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Dynamic rheology, microstructure and texture properties of model porcine meat batter as affected by different cold-set binding systems

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ABSTRACT

The efficacy of cold-set binding systems on the network formation and rheological structuring mechanisms of restructured meat depends on the binding system, time and temperature of cold setting, and the presence of NaCl. Therefore, the structure formation during the binding process using transglutaminase (TG), Ca-alginate (AL) or glucono-δ-lactone (GdL) for 20 h at 4 °C with or without added NaCl was investigated. The dynamic oscillation rheology, water binding capacity, firmness and microscopic structure of the resulting meat gels were studied.

The results showed that cold-set binding systems significantly affect the pH, water binding capacity and the textural properties of the resulting gels. The main process of gel setting took place within the first 1.5 h without the use of salt. Adding salt to the matrix shortened this period to 1 h. The pH of the resulting gels was only influenced by GDL, which caused a decrease from pH 5.48 to 4.90 when applied to the meat batter alone. AL gels showed a soft and semi solid-like behavior with a spreadable texture, TG provided with increased solid-like viscoelastic behavior and a coherent structure, and GdL resulted in an unstable aggregation and an incoherent structure between the meat particles. The water binding capacity was highest in AL gels (86.1%), followed by TG (72.6%). GDL had no effect on the water binding capacity (63.3%), which was strongest influenced by the addition of NaCl to the meat batter (99.9%). The later minimized most of the differences between the binding systems, demonstrating a greater impact on the matrix than the pure binding systems. Furthermore, the AL has to be added as a pre-formed gel to the meat batter to aid gel formation in the presence of NaCl.

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1. Introduction

Dynamic oscillation rheology provides data regarding rheological parameters of protein-containing samples, especially of meat, without destroying the structure under investigation (Haj Ahmad, Düring, Blochwitz, & Senge, 2013; Tunick, 2011). As only a small deformation is required to ensure linearity in the viscoelastic behavior, this non-destructive method may be used to study the bonding characteristics and structural changes during cold-set binding and restructuring of meat as well as the strength of the formed gel (Figura, 2004; Haj Ahmad et al., 2013) without irreversibly damaging the binding sites and the matrix. Hildebrandt, Thiemig, and Senge (2007) and Hildebrandt, Kastner, and Senge (2009) analyzed minced meat during a fermentation process by applying oscillation rheology method, in particular time-sweep measurements, and pointed out that among the rheological parameters the storage modulus (G') and the loss factor (tan δ) were the most useful descriptors to obtain information on the structuring mechanisms during fermentation.

The use of cold-set binding systems provides the opportunity to offer consumers reformed compact raw or refrigerated meat products with uniform shape, color and texture (Boles, 2011; Moreno, Carballo, & Borderías, 2008). Possible cold-set binding systems include alginates, glucono-δ-lactone (GdL) and transglutaminase (TG), and have previously been utilized to produce restructured meat products (Devatkal & Mendiratta, 2001; Kaufmann, Koppel, & Widmer, 2012; Sadeghi-Mehr, Lautenschlaeger, & Drusch, 2016a). Concentration and type of binding system affect the course of the binding process and the final

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product structure. As a consequence the binding process is also time- and temperature-dependent. According to Farouk (2010), the cold-setting temperature and time used for restructuring meat should generally range from 0 to 4 °C, and 6–24 h, respectively.

During the cold-set binding stage, depending on the binding system, different structuring mechanisms occur. Haj Ahmad et al. (2013) investigated structure formation of cuttable reconstituted poultry meat applying cold-set binders Ca-alginate (AL) and TG (cold-set temperature: 2 °C; cold-set time: 13 h), and fermentation technology using starter cultures (fermentation temperature: 30 °C; setting time: 18 h). They divided the time-sweep measurements of the cold-set binding systems into three structural phases. In the first phase, crosslinking of proteins and gelling took place being reflected in a fast increase of storage modulus (steep curve). In the second phase, the cure has begun to flatten off indicating a decrease of crosslinking and gelling, while in the third section, between 5 and 18 h, no significant changes in structural formation were observed and the sigmoid approached constant level. The authors reported that TG samples showed more solid-like behavior and elasticity compared to AL samples. Suklim et al. (2004) studied the effects of TG and AL on the physical properties of restructured scallops at a setting temperature of 5 °C and setting time of up to 24 h, and reported that the TG samples were approximately twice as elastic as that of AL samples. In general, less time is required for biochemical reactions at elevated temperature to reach a similar effect compared to a lower temperature. Ngapo, Wilkinson, and Chong (1996) used GdL to achieve acid-induced gelation of bovine myofibrillar proteins at 4 °C and setting time of up to 23 h. The authors reported that the slow lowering of the pH of myofibrils by GdL resulted in the formation of acid-induced gels, whereas the gelation increased with increasing rate of drop in pH. Furthermore, Ngapo et al. (1996) pointed out that the addition of NaCl to myofibrillar protein gels may have a significant strengthening effect on the gel. This observation has recently been confirmed by other studies. A low to moderate sodium concentration (below 3% NaCl in a formulation) resulted in weak gel formation or prevention of gelation of AL in dry-cured formed ham (Sadeghi-Mehr, Lautenschlaeger, & Drusch, 2016b) and in myofibrillar protein gels (Hong & Chin, 2010), while NaCl at higher concentrations may result in an increased gel strength of myofibrillar protein gels (Hong & Chin, 2010) or restructured fish products treated with TG (Ramírez, Uresti, Téllez, & Vázquez, 2002). Hong, Min, and Chin (2012) investigated the effects of TG and AL on isolated myofibrillar proteins under various pH conditions, and Hong and Chin (2010) at different NaCl levels. The authors reported that both TG and AL had optimal but different NaCl and pH levels to form an acceptable cold-set myofibrillar gel. A drawback of these studies is that a rotational rheometer was used, which cannot be considered as a non-destructive method, and have affected the structure during analysis.

The functionality of binding systems in meat products depends on the possible interaction between proteins and binding systems as reported in numerous studies (Borges, Schnäckel, & Kurze, 2009; Raharjo et al., 1994; Kuraishi et al., 1997; Sadeghi-Mehr et al., 2016a). However, the structuring mechanisms and network formation as well as the resulting texture of meat product may depend on the used binding system and other ingredients such as NaCl.

To the best of our knowledge, there is no study reporting on the non-destructive dynamic rheological characteristics during the cold-set binding at defined temperature of porcine meat batter using TG, AL and GdL. The objective of the present study therefore was to obtain evidence for the rheological structuring mechanisms and network formation of model porcine meat batter using different cold-set binding systems. These systems included enzymatic crosslinking by TG, hydrocolloid gelation using AL and pH-induced gelation by GdL. Thus, we suggest that the differences in the structuring mechanisms and network formation depend on the used binding system. In addition, all systems were investigated with and without the addition of NaCl at 4 °C. The resulting texture of the meat systems was characterized by mechanical compression test and qualitatively described by confocal laser scanning microscopy. For a better understanding of the process and the resulting mechanical properties, important physicochemical parameters like water binding capacity (WBC) and pH were investigated.

2. Materials and methods

2.1. Preparation of model porcine meat batter

Fresh pork meat (*M. longissimus dorsi*) was purchased 48 h post mortem from a local slaughterhouse. All visible external fat, tendons and connective tissue were trimmed off. The meat was diced into cubes with an edge length of approximately 2 cm. The meat cubes were individually placed into plastic trays and frozen at −18 °C for 24 h. The frozen meat cubes were then chopped at low speed (1300 rpm) in a bowl chopper (MK 23, Eduard Müller, Saarbrücken, Germany; bowl diameter: 560 mm, knife diameter: 270 mm, bowl speed 24 rpm) for 1 min followed by mincing at high speed (2600 rpm) for 4 min. During chopping liquid nitrogen was added to avoid thawing. The model porcine meat batter was divided into portions of 180 g and packed in PA/PE plastic bags (oxygen permeability $\leq$ 60 cm^3/m^2/24 h/bar at 23 °C and rH 50%, water vapor permeability $\leq$ 1.7 g/m^2/d at 23 °C and rH 85%) (Siegelrand-Vacuumbeutel BST/SR, Metzger Genossenschaft eG., Bayreuth, Germany) at absolute pressure of 2 kPa using a vacuum packaging machine (Multivac A300/42 MC, MULTIVAC Sepp Haggenmüller GmbH & Co. KG, Wolfertschwenden, Germany), and stored at −80 °C for up to three weeks.

2.2. Preparation of cold-set binding systems and samples

The freeze-dried microbial transglutaminase (TG) formulation (Activa PB, Ajinomoto Foods GmbH, Hamburg, Germany) contained calcium chloride, porcine protein, maltodextrin, silicon dioxide, transglutaminase with an activity of 63 units/g, and vegetable oil. The alginate (AL) preparation (Alginate: 8635 Welginat AM 4225, Welding GmbH& Co. KG, Frankfurt, Germany) contained sodium alginate, maltodextrin, calcium sulfate, and tetra sodium diphosphate. For both preparations, a slurry was prepared according to the instructions of the supplier: 1.0 wt% (relative to meat) of TG or AL formulation was added to distilled water (ratio 1:5) and mixed (Ultra-Turrax T 18 basic, IKA-Werke GmbH & Co. KG, Staufen, Germany) until a homogeneous paste was obtained.

The model porcine meat batter samples were formulated as shown in Table 1. Frozen meat was thawed at room temperature

Table 1
Sample formulations and experimental design (M: minced porcine meat, TG: microbial transglutaminase, AL: calcium alginate, GdL: glucono-δ-lactone; +S: samples with the addition of NaCl).

Treatment	Ingredient (%)					
	M	H_2O	NaCl	TG	AL	GdL
Ref	94.34	4.72	–	–	–	–
TG	94.34	4.72	–	0.94	–	–
AL	94.34	4.72	–	–	0.94	
GdL	94.34	4.72	–	–	–	0.94
Ref+S	91.74	4.59	2.75	–	–	–
TG+S	91.74	4.59	2.75	0.92	–	–
AL+S	91.74	4.59	2.75	–	0.92	–
GdL+S	91.74	4.59	2.75	–	–	0.92

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