami) due to their ability to operate continuously, decrease the required processing time, and improve structural attributes of products (1). During the last 15 years the technology of continuous high shear grinding and vacuum filling has been further improved. With the filling-grinding technique the raw materials are turned into a finished product of outstanding quality using a single piece of process equipment. The systems are easily automatable and in combination with auxiliary attachments versatile applicable. The investment costs are relatively low and easily offset by the energy savings that may be realized due to the improved efficiencies (2, 6). For example, Haack et al. found that savings of up to 75% for labor, energy, investment and space are possible (5). Numerous studies have shown that the selection and design of cutting tools have a major influence on the performance of the grinder systems (3-5, 7-8, 9).

The objective of this study was to investigate the influence of filling conditions and blade - perforated plate geometries on the structure and product quality of fermented coarse meat emulsions (aka salami). In order to better understand the effect of these parameters, physicochemical properties of products were determined and texture, image and sensory analysis conducted. Two separate experiments were carried out. In the first set of studies, the number of blades in the cutting sets and filling capacity were varied. In the second set, bulk mass temperature and filling capacity were altered (**Table 1**). Moreover, potential economical and technical advantages of this modern grinding technology were assessed by measuring the energy consumption and the acting torque of the grinding unit.

II. MATERIALS AND METHODS

Coarse meat emulsions were manufactured of lean pork meat from ham and shoulder. The meat had been standardized and was used at +2°C in minced (8 mm) conditions. As fat components, frozen pork belly was cut to fist sized pieces (-18°C). The raw sausages were then manufactured according to a standard recipe by the Houdek company (65% pork, 35% pork belly). The following ingredients and additives were added to the raw mass.

Amount (g/kg)	Ingredients	Specification
29.0	nitrite curing salt	Gena, Hans-Felix-Rätzel GmbH, Zerbst/Pulspforde
9.3	fermentation mix (containing sugars and spices)	Avo Werke August Beisse GmbH, Belm
0.04	starter cultures (Micrococces, Lactobacills and Pediococces)	CXSP, Cargill France SAS, La Ferté sous Jouarre

Salami manufacturing:

1. Pre-ground meat and pork belly pieces were cut and homogenized in a bowl chopper to average particle sizes of 13 mm at –3, 0 and +2°C.
2. The coarse mass was then processed by the high-shear grinding system to obtain an unfermented meat-fat dispersion that was then stuffed by ordinary vacuum stuffing in casings (diameter: 59 mm).
3. Raw sausages were fermented for 21 days at 24-14°C and 94-74% RH to a weight loss of 30%
4. Salamis were finally packed in vacuum bags under modified atmosphere (80% CO_2, 20 % N_2) and kept on cold storage (1°C) until analysis...

Table 1. Cutting-set combinations (Test 1: Cutting-set components, Test 2: Bulk mass temperature)

Test 1	Batch	5 part cutting-set					Filling capacity (l/min)
		end-plate	knife	mid-plate	knife	pre-cutter	
1	6-armk (c.)	2 mm	6-arm spec.	4 mm	6-arm pec.	Standard	46
2	8-armk	2 mm	8-arm spec.	4 mm	8-arm spec.	Standard	46
3	8-armkf	2 mm	8-arm spec.	4 mm	8-arm spec.	Standard	97
4	10-armk	2 mm	10-arm spec.	4 mm	10-arm pec.	Standard	46
5	10-armkf	2 mm	10-arm spec.	4 mm	10-arm spec.	Standard	97
Test 2	**Batch**	**5 part cutting-set**					**Filling capacity (l/min)**
		end-plate	**knife**	**mid-plate**	**knife**	**pre-cutter**	
1	6-armk	2 mm	6-arm spec.	4 mm	6-arm spec.	Standard	46
2	6-armk0	2 mm	6-arm spec.	4 mm	6-arm spec.	Standard	46
3	6-armk2	2 mm	6-arm spec.	4 mm	6-arm spec.	Standard	46
4	6-armk2f	2 mm	6-arm spec.	4 mm	6-arm spec.	Standard	78

Experimental design: For the first experiment five batches were manufactured with varying number of blade arms, and volume throughputs (filling capacities). In the second set of studies, 4 batches were manufactured with varying bulk temperatures and volume throughputs. In all batches, a 5 part cutting-set with different knives was used (**Table 1).** All batches were manufactured in duplicate.

Fig. 1: 5 part cutting set 6 armk (Fa. Jopp)

pH determination. The pH values were determined in raw sausage after 1, 2, 3, 9, 12, 15 and 18 days during fermentation using a calibrated pH meter.

Weight loss. The weight loss as a consequence of water diffusion during ripening was determined after 1, 2, 3, 4, 6, 7, 9, 11, 14, 17, 18 and 20 days. Average values reported are means of 5 measurements.

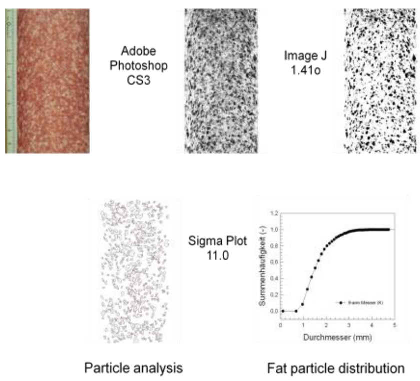
Texture analysis. The textural properties were evaluated using the Instron texture analyzer (Model 1011, Instron Corporation Ltd., Canton, MA, USA). The products' hardness (N/100g sample) was measured using 8 portions of each salami (5 mm high and 4.5 cm in diameter) at 15, 20, 25 and 30% weight loss.

Particle size determination. The structure of the produced salamis was assessed by image analysis **(Fig. 2)**. This method involved a conversion of images to grey and black and white color scales using Adobe Photoshop CS 3 (Adobe System Inc., San Jose, CA, USA). The binary images were subjected to particle size analysis (Image J 1.41o, National Institutes of Health, USA) yielding the fat particle size (mm²), the fat particle perimeter (mm), the ferret diameter (mm), the partial distribution of fat within the product as well as circularity (form factor) of fat particles.

Sensory analysis. Samples were evaluated a trained panel (25 panelists) from the University of Hohenheim. A hedonic test was carried out using a non-structured 6 point scale where panelists evaluated product appearance, fat particle size, pores and visible amount of sinews.

Machine parameters. Machine parameters were recorded during production including conveying pressure (bar), relative electricity consumption (%) and blade speed (rpm).

Fig. 2: Method for fat particle size distribution determination



Statistical analysis. Means and standard deviations of physicochemical and textural properties were calculated using Excel (Microsoft). The particle sizes and the attributes of the hedonic test were statistically analysed by a one-way analysis of variance (Tukey-Kramer test) described by Jensen et al. (*10*).

III. RESULTS AND DISCUSSION

pH changes. During fermentation, the pH of 5.75 decreased in all samples within the first three days to 4.80-4.81 and then increased slightly to 4.83-4.84 toward the end of the fermentation period. The uniform pH drop in all samples indicated that the cutting-set components had no influence on the metabolic activity of starter cultures and thus on pH.

Weight loss and Textural properties. The weight loss was determined from the day of preparation to a value of 30%. Almost no delays were observed during fermentation (**Figure 3)** Only minimal divergences of 1-2% occurred within the samples due to the mode of operation of the ripening chamber. The weight loss is a direct consequence of mass transport processes like capillary convection and water diffusion. The uniform loss of weight indicates that neither the cutting-set components, nor the bulk mass temperature has a significant influence on fermentation time of raw fermented coarse meat emulsions. Hardness showed a significant increase in all samples during fermentation (**Figure 4**). The progressing loss of water leads to a dehydration of the protein network which directly affects the strength of the gel structure. The minimal differences in hardness values showed that the cutting-set components had only a minor effect on product hardness which was sensory not detectable.

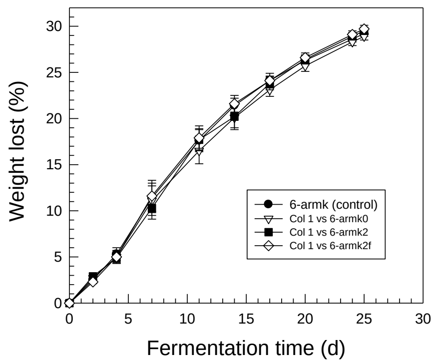


Figure 3: Weight loss recorded during fermentation

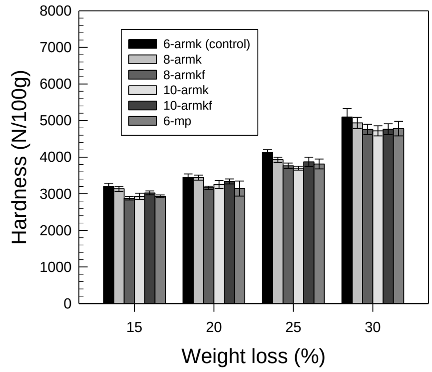


Figure 4: Hardness development during fermentation

Particle size. The mean particle diameter of all batches after 30% weight loss varied little between different samples and ranged from 1.63-1.81 mm, respectively. The Sauter mean diameter d_{32} was nearly constant except for the samples that had been manufactured with the 10-arm knifes (10-armk). In comparison to the other samples those batches had a slightly coarses fat particle size distribution. The observed increase in Sauter mean diameter with the 10-arm knifes suggests that despite the higher number of blade arms, the lower speed of the grinder caused the cutting to be less efficient resulting in a coarser distribution of the fat particles. An increase in filling capacity did not affect the fat particle size in the product. In experiment 2, where the batches had been manufactured at -2°C, 0, 2°C and 2°C, 78 l/min there was no significant difference in mean particle size **(data not shown).**

Sensory properties. In general, all batches scored high for all sensory parameters evaluated. The only noticeable lower score was that of batch 10-armk and 10-armkf in relation to the visible amount of sinews (**Table 2**). This may be attributed to the low speed of the grinder causing sinews and gristles to be less reduced when using the 10-arm knifes. Similar high quality products could be obtained without the need to use frozen raw materials. Coarse meat emulsions (aka salami) filled at bulk mass temperatures of 0 and +2 °C had excellent sensory scores based on their product appearance, fat particle size distribution and number of pores (**Table 3**). These findings differ substantially from results obtained with the conventional technology of raw sausage production on bowl choppers. Results show that production of coarse meat emulsions (aka salami) with unfrozen raw materials is thus feasible (*3*) due to the short residence times of the raw material in the machine that limit frictional heat generation (*2*).

Table 2. Sensory Test 1, $\alpha \leq 0.00625$, cutting-set components

Batch	Product appearance	Particle size	Pores	Visible amount of sinews
6-armk (c.)	2,3	2,3	1,9	2,2
8-armk	2,6	2,6	1,4	2,5
8-armkf	3,0	2,8	1,3*	2,5
10-armk	2,8	2,7	1,7	2,9*
10-armkf	2,7	2,5	1,6	3,2*

Table 3. Sensory Test 2, $\alpha \leq 0.017$, bulk mass temperature

Batch	Product appearance	Particle size	Pores	Visible amount of sinews
6-armk (c.)	2,2	2,7	1,4	1,2
6-armk0	2,1	2,7	1,3	2,7*
6-armk2	2,6	2,8	1,5	2,4*
6-armk2f	2,6	2,9	1,6	2,6*

Machine parameters. Salami manufactured with 8 and 10-arm knifes showed a remarkably reduced energy consumption, e.g. 25% and 20% for 8-armk and 10-armk, respectively. The energy consumption of the grinder decreased from 5.1 kW (6-armk) to 3.8 kW (8-armk) and 4.1 kW (10-armk) (**Table 4**). Interestingly, salamis manufactured with 10-arm knifes required more energy than products produced with the 8-arm knifes. This indicates that the high number of blade-arms impeded the conveying process by blocking bore holes. Moreover, in this series of experiments we examined the influence of bulk mass temperature on the relative acting torque and the energy consumption of the grinder. At bulk mass temperatures of 0 and +2°C the warmer raw material decreased the power consumption and the acting torque by nearly 40 %. In comparison to the control-batch (6-armk) filled at -2,8°C, the relative acting torque of the grinder decreased from 75% (6-armk) to 45% (6-armk0) and 44% (6-armk2) while the energy consumption from 6,4 kW (6-armk) to 3,8 kW (6-armk0) and 3,7 kW (6-armk2), respectively (**Table 5**). The observed decrease in acting torque and conveying pressure at bulk mass temperatures of 0 and +2°C indicates that the bulk mass temperature has a major influence on the forces required for particle size decreases (*3*).

Table 4. Machine parameters experiment 1: cutting-set components

Batch	Speed grinder (rpm)	Relative acting torque grinder (%)	Energy consump-tion grinder [kW]	Temp. before filling [°C]	Temp. after filling [°C]
6-armk (c.)	227	60,5	5,1	-3,9	-4,1
8-armk	170	60,3	3,8	-3,8	-3,8
8-armkf	356	71,1	9,4	-3,5	-3,7
10-armk	161	68,5	4,1	-3,8	-3,9
10-armkf	341	83,0	10,7	-3,7	-3,7

Table 5. Machine parameters experiment 2: filling temperature.

Batch	Speed grinder (rpm)	Relative acting torque grinder [%]	Energy consumption grinder [kW]	Temp. before Filling [°C]	Temp. after Filling [°C]
6-armk	226	75	6,4	-2,8	-3,0
6-armk0	225	45	3,8	-1,0	0,0
6-armk2	225	44	3,7	2,2	3,5
6-armkf	325	-	-	2,2	3,5

IV. CONCLUSION

This study has shown that cutting-set components, filling capacity and bulk mass temperature had only minor influences on the physicochemical properties and hardness of fermented meat emulsions manufactured by high shear grinders. However, particle size, sensory performance and machine parameters were affected by the filling conditions (e.g. bulk mass temperature and filling capacity). Most importantly, energy consumption and torque strongly depend on the design of the perforated plate – knife assembly and the temperature of the bulk mass. Acting torques and power consumption of the high shear grinder be decreased by as much as 40% when warmer raw material was used. The results demonstrate that new continuous processes dispersion and size reduction processes may not only produce products of equivalent quality compared to bowl chopper, batch manufactured products but that these processes may simultaneously reduce process time and energy costs thereby lowering overall production costs.

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REFERENCES

1. ANONYM (**2008**): Füllwolftechnologie. Vorteile und Möglichkeiten der modernen Füllwolftechnologie. Vortrag Maschinenfabrik Handtmann, Biberach a. d. Riss
2. HAACK, E., WARNECKE, H. W. and WILKE, J. (**1999 a**): Entwicklungstendenzen in der Wolftechnik – Rohstoff Fleisch bestimmt die Effizienz der Maschine. *Fleischwirtschaft* 79 (5), 46-51.
3. HAACK, E., SCHNÄCKEL, W. and HAACK, O. (**2003 a**): Probleme, Ursachen und Lösungen – Grundlagen und Vorgänge bei der Fleischbearbeitung mit Maschinen der Wolftechnologie – 1. Teil. *Fleischwirtschaft* 83 (4): 52-56.
4. HAACK, E., SCHNÄCKEL, W. and HAACK, O. (**2003 b**): Optimal Fördern und Zerkleinern – Grundlagen und Vorgänge bei der Fleischbearbeitung mit Maschinen der Wolftechnologie – 3. Teil. *Fleischwirtschaft* 83 (6), 41-45.
5. HAACK, E., SCHNÄCKEL, W. and HAACK, O. (**2003** c): Eine Revolution kündigt sich an – Der Pumpwolf wird alle Bereiche der Fleischbearbeitung erfassen – 6. Teil. *Fleischwirtschaft* 83 (9), 67-71.
6. HAACK, E. and SCHNÄCKEL, W. (**2004**): Unverzichtbar in der Produktion. Füllmaschinen mit integrierter Wolftechnik und Füllwölfe gewinnen an Akzeptanz – IFFA-Bericht 2. Teil. *Fleischwirtschaft* 84 (10), 21-24.
7. HAACK, E., SCHNÄCKEL, W. and STOYANOV; S. (**2007 a**): Der Rohstoff spielt eine Doppelrolle – Konstruktionsqualität und abgestimmte Messergeometrien ermöglichen neue Leistungsbereiche. *Fleischwirtschaft* 87 (1), 50-55.
8. HAACK, O. (**2007 b**): Mit neuen Geometrien höhere Leistungen. Schneidwerkzeuge für die Rohstoffbearbeitung sind eine besondere Herausforderung. *Fleischwirtschaft* 87 (4), 134-137.
9. HAACK, E. and SCHNÄCKEL, W. (**2008 b**): From meat to emulsion - a single operation. Separation systems for upgrading material properties of meat - Part 2. *Fleischwirtschaft International* 88 (5), 23-28.
10. JENSEN, U. (**2004**): Varianzanalyse. In: DUFNER, J., JENSEN, U. und SCHUMACHER, E. (Hrsg.). Statistik mit SAS. Verlag B.G. Teubner, Wiesbaden, 220-228.