Cryoprotective Effect of Polydextrose on Chicken Surimi

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Abstract

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Two thermal analysis techniques – Differential scanning calorimetry (DSC) and Differential thermal analysis (DTA), – were used to study the cryoprotective effects of polydextrose on chicken surimi. The samples of chicken surimi were mixed with: (a) different mass fractions of polydextrose (w = 2–10%), (b) κ-carrageenan (w = 0.5%) and different mass fractions of polydextrose (w = 2–10%), and (c) NaCl (w = 2%) and different mass fractions of polydextrose (w = 2–10%). Chicken surimi was produced following a modified procedure of Dawson *et al*. (1988) on a broiler (Sasso, 12 weeks, and 1.73 kg live wt.), that was quickly frozen and stored for 3 months at –25°C. Initial freezing point (T_i), thermal transition temperature (T_p), and denaturation enthalpy (ΔH) were evaluated. The greatest effects of the cryoscopic depression of the initial freezing point T_i were exhibited by the samples of chicken surimi with added 2% NaCl and 10% polydextrose. Differential scanning calorimetry (DSC) revealed a shift in the thermal transition temperature of myosin and actin to a higher temperature as the mass fraction of polydextrose increased. Since the denaturation enthalpy is directly related to the amount of native proteins, higher values of ΔH indicate higher cryoprotective effects of polydextrose.

Keywords: thermal transitions temperature; initial freezing point; DSC; DTA; chicken surimi; polydextrose

Chicken myofibrillar protein concentrate also called chicken surimi, produced by means of the modified technology from fish surimi (Dawson *et al*. 1988), has very good technological properties, primarily a strong capacity to form strong gels after heating. Freezing and frozen storage is the most frequently used preservation technique for this kind of meat product, however, it causes protein denaturation, which is expressed as the loss of functional properties such as protein solubility and water holding capacity on heating (Uijttenboogaart *et al*. 1993; Kijowski & Richardson 1996; Stangierski & Kijowski 2003; Thawornchinsombut & Park 2006; Stangierski & Kijowski 2008). To protect myofibrillar proteins from cold-denaturation during frozen storage, cryoprotectants are generally added (Lee 1984; Park *et al*. 1996). The most effective cryoprotectants for myofibrillar proteins are carbohydrates, such as sucrose, sorbitol, maltodextrins, and polydextrose (Lanier & MacDonald 1991; Tornaniak *et al*. 1998; Auh *et al*. 2003; Herrera & Mackie 2004). The cryoprotective effects of polydextrose may be attributed to the numerous hydroxyl groups available for hydrogen bonding with proteins, leading to increased protein hydration, reduced surface tension of water, and decreased aggregation (denaturation). Other possible mechanisms such as hydrophobic interaction effects, reduction of the quantity of frozen water (increase of the mass fractions not clear bound or unfreezable water), and reduction of solute concentration might also be involved (Sych *et al*. 1990; Park *et al*. 1993; Smolinska *et al*. 1995).

The most commonly used methods for the determination of cryoprotective effects of the added substances are the measurements of myofibrillar protein solubility SEP (Saltz extractable protein), Ca^{2+}ATP-ase activity, unfrozen water content by

Nuclear magnetic resonance (NMR), and transition temperatures and enthalpy of myofibrillar proteins by Differential scanning calorimetry (DSC) (Dileep *et al*. 2005; Osako *et al*. 2005). The initial freezing point is one of the related properties which also include: boiling point, osmotic pressure, and water activity. The lower is the initial freezing point, the more microbiologically stable is the food, the lower is the water activity, the higher is its boiling point, and the more slowly the ice content increases with the temperature lowering (Miles *et al*. 1997). Differential scanning calorimetry (DSC) is a useful technique for studying thermal behaviour of muscle proteins (Barbut & Finday 1991). The changes in the protein structure during DSC analysis are referred to as transition changes, and the peak temperatures at these transitions are used to represent the transition temperatures (Jittinandana *et al*. 2003).

The aim of this work was to investigate cryoprotective effects of polydextrose on chicken myofibrillar proteins using two different thermal analysis techniques. Differential scanning calorimetry (DSC) and Differential thermal analysis (DTA).

MATERIAL AND METHODS

The samples of chicken surimi were prepared in the laboratory from a broiler (Sasso, 12 weeks, 1.73 kg live wt.) by the modified procedure of Dawson *et al*. (1988). The samples were divided in three groups and each was mixed respectively with: (a) polydextrose (w = 2–10%), (b) NaCl (w = 2%) and different mass fractions of polydextrose (w = 2–10%), (c) κ-carrageenan (w = 0.5%) and different mass fractions of polydextrose (w = 2–10%). The mass fractions were determined as percentages of total mass. The moisture content was 84.05% and ash content was 0.27% as determined by the A.O.A.C. method (AOAC 1980) for meat products before the components addition. Total protein mass fraction in the samples was 15.12% as determined by the Kjeldahl method (Kjeltec System, model 1002 Distilling Unit, Tecator Inc., Boulder, USA). The samples were packed in polyethylene bags, fast frozen in liquid nitrogen and stored at –25°C. The average storage time was 3 months before DSC and DTA experiments.

DTA apparatus was constructed in the laboratory (Kovačević & Kurtanjek 1993) and used for the measurement of the initial freezing point (T_i).

Differential scanning calorimetry (DSC) was performed on Mettler Toledo DSC 822e differential scanning calorimeter equipped with STARe software. The samples of ca 15 mg (± 1 mg) were weighed and sealed into standard aluminum pans (40 µl) and subsequently scanned over the range from 25°C to 95°C at a heating rate of 5°C/min, using empty standard aluminum pan as a reference. The peak temperatures (T_p) were determined from DSC curves. The changes in enthalpy (ΔH in J/g), associated with the denaturation of proteins, were determined by measuring the area under the DSC curves using STAR^e software.

Statistical analyses. Experimental data were analysed by analysis of variance (ANOVA) and Fisher's least significant difference (*LSD*), with the software program STATISTICA 7 (StatSoft, Inc., USA).

RESULTS AND DISCUSION

DTA measurements of chicken surimi samples containing added substances were conducted over the temperature range from –25°C to 5°C. The results of DTA are presented in Figures 1 and 2. The peak points were read off as the initial freezing points from DTA diagrams. Systematic shifts of the initial freezing points towards lower temperatures with increased concentration of polydextrose can

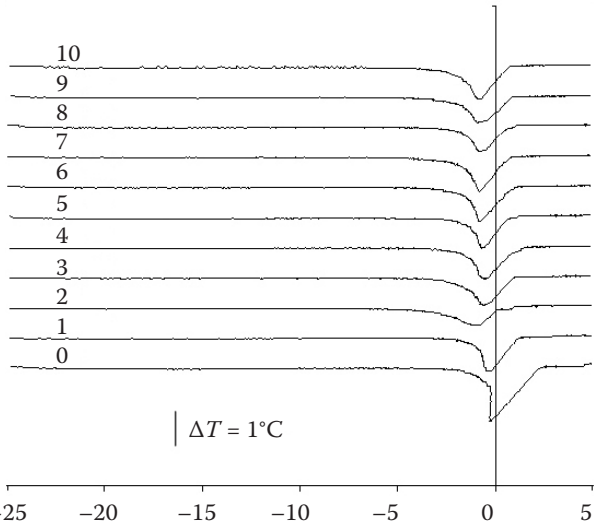

Figure 1. DTA curves of chicken surimi with 0.5% κ-carrageenan as a function of w (%) of polydextrose, ΔT is temperature difference between sample and reference substance

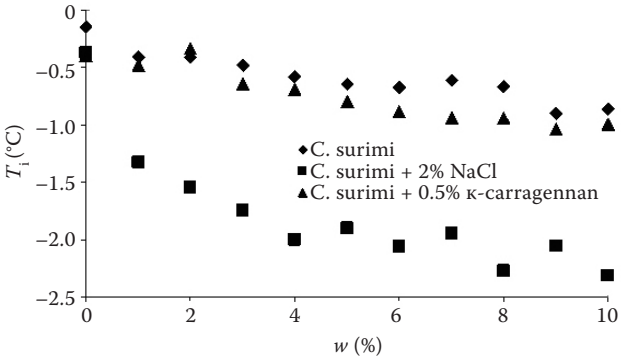

Figure 2. Initial freezing points (T_i) of chicken surimi as a function of mass fraction (w) of polydextrose and polydextrose in presence of 2% NaCl and 0.5% κ-carragennan

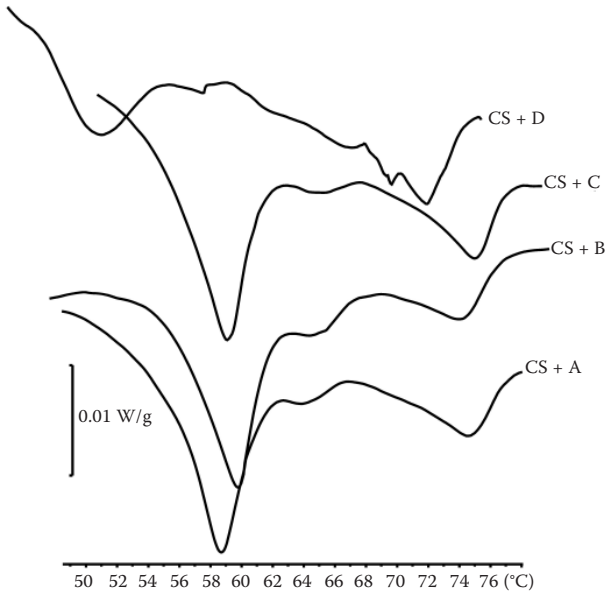

Figure 3. DSC thermograms of chicken surimi (CS) stored for 3 months at –25°C mixed with: A (no additive), B (6% of polydextrose), C (0.5% of κ-carrageenan and 6% of polydextrose), and D (2% NaCl and 6% of polydextrose)

be observed (Figures 1 and 2). Below the initial freezing points, DTA diagrams for all samples show a systematic increase in the temperature difference with increased levels of polydextrose (Kovačević *et al*. 2003). The greatest effect of cryoscopic depression of initial freezing point T_i is exhibited by the series of samples mixed with 2% NaCl and different mass fractions of polydextrose (w = 2–10%). NaCl decreases strongly the initial freezing point, which is a consequence of NaCl colligative properties (small molecular mass and the effect of dissociation) (Holtzclaw *et al*.1984). On the other hand, polydextrose also decreased

Table 1. Thermal transition temperatures (T_p) of myosin and actin

Mass fraction of polydextrose w (%)	Myosin T_p (°C)		
	chicken surimi	chicken surimi + 2% NaCl	chicken surimi + 0.5% κ-carrageenan
Myosin			
0	58.03^{a} ± 0.07	58.03^{f} ± 0.07	58.03^{a} ± 0.07
2	58.80^{b} ± 0.03	52.48^{a} ± 0.09	58.37^{b} ± 0.04
4	59.20^{c} ± 0.02	53.20^{b} ± 0.04	59.05^{c} ± 0.15
6	59.28^{c} ± 0.04	53.55^{c} ± 0.07	59.86^{d} ± 0.14
8	61.43^{d} ± 0.05	53.82^{d} ± 0.06	61.64^{e} ± 0.07
10	62.02^{e} ± 0.08	54.08^{e} ± 0.04	62.31^{f} ± 0.10
Actin			
0	74.42^{a} ± 0.11	74.42^{f} ± 0.11	74.42^{b} ± 0.11
2	74.62^{ab} ± 0.09	68.89^{a} ± 0.06	74.55^{ab} ± 0.02
4	74.69^{bc} ± 0.15	69.39^{b} ± 0.06	74.59^{b} ± 0.02
6	74.87^{c} ± 0.11	69.73^{c} ± 0.06	74.69^{b} ± 0.10
8	75.36^{d} ± 0.13	70.16^{d} ± 0.08	76.81^{c} ± 0.06
10	75.46^{d} ± 0.10	70.56^{e} ± 0.10	77.60^{d} ± 0.16

Values are means ± SD of triplicate; values in the same column with different superscripts (a–f) are significantly different ($P < 0.05$)

the initial freezing point T_i in all samples, but to a smaller extent than NaCl, which is also the consequence of its colligative properties (large molecular mass, Mr ≈ 2000) (Figures 1 and 2).

Differential scanning calorimetry thermograms of chicken surimi mixed with: A (no additive), B (6% of polydextrose), C (0.5% of κ-carrageenan and 6% of polydextrose), and D (2% NaCl and 6% of polydextrose), after 3 months of frozen storage are illustrated in Figure 3. Chicken surimi thermogram normally contained two endothermic transitions. Referring to previous DSC studies of similar (Figure 3) samples (Sych *et al*. 1990, 1991; Herrera & Mackie 2004; Kim *et al*. 2005; Thawornchinsombut & Park 2006), it can be assumed that the two peaks in this study are related to the thermal denaturation of myosin and actin. The data related to thermal transition temperatures (T_p) of myosin and actin are presented in Table 1. Thermal transition temperatures (T_p) of myosin and actin of chicken surimi with: (a) polydextrose (w = 2–10%) were, respectively, in the range from 58.03°C to 62.02°C, 74.62°C to 75.46°C, (b) NaCl (w = 2%) and different mass fractions of polydextrose (w = 2–10%) were in the range from 52.48°C to 54.08°C, 68.89°C to 70.56°C, (c) κ-carrageenan (w = 0.5%) and different mass fractions of polydextrose (w = 2–10%) were in the range from 58.37°C to 62.31°C and 74.55°C to 77.60°C. By increasing the mass fraction of polydextrose in all samples, T_p of myosin and actin shifted to higher values. The increase of T_p can be interpreted as thermal stabilisation of myofibrillar proteins since a higher temperature was required to denature these proteins (Sych *et al*. 1991). T_p of myosin showed a greater shift due to the increase of the mass fraction of polydextrose than T_p of actin for all samples of chicken surimi (Table 1).

The greatest shifts in T_p of myosin and actin were shown by the samples of chicken surimi mixed with κ-carrageenan (w = 0.5%) and different mass fractions of polydextrose (w = 2–10%), (3.94°C and 3.05°C).

The method of expressing peak enthalpies ΔH was adopted to provide an estimate of the quantity of native proteins (Sych *et al*. 1991; Kijowski & Richardson 1996; Stangierski & Kijowski 2008). Denaturation enthalpies (ΔH) of myosin and actin for all samples are shown in Table 2. The values of ΔH for myosin and actin show a linear

Table 2. Denaturation enthalpies (ΔH) of myosin and actin

Mass fraction of polydextrose (%)	Myosin ΔH (J/g)		
	chicken surimi	chicken surimi + 2% NaCl	chicken surimi + 0.5% κ-carrageenan
Myosin			
0	$0.93^{a} \pm 0.04$	$0.93^{e} \pm 0.04$	$0.93^{a} \pm 0.04$
2	$1.15^{b} \pm 0.05$	0.50 ± 0.03	$1.20^{b} \pm 0.04$
4	$1.23^{c} \pm 0.03$	$0.58^{b} \pm 0.07$	$1.36^{c} \pm 0.07$
6	$1.34^{d} \pm 0.04$	$0.72^{c} \pm 0.06$	$1.51^{d} \pm 0.03$
8	$1.41^{e} \pm 0.03$	$0.92^{e} \pm 0.06$	$1.59^{d} \pm 0.02$
10	$1.46^{e} \pm 0.04$	$0.91^{e} \pm 0.03$	$1.80^{e} \pm 0.06$
Actin			
0	$0.27^{a} \pm 0.03$	$0.27^{abc} \pm 0.03$	$0.27^{a} \pm 0.03$
2	$0.30^{ab} \pm 0.02$	$0.22^{a} \pm 0.02$	$0.30^{ab} \pm 0.03$
4	$0.30^{abc} \pm 0.04$	$0.25^{ab} \pm 0.01$	$0.32^{b} \pm 0.02$
6	$0.32^{bc} \pm 0.02$	$0.30^{bcd} \pm 0.03$	$0.34^{bc} \pm 0.02$
8	$0.32^{bc} \pm 0.02$	$0.32^{cd} \pm 0.05$	$0.38^{c} \pm 0.02$
10	$0.34^{c} \pm 0.01$	$0.34^{d} \pm 0.02$	$0.42^{d} \pm 0.03$

Values are means ± SD of triplicate. Values in the same column with different superscripts (a–e) are significantly different ($P < 0.05$)

increase with the increase of the mass fraction of polydextrose (Table 2).

The highest values of ΔH of myosin and actin were obtained with the series of samples mixed with 0.5% of κ-carrageenan and different mass fractions of polydextrose (w = 2–10%). Denaturation enthalpy (ΔH) values of myosin for all samples seems to have been more influenced by the addition of polydextrose then the denaturation enthalpy of actin, which is in agreement with the previously reported data for fish surimi (Sych *et al*. 1991). The lowest values of ΔH were shown by the samples mixed with 2% NaCl. The salt ions are believed to cause weakening of the interaction between the oppositely charged side chains, resulting in stronger protein-protein bonds, shrinkage of the muscle and dehydration, which may be the result of increased protein denatuaration and lower values of denaturation enthalpy and thermal transition temperatures. This destabilising effect of NaCl is in agreement with previous results obtained with poultry breast meat and washed and mechanically recovered broiler meat (Kijowski & Mast 1988).

CONCLUSIONS

Differential scanning calorimetry of chicken surimi shows that the addition of polydextrose results in stabilisation of myofibrillar proteins. The enthalpies of myosin and actin transitions increase with the increase of the mass fraction of polydextrose. Differential thermal analysis (DTA) results also show a shift of T_i to lower values as the mass fraction of polydextrose increases.

The shift in thermal transition temperatures of myosin and actin to higher temperatures, increase of enthalpies of myosin and actin transition, and shift of T_i to lower values as the mass fraction of polydextrose increases prove that polydextrose acts in accordance with the cryoprotecting mechanism and interacts with proteins in chicken surimi.

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