SHORT- AND LONG-TERM CONDITIONING AND EXPANDER PROCESSING OF MAIZE AND ITS IMPACT ON ANIMAL PERFORMANCE, NUTRIENT DIGESTIBILITY AND PRODUCT QUALITY OF FATTENING PIGS AND BROILER CHICKS

Reinhard Puntigam, Karl Schedle, Christiane Schwarz, Elisa Wanzenböck, Jens Eipper, E.-M. Lechner, Martin Gierus

Department of Agrobiotechnology, Institute of Animal Nutrition, Livestock Products and Nutrition Physiology
University of Natural Resources and Life Sciences
Vienna. 1190 Vienna, Austria

Corresponding author: Reinhard Puntigam
e-mail: reinhard.puntigam@boku.ac.at; phone: +(43~1) 47654-97620

Abstract: Feed manufacturers are constantly trying to reduce processing costs with few losses in quality of processed feed. Especially processing feed with high temperature short time (HTST) technology like the expander processing yields technological and nutritional benefits such as improved physical pellet quality as well as feed efficiency. While this treatment may yield benefits in terms of performance of monogastric animals, it may possibly damage heat sensitive ingredients. In this context, a study with 2 experiments was conducted to determine the effects of expander processing on the nutritive value of the single component maize, fed to barrows and/or broiler chicks. Short-term conditioned (SC; 60 s) maize was quantitatively replaced by long-term conditioned (LC; 1080 s) and both were subsequently expanded. SC and LC expander processed maize had no effect on daily feed intake and on the average daily gain in both trials. Also, no effect of the preconditioning time on feed conversion ratio of broiler chicks or fattening pigs was observed. In contrast to the broiler chicks, a positive effect on the apparent total tract digestibility of DM and, as a result, the ATTD of GE in fattening pigs was observed in SC. A higher amount of breast meat proportion was measured in broiler chicks fed LC and expanded maize. Results of the specific carcass characteristics and meat quality parameters showed an increased chewiness and springiness of breast muscles of the broiler chicks, while the fattening pigs only showed a decreased meat lightness of loin affected by the expander LC processing of maize. In conclusion, LC conditioning showed no improvement on zootechnical performance but declined nutrient digestibility in pigs. Specific carcass characteristics were hardly modified between treatments in both monogastric animals.

Keywords: maize, HTST technology, performance, carcass characteristics, digestibility, product quality

Introduction

Improving the nutritive value of maize is important, since maize is one of the main energy sources in monogastric animal nutrition (Ljubojević et al., 2011). Commercial rations for broiler chicks and fattening pigs are often formulated to contain up to 60−70% of maize (Bach Knudsen et al., 2012). During the use of high temperature short time (HTST) technology, like expanding and extruding, the application of heat, moisture, pressure and shear force alters the physicochemical properties of feedstuffs (Johnston et al., 1999). In order to decrease the energy consumption and material wear of the mentioned HTST technologies, preconditioning has been used (Rehman and Shah, 2005). Depending on the retention time, conditioning can be classified as short- and long-term treatment, which also plays a role in feeding costs. In addition, the specific mechanic energy (SME) input bears a large portion of costs. In comparison with the treatment of the whole ration, where SEI of about 10−12 kWh/t are used, by the treatment of single components much higher SEI inputs per ton are used to obtain specific effects (Odjo et al., 2015). Besides the inactivation of anti-nutritional compounds (e.g. trypsin inhibitors; Clarke and Wiseman, 2007) and an increase of the hygienic status of the feed and product safety (Torok et al., 2011; Goodarzi Boroojeni et al., 2014), heat processing may maximise gelatinisation of starch (Svihus, 2014), denaturation of protein (Lundblad et al., 2012) and cell rupture of fibre as well as the release of lipids from oil bodies (Htoo et al., 2008; Kraler et al., 2014). Due to improved nutrient digestibility, an increase of approximately 10% of the energy (broiler chicks: AME_N , fattening pigs: DE) per kg of maize (dry matter) can be expected (Svihus et al., 2005). However, specific consideration regarding the heat sensitive ingredients like AA, vitamins, feed additives and carotenoids must be given, as it might adversely affect animal performance and product quality (Coelho, 1994; Muzhingi et al., 2008; Svihus and Zimonja, 2011). Therefore, it is very important that the mentioned advantages and disadvantages of HTST technology have to be carefully weighed and justified (Keith Behnke, 1996).

The hypothesis of the present study was that short-term conditioning before expander treatment of maize affects the apparent total tract digestibility (ATTD), animal performance, carcass characteristics and product quality in both fattening pigs and broiler chicks equally.

Material and methods

Animals and housing. Two experiments were conducted. In the first experiment, 30 crossbreed barrows (Large White x Landrace) x Piétrain (OEHYB) with 30.7 ± 0.3 kg live weight (LW) were included. The fattening pigs where housed in an Austrian pig testing facility (Streitdorf, Austria), where the animals were allotted to 6 pens of 5 animals each (i.e. 5 animals per pen, 3 replicates), considering litter and body weight applying a randomised complete block design. Each pen offered fully slatted concrete floor and was equipped with an automatic dry-feeding system. Feed intake, as well as the number of visits of the feeding system of each animal, was registered and recorded daily by a transponder system. Individual body weight was determined continuously weekly. Water was available through a nipple drinker *ad libitum*.

In the second experiment, 192 1-day old broiler chicks (Hybrid strain ROSS 308) with 44 ± 0.14 g initial LW of both sexes were assigned to one of 2 trial groups. The broiler chicks where housed at the poultry research station 'Wimitz' in Carinthia, Austria. At arrival, the 192 broilers were divided into the same 2 treatment groups as experiment 1 with 6 replicates per treatment of 16 or 17 animals per pen each, considering equal body weight of the pen. Every pen had an area of 3 m² and was scattered with 8 kg of wood shavings. All boxes were equipped with infrared lamps, automatic feed and drinking systems. The broiler chicks were weighed on arrival and then body weights (BW) were recorded per pen on day 8, 22 and individually on day 38. Feed intake per pen was determined at the end of day 8, 22 and 35 of the experimental period. During the trial, the animals had free access to feed and drinking water by using ground feeding troughs and automatic waterers. Average daily gain (ADG), average daily feed intake (ADF) and feed conversion rate (FCR) were calculated for starter, grower and finisher phase in both experiments.

Maize treatment and diet formulation. Short- (SC, 60 s) and long-term (LC, 1080 s) conditioned and subsequently intensively expanded maize (approx. 45 kWh/t using expander Model OEK 15, Amandus-Kahl, Hamburg, Germany) of the same batch was used. Technical parameters of the maize treatment are summarised in Table 1. For both experiments, conventional dried maize (S 240/ ca. K 240, KWS SAAT SE, Austria) of the same batch was ground through a 2 mm screen with a hammer mill.

Afterwards, the mash was firstly steam conditioned by the use of a paddle mixer with a total mixing time of either 60 s (SC) or 1080 s (LC) at 80°C prior to expanding. After short- and long-term preconditioning, the OEK15.2 Kahl Expander (crown gap release) was used. The expander parameters are summarised in Table 1. Production rate was held constant at 1400 kg/h.

Table 1. Technical parameters of the heat treatment of maize

	SC (60 sec.)		LC (1080 sec.)	
	Expanding	Pelleting	Expanding	Pelleting
Temperature, (°C)	145	90	147	92
Pressure, (bar)	70	30	90	40
Spec. mech. energy, (kWh/t)	45.0	3.6	46.4	12.1
Moisture, (%)	17.8	-	19.4	-
Steam, (%)	3.6	-	3.6	-
Bulk density, (kg/dm³)	0.25	0.47	0.24	0.45

After treatment, maize SC and LC was mixed with further components (fattening pigs: barley, soybean meal, wheat bran, vegetable oil, vitamin and trace element premix; broiler chicks: soybean meal, maize gluten meal, grass meal, feed fat, vitamin and trace element premix) at the same proportion to meet or exceed nutritional requirements of the animals (GfE 2006, Ross 308). TiO_2 was used as an indigestible marker in both trials. The pig trial was split in a fattening (up to 94.4±1; 13.2 MJ/ME, 17.50% CP) and a finisher (up to 116.2±0.3; 13.10 MJ ME, 13.23 CP) period. Further, a 3-phase feeding was used in the trial of the broiler chicks. During the first 8 days of the experiment, all the chickens were fed a starter diet (12.35 AME_N, 22% CP). Afterwards, a grower diet was fed for 13 days (12.80 AME_N, 21% CP) and, finally, the birds received a finisher diet for 15 days (12.70 AME_N, 20% CP). Mash feed and water were provided *ad libitum*.

Slaughter, sampling, carcass characteristics and product quality. The fattening pigs were slaughtered under standardised conditions in the abattoir of the Austrian Pig Testing Facility when individual body weight of animals reached 116.2 ± 0.3 kg. During slaughter, faeces samples were collected from the rectum. Carcass characteristics and meat quality parameters were determined at the pig testing facility. Besides, during the finisher phase of the broiler trial (day 35), excreta samples were collected to evaluate apparent total tract digestibility. The excreta of the whole pen were pooled. Excrete/faeces samples were immediately frozen and stored at −20°C until further processing. Slaughtering of the broiler chicks took place at the same time for all animals at the poultry research station. Additionally to zootechnical performance and slaughter characteristics, meat quality parameters were recorded. Furthermore, in breast meat of 48 representative broiler chicks, quality parameters (colour, cooking loss, water holding capacity, fatty acid pattern, crude nutrients, texture profile analysis and anti-oxidative capacity) were recorded.

Chemical analyses of feed and excreta/faecal samples. All the diets were analysed for dry matter (DM), crude protein (CP), crude fibre (CF), ether extract (EE), ether extract after acid hydrolysis (EEh), ash (CA), starch and sugar according to standard methods of VDLUFA. Besides, starch gelatinisation was enzymatically (amyloglucosidase method, AMG) determined as described by Naumann and Bassler (2012). For the determination of ATTD, excreta/faeces were defrosted, homogenised and DM determined. Gross energy (GE) content was determined by bomb calorimetry (IKA C 200, Wien, Austria). The AA pattern of feed was analysed by applying the methods of Altmann (1992). For estimating heat damage of HTST treatment of maize, contents of reactive lysine (photometrically, Booth, 1971), vitamin E (Claeys et al., 2016) and carotenoids were analysed. The apparent faecal digestibility coefficients of DM, EEh, and GE were calculated on the basis of the respective ratios of DM and crude nutrients to TiO_2 in feeds and faeces using the following formula:

Apparent digestibility (%) =

$$100 - \left(\frac{\%\ TiO_2\ in\ feed}{\%\ TiO_2\ in\ faeces} * \frac{\%\ DM\ or\ nutrients\ in\ faeces}{\%\ DM\ or\ nutrients\ in\ feed} * 100\right)$$

All chemical analyses were performed in duplicate. The experimental data were statistically analysed by GLM procedure (SAS, Cary, USA), including treatment as fixed effect in the model. Outliers (data observation which was more than 2-fold standard deviation from the group mean) were removed from the statistical evaluation. Treatment means were separated using the least-squares means statement, and differences were determined using the Tukey-Kramer Test. Statistically significant differences ($P < 0.05$) among least-squares means were indicated by different letters in the superscripts. Differences with P values < 0.1 and > 0.05 were considered as a tendency. As a model, a factorial variance analysis with interaction was taken. The used factorial stages were trial group and replication.

Table 2. Nutritional composition of maize

Nutrients		SC	LC
Dry matter	%	88	88
Crude protein	g/kg	81.53	79.86
Ash	g/kg	12.22	12.33
P	g/kg	0.26	0.31
Starch	g/kg	657.22	660.53
Sugar	g/kg	15.22	16.02
AMG[4]	%	70	79
Ether extract [1]	g/kg	45.22	45.5
Ether extract [2]	g/kg	21.16	19.26
GE	MJ/kg	16.80	16.82
α Tocopherol	(mg/kg)	3.54	3.18
δ Tocopherol	(mg/kg)	3.25	3.09
Lysine	mg/g	2.21	2.17
Reactive Lys.	mg/g	1.69	1.65
SFA	mg/g	6.94	7.04
UFA	mg/g	38.73	39.72
MUFA	mg/g	11.84	12.15
PUFA	mg/g	26.88	27.56
DPPH[3]	mmol/kg	11.90	11.28

[1] with acid hydrolysis, [2] without acid hydrolysis, [3]2,2-Diphenyl-1-picrylhydrazyl, [4]Amyloglucosidase – kit

Results

The analysed nutrient concentrations of the different maize treatments, concentration of gross lysine as well reactive lysine, fatty acid composition and content of vitamin E are shown in Table 4.

The majority of analysed nutrients of maize were unaffected by the HTST treatments. Moreover, the amount of reactive lysine was not reduced due to technological modification of the maize comparing the 2 conditioning processes. However, a decrease of vitamin E with an increase of specific mechanical energy could be observed. In addition, an increase of starch gelatinisation, measured by the AMG method, was detected. Interestingly, the amount of ether extract after acid hydrolysis was hardly affected but decreased almost by half without applying acid hydrolysis after processing. However, that fact did not affect the fatty acid profile or the antioxidative capacity of maize, measured photometrically by the DPPH method. Using colorimetric analysis, a strongly reduced yellow colour of ether extract was observed, which may be related to the fact that HTST treatments may lead to carotenoid damage. As expected, the quantitative replacement of the SC single component maize by LC maize had no effect on the nutritional values of the rations. The calculated values were within analytical ranges for the 2 treatments in both trials (data not shown). Results of animal performance and ATTD are given in Table 3. SC versus LC expanding showed no effect on daily feed intake, average daily gain (ADG) as well as FCR in both trials ($P > 0.1$). ATTD of DM and, as a result, ATTD of GE ($P < 0.05$) were significantly improved by SC thermal treatment in fattening pigs. A higher amount of breast meat proportion in broiler chicks due to LC was observed. In fattening pigs, a tendency ($P < 0.1$) of the parameter dressing was recorded due to LC. Further carcass characteristics and meat quality parameters are shown in Tables 4 (broiler chicks) and 5 (fattening pigs).

The observed effects of the LC treatment were an increased springiness as well as an enhanced chewiness of breast muscles of the broiler chicks ($P < 0.05$).

Discussion

Feed manufacturers have to consider possible trade-offs between the cost of a technological treatment when using HTST technology and the expected benefit in terms of performance of the animals (Millet et al., 2012). In the last decades, there has been a lot of research testing the effects of HTST treatment of feed in monogastric animals. The observations were not always consistent, because the beneficial and impairing effects of the mentioned processing are related to a couple of variables. For example, the type of feed ingredients, the heating temperature, processing time at a certain temperature, the initial moisture and the volume of water during processing are important factors which may affect the feed and animal performance (Rehman and Sarah, 2007).

Furthermore, the type of monogastric animals plays a major role, which is also supported by the results of the present study. Regarding the comparison of different conditioning times, literature reports are very scarce.

Lundblad et al. (2011) compared diets steam conditioned at 47°C and 90°C, respectively, for approximately 20 s prior to pelleting in nursery pigs and broiler chickens. In the pig experiment, digestibility of DM and GE was significantly higher in the 47°C conditioned diet compared with the 90°C diet. Both treatments showed no impact on the zootechnical performance of both monogastric animals. Park et al. (1998) reported that conventional steam conditioning and pelleting of a wheat-based diet improved FCR by 2%, whereas expander processing prior to pelleting improved FCR by 7% compared with a mash control. Furthermore, O´Doherty et al. (2000) observed a significant decrease of the daily feed intake due to the expander process in a wheat-based diet. Hence, the results of the present study show that an increasing conditioning time does not improve performance. In several studies, the improved feed utilisation in fattening pigs and broiler chicks affected by an expander treatment was attributed to increased nutrient digestibility and also to decreased feed wastage. This is also supported by the present study.

Table 3. Effect of SC and LC expander treatment of maize on feed intake, FCR, ADG and the ATTD of nutrients and their effect on slaughter performance

Item	Fattening pigs				Broiler chicks			
	SC	LC	SEM	P Value	SC	LC	SEM	P Value
Feed intake[1,2]	2.4	2.4	0.03	n.s.	87.8	89.0	0.84	n.s.
FCR[1,2] , kg/kg	2.7	2.6	0.03	n.s.	1.52	1.50	0.02	n.s.
ADG[1,2], g/d	891	913	8.33	n.s.	57.8	59.3	0.10	n.s.
ATTD- DM, %	87.3	84.8	0.38	***	73.7	72.6	0.31	n.s.
ATTD- EEh, %	77.3	77.8	1.88	n.s.	87.0	86.0	0.40	n.s.
ATTD- GE	88.2	85.8	0.44	***	77.6	77.1	0.26	n.s.
fat [3,4]	21.8	20.6	0.30	n.s.	1.67	1.69	0.03	n.s.
loin depth[5]/ breast[6]	73.2	74.2	0.51	n.s.	30.5	32.0	0.25	**
dressing, %	58.9	59.8	0.24	*	80.7	80.9	0.09	n.s.

[1] average of the whole period (kg DM/d, 31-116 kg LW); [2] average of the grower period (g DM/d, day 9.-22.); [3] depth back fat (in mm); [4] amount of abdominal fat (in % of life weight); [5] loin depth (in mm); [6] amount of breast (in % of life weight)

a,b Means within a row without a common superscript differ (P < 0.05)
(a,b) Means within a row without a common superscript differ (P < 0.10)
n.s. not significant, ** significant P < 0.05, *** highly significant P < 0.01, * trend P < 0.10

Table 4: Quality characteristics of breast meat of broiler chicks

Parameter	SC	LC	SEM	P Value
L*	52.64	52.39	0.44	n.s.
a*	3.40	2.31	0.19	n.s.
b*	7.94	7.56	0.29	n.s.
Cohesiveness, (%)	0.46	0.47	0.01	n.s.
Springiness, (%)	0.77	0.94	0.02	**
Chewiness	15.26	20.14	0.79	**
DPPH, mmol/kg TM	18.20	18.75	0.04	n.s.

Table 5: Carcass measurements of pigs fed differing hydrothermal treated maize

Parameter	SC	LC	SEM	P Value
Valuable cuts, %	51	50.9	0.14	n.s.
Back fat thickness, mm	21.8	20.6	0.30	n.s.
Meat thickness, mm	73.2	74.2	0.51	n.s.
Meat lightness of loin (U)	74.7	69.3	0.60	**

The improved ATTD of DM in SC maize could be the trade-off between a sufficient access of digestive enzymes and a moderate damage of nutrients (Keith Behnke, 1996). In comparison with our findings, Kidd et al. (2005) and O'Doherty et al. (1999) also observed only little differences in carcass yield, amount of breast meat/loin depth and abdominal fat proportion in broiler chicks or fattening pigs using HTST technology for maize processing. The reason for this result could be the reduced ileal protein and lysine digestibility of the animals due to heat damage.

Further labile nutrients are affected and the observed damage of both antioxidant substances could be related to the colour of meat from fattening pigs. This could also be useful for consumers' decisions. Muzhingi et al. (2008) also found a strong reduction of heat sensitive nutrients (e.g. carotinoids, vitamin E) in yellow maize when high temperatures were used.

However, only little information is available considering expander processing effects on increased chewiness and springiness of breast muscles. The reason for this observation is possibly related to the changes of lysine to energy ratio.

Conclusion

The results indicate that long-term conditioning showed no improvement on zootechnical performance but declined DM and EE digestibility in pigs. Specific carcass characteristics can be modified in both monogastric animal species by different treatment conditions.

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