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Effect of sugar types on physical attributes and crystalline structure of sweet-dried chicken meat product

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Abstract

The sweet-dried chicken, an intermediate-moisture meat (a_w 0.7-0.8), was prepared by marinating ground chicken meat with 2% salt and 35% sugar level by weight of meat. The mixture of sweet-dried chicken meat varied sugar types (sucrose, fructose, lactose and sorbitol) underwent drying (45°C) and frying (120°C) processes, respectively. The color (L^*, a^*, b^*), browning intensity, shear force values, X-ray diffraction (XRD) and sensory evaluation of sweet-dried chicken meat samples were determined. Samples prepared with fructose and lactose after frying showed darker brown color than those of sucrose and sorbitol treatment samples ($p < 0.05$). Shear force values of samples prepared with sorbitol and sucrose were lower than those of fructose and lactose treatment samples ($p < 0.05$) which was corresponded to the higher sensory score in tenderness and overall acceptance. The sweet-dried chicken meat prepared with sucrose and sorbitol had the highest sensory scores in all attributes ($p < 0.05$). Degree of molecular ordering of samples was evaluated by X-ray diffraction patterns. After frying, sample prepared with lactose showed the highest order of crystalline structure compared to other treatments. However, the sensory score in glossy of sample prepared with lactose was lower than those prepared with sucrose, sorbitol and fructose, respectively ($p < 0.05$).

Introduction

Jerky or dried cured meat is preferable with glossy and light brown color, specific flavor and chewiness texture. It has been promoted as nutritious and low calorie product which is low in cholesterol and fat and high in protein and energy (Nummer *et al*., 2004; Pegg *et al*., 2006). Color is an important attribute since it is perceived immediately by the consumer for the formed and/or degraded compounds which contribute a specific coloration. A chicken-jerky type is one choice of jerky meat because chicken meat is considered as the cheapest meat, lower cholesterol and restriction food in religion. However, the color of dried chicken meat was undesirable for the consumers because chicken meat has low myoglobin content (Pearson and Young, 1989). In Thailand, the dried meat sometimes is added more sugar level to produce the palatable sweet taste which is different to jerky. This product is formulated like the Chinese-style processed meats (Chen *et al*., 2002), and in this work also called “sweet-dried meat”. There are two main thermal processing for sweet-dried meat production after marinating. The sweet-dried meat is dried approximately at 45-60°C to reduce moisture content and stabilize protein in jerky product. Then, the dried meat is fried (110-130°C) by deep-fat frying to produce the ready-to-eat and shelf-stable product.

The sweet-dried meat is a kind of intermediate-moisture foods that are preserved by salting, sugar addition and drying to reduce water activity (a_w) in the region 0.9–0.6 (Roos, 2001). A ready-to eat sweet-dried meat is generally considered to be shelf-stable product that does not require refrigeration after proper processing. Although the microbial deterioration of this product is more stable than raw or cooked meat, they are still subjected to deterioration through chemical and physical processes (Huang and Nip, 2001). Sugar is the main ingredient in sweet-dried chicken meat product which has two different effects on muscle protein. First, sugar can cause brown color by Maillard reaction and caramelization. Second, sugar can act to stabilize proteins to heat denaturation (Rich and Foegeding, 2000).

Maillard reaction is the spontaneous interactions occurring between carbonyls and amines, mainly in the form of reducing sugars and amino groups of proteins (Ajandouz *et al*., 2008). The rate of Maillard reaction accelerates as a_w increased above 0.25-0.3 (Esse and Saari, 2004). The other nonenzymatic browning reaction which may occur in sweet-dried chicken meat process is caramelization or sugar degradation in which is usually formed when sugar are heated at high temperature without amino groups (above 120°C and 9 < pH < 3) (Kroh, 1994; Laroque *et al*., 2008). The rate of nonenzymatic browning

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reactions is strongly dependent on pH (Ajandouz *et al.*, 2008; Tsai *et al.*, 2009), time, temperature (Quintas *et al*., 2007; Ajandouz *et al*., 2008), concentration of reactants and reactants type (Morales and Jiménez-Pérez, 2001; Ajandouz *et al*., 2008; Laroque *et al*., 2008). The different types of sugar significantly affected on nonenzymatic browning reaction. Laroque and coworkers (2008) studied the reactivities of five reducing sugars (ribose, xylose, arabinose, glucose and fructose) with shrimp hydrolysate (55°C, pH 6.5) and found that brown color development (absorbance at 420 nm) of systems containing pentose was higher than the systems containing hexose. The hexose reactivity in the browning development was found in aldoses are more reactive than ketoses (Laroque *et al*., 2008). Additionally, Kwak and Lim (2004) showed the browning intensity of the Maillard reaction products from lysine which reacted with five reducing sugars, the sugar reactivity was in the order of xylose higher than arabinose, glucose, maltose and fructose, respectively.

Furthermore, thermal treatments could induce changes in functional properties of proteins. As a consequence of high temperature on food texture may be covalently or non-covalently modified proteins, resulting in conformation changes and/or aggregation (Arakawa *et al*., 2001; Semenova *et al*., 2002). Sugars can stabilize the proteins from heat denaturation (Yoo and Lee, 1993; Rich and Foegeding, 2000). Rich and Foegeding (2000) indicated the ability of sugars to inhibit heat-induced aggregation of proteins that the addition of ribose or lactose increased peak denaturation temperature of whey protein isolate solutions. Yoo and Lee (1993) concluded the proposed mechanisms of sugars to stabilize proteins are as follows: (1) promotion of preferential hydration which is facilitated by an increased surface tension of water during freezing; (2) preservation of the native conformation through a direct interaction between sugars and polar residues in the protein surface during drying; (3) strengthening of hydrophobic interaction during heating. The objective of this study was to evaluate the effect of different sugar types on color, texture and X-ray diffraction patterns of sweet-dried chicken meat accompany with the sensory evaluation.

Materials and Methods

Materials

The chicken meat (mixed thigh and leg) obtained from Saha Farms Company Limited (Songkhla, Thailand). The frozen chicken meat was thawed at 4°C for 24 h. The obvious fat and connective tissue were removed from chicken thigh and leg. After that, the chicken meat was ground using blender (MK-5086M, Panasonic Co., Ltd., Malaysia). The ground chicken meat was held at 4°C before ingredients mixing.

Sweet-dried chicken meat preparations

The ground chicken meat was marinated directly with 2% salt and 35% sugar (w/w of meat) using different sugar types include of sucrose, fructose, lactose, and sorbitol, and then held at 4°C for 15 min. The mixture paste were formed a piece with a plastic block into size 4 × 6 × 0.3 cm^3. Samples were preheated in air dryer at temperature of 45°C until obtained 30±3% moisture content of samples. All sample treatments (before frying, BF) were collected in plastic zip-lock bag and kept at room temperature for analysis. The remaining of samples after drying was deep-fried in palm oil at 120°C for 8 min. All samples with different sugar types were cooled at room temperature and blotted the excess surface oil with towel paper. All samples of sweet-dried chicken meat (after frying, AF) were placed in plastic zip-lock bag and kept at room temperature for analysis. The sweet-dried chicken meat with various sugar types both before and after frying were subjected to analyse the physical and chemical characteristics, X-ray diffraction and sensory evaluation within 3 days.

Color measurement

Samples were measured in ten replicates using a Hunterlab colorimeter (ColorFlex, Hunter Lab Reston, USA) and were reported as the complete International Commission on Illumination (CIE) system color profiles of lightness (L*), redness (a*), and yellowness (b*).

Warner-Bratzler shear force measurement

Samples were cut into size 2 × 3 × 0.3 cm^3 for shear force measurements using the Texture Analyzer equipped with a Warner-Bratzler shear apparatus (Stable Micro System, TA-XT2i, UK). The operating parameters consist of a cross head speed of 2 mm/s and a 50 kg load cell. The shear force of the sample was measured in ten replicates for each treatment. The peak of the shear force profile was regarded as the shear force value (kg).

Water activity measurement

The blended samples were put into water activity cups, and determined in triplications with a water activity meter (AquaLab 3TEB, Decagon, USA). The calibration was done at ambient temperature

(25°C) with distilled water (a_w = 0.999).

Moisture content

The blended samples were dried in hot air oven at 105°C until constant weight by the standard method of AOAC (1999). The measurement was performed in triplications.

Browning intensity

The degree of browning usually measure via absorbance at wavelength 420 nm which assesses the extent of nonenzymatic browning reaction took place. A protocol described by Ramírez and Cava (2005) was applied with slight modification for extraction of sample's brown color. Blended samples (5 g) were homogenized in methanol (40 ml) and adjusted the volume to 50 ml. The homogenate were extracted brown color in hermetically closed bottle (100 ml-Duran) using magnetic stirrer at room temperature for 2 h. The suspension was centrifuged at 8000 *g* for 15 min and recorded the absorbance at wavelength 420 nm.

X-ray Diffraction (XRD)

The XRD investigations were carried out on a Philips X-ray generator (X' Pert MPD, Philips, Netherlands) with 30 kV accelerating voltage and 30 mA current. CoKα1 radiation was used. A variable divergence slit was used to give an irradiated area with a diameter of 20 mm. An anti-scatter slit of 0.6 mm and a detector slit of 0.2 mm was employed. Diffractograms were taken between 0 and 100° (2θ) at a rate of 1°/min (2θ) and with a step size of 0.1° (2θ).

Sensory evaluation

The sweet-dried chicken meat samples after frying were evaluated for glossy, tenderness, color, sweetness, taste and overall acceptance by 30 panellists using 9-points hedonic scales (1 = extremely dislike to 9 = extremely like). The panellists required cleansing their palate between samples with water.

Statistical analysis

The completely Randomized Design (CRD) was used to study for physical and chemical analysis. The sensory evaluation was experimented with Randomized Complete Block Design (RCBD). All experimental data were analyzed by analysis of variance (ANOVA). The statistical analyses were performed at a significant differences level of 95% ($p < 0.05$) applied by Duncan's Multiple Range Tests (DMRT) among the means from triplicate.

Table 1. Moisture content, water activity (a_w) and shear force value of sweet-dried chicken meat prepared with different sugar types before frying (BF) and after frying (AF)

Treatment	Moisture content (%)		water activity (a_w)		Shear value (Kg)	
	BF	AF	BF	AF	BF	AF
Sucrose	29.43±0.39^c	20.17±0.09^c	0.809±0.003^b	0.685±0.003^b	0.62±0.10^c	1.47±0.29^b
Fructose	28.60±0.31^d	23.47±0.46^a	0.696±0.002^d	0.595±0.002^d	1.20±0.23^a	2.19±0.31^a
Lactose	30.69±0.63^b	15.56±0.04^d	0.888±0.000^a	0.745±0.006^a	0.96±0.20^b	2.41±0.23^a
Sorbitol	33.19±0.32^a	20.79±0.23^b	0.730±0.003^c	0.610±0.002^c	0.42±0.11^d	1.31±0.14^b

[a,b,c,d] Mean within columns with differing superscripts are significantly different at $p < 0.05$

Table 2. Color values (L^*, a^*, b^*) and browning intensity of sweet-dried chicken meat prepared with different sugar types before frying (BF) and after frying (AF)

Treatments	L*		a*		b*		Browning intensity	
	BF	AF	BF	AF	BF	AF	BF	AF
Sucrose	38.05±1.81^c	43.40±1.71^b	3.36±0.37^b	2.61±0.34^c	12.24±0.99^c	15.52±1.25^b	0.025±0.001^b	0.045±0.010^c
Fructose	35.50±2.62^d	27.91±1.80^c	2.77±0.40^c	10.99±0.91^a	13.06±0.96^b	10.43±1.52^c	0.034±0.002^a	0.195±0.009^a
Lactose	60.43±1.11^a	53.50±1.54^a	4.33±0.35^a	7.59±1.27^b	20.07±0.65^a	24.17±1.66^a	0.034±0.002^a	0.175±0.002^b
Sorbitol	40.53±1.37^b	43.61±0.82^b	2.82±0.36^c	2.76±0.63^c	13.11±0.87^b	14.46±0.78^b	0.020±0.001^c	0.028±0.005^d

[a,b,c,d] Mean within columns with differing superscripts are significantly different at $p < 0.05$

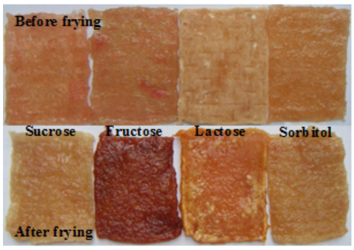

Figure 1. Appearance of sweet-dried chicken meat prepared with different sugar types before frying and after frying

Results and Discussion

All sweet-dried chicken meat with various sugar types before frying were dried at mild temperature (45°C) to reduce moisture content until obtained 29-33% (Table 1). The surface color of sweet-dried chicken meat with different sugar types is shown in Figure 1 and Table 2. The sweet-dried chicken meat before frying performed in golden-brown color with the transparent paste except lactose sample (Figure 1). The sample prepared with lactose showed an opaque brown color which contributed to high L^*, a^* and b^* values compared to other samples ($p < 0.05$). After frying, the sweet-dried chicken meat prepared with fructose and lactose had lower in L^* and higher in a^* compared to samples before frying. While, the opposite results were obtained from samples prepared with sucrose and sorbitol (Table 2). During thermal processing, Maillard reaction was continuously underwent resulting in decreasing L^* as well as the increasing a^* and b^* values (Bosch *et al*., 2007; Ngadi *et al*., 2007). This result showed the development of brown color pigment in Maillard reaction and sugar degradation by which fructose and lactose were more reactive than sucrose and sorbitol. After frying at high temperature (120°C), samples prepared with fructose had the lowest L^* values and highest a^* values ($p < 0.05$) because Maillard reactions between reducing sugars and amino groups took place contributing to the brown color. The results of color (L^*, a^*, b^*) values were consistent to browning intensity which is shown in Table 2. Brown color development is often used analytically to assess the extent of nonenzymatic browning reaction in foods (Laroque *et al*., 2008). It was found that sample prepared with fructose had higher browning intensity after frying than those prepared with lactose, sucrose and sorbitol, respectively ($p < 0.05$). Fructose is a monosaccharide of the family of ketose sugar. Lactose and sucrose are disaccharides, but sucrose is a kind of non-reducing sugar which no contribution in the Maillard reaction (BeMiller and Whistler, 1996). Sorbitol is sugar alcohol which is very stable and chemically unreactive. It can withstand high temperatures and does not participate in Maillard browning reactions (Nezzal, 2009). These sugars differ in their structure resulting in different rate of browning. Some investigators reported the following order of reactivity: aldopentoses > aldohexoses > ketohexoses > disaccharides (Laroque *et al.*, 2008). The reactivities of reducing sugars in chemical and biochemical involved in an acyclic or an open chain form (Naranjo *et al*., 1998). Fructose has a high proportion of open chain form which highly dependent on high temperature (Naranjo *et al.*, 1998; Laroque *et al*., 2008). This was agreed with the study of Brands and van Boekel (2001) by which concluded that ketoses seemed to be more reactive in the sugar degradation reactions and Maillard reaction than their aldose isomers. In contrast, Kwak and Lim (2004) showed the browning intensity of the Maillard reaction products from lysine which reacted with five reducing sugars, the sugar reactivity was in the order of xylose > arabinose > glucose > maltose > fructose. This might be described to the ketose sugar proceeding through imine intermediates that favor the formation of Heyns' products, while the aldose sugars proceeded through Amadori products (Silván *et al*., 2006). The rate of browning of Heyns' products is known to be slower than that of Amadori products (Jing and Kitts, 2002). However, the differences between the reactivities of sugar might be due to the diversity of the composition of the systems and of the condition of the reactions such as temperature, pH, solvent and inorganic salts affected Maillard reaction rates of sugars (Naranjo *et al*., 1998).

The moisture content and a_w are an important attributes of jerky-type meat which are shown in Table 1. Moisture content of all treatments before frying was controlled in a range of 30±3%. After frying, moisture content of those samples was decreased which varied between 15-23%, and a_w ranged from 0.59-0.75.

Table 1 showed a significantly different in moisture content and a_w of samples with different sugar types after frying ($p < 0.05$). After frying, it was found that sample prepared with fructose had high moisture content and low a_w, while, sample prepared with lactose had low moisture content and high a_w. It is generally known that sugar is hydrophilic substance. The interactions between water and hydrophilic solutes are water-solute hydrogen bonds (Yoo and Lee, 1993). The a_w of those samples was different probably due to the water binding ability of sugar to other components. Fructose had higher water solubility that can easily bind to proteins compared to lactose resulting in higher bound water of sample prepared with fructose compared to sample prepared with lactose (Jouppila, 2006). Grosso *et al.* (2000) indicated that the weakest gels (amidated low methoxyl pectin) with fructose and sorbitol had the highest content of bound water. The moisture content of samples after frying was corresponding to the shear force value (Table 1). The results showed that samples prepared with sucrose and sorbitol had the lowest shear force values ($p < 0.05$). Iseya *et al.* (2000) found that sorbitol curing effectively suppressed the hardening of the dried squid meats which meat protein impaired by heat denaturation. By the way, sugar can promote preferential hydration which is facilitated by an increased surface tension of water (Yoo and Lee, 1993). Lee and Timasheff (1981) indicated that the protein structure stabilization related to the increase in free energy required unfolding the protein in the presence of sucrose. The sucrose induced an increase in enlarging the surface cavities which contain the bulky solute molecules corresponding to the transition temperatures of the proteins at the various solvent compositions (Lee and Timasheff, 1981; Semenova *et al*., 2002). On the other hand, Semenova *et al.* (2002) reviewed that the presence of sugar might cause slower gelation rate which was attributed to an increase in viscosity of the continuous phase, causing a decrease in the frequency of protein-protein encounters. Furthermore, it was found that sample prepared with lactose had the lowest moisture content ($p < 0.05$) resulting in highest shear value ($p < 0.05$) (Table 1). This might be implied that lactose sugar had low solubility because lactose had the composition endotherm near 220°C (Jouppila, 2006), so lactose sugar conjoined in a cluster and had no interaction with meat protein to produce surface tension of water. However, fructose had the highest moisture content but showed a high shear value (Table 1). This was probably due to fructose has a faster rate of glycation to form covalent cross-links

Table 3. Sensory evaluation of sweet-dried chicken meat prepared with different sugar types after frying at 120°C for 8 min

Treatments	Glossy	Tenderness	Color	Sweetness	Taste	Overall acceptance
Sucrose	7.08±1.04^{a}	6.84±1.14^{a}	7.04±1.17^{a}	6.40±0.91^{a}	6.68±1.03^{a}	6.88±1.09^{a}
Fructose	4.80±1.73^{b}	5.24±1.64^{b}	2.52±1.48^{c}	4.56±1.47^{b}	4.56±1.58^{b}	4.36±1.41^{b}
Lactose	3.84±1.31^{c}	3.52±1.64^{c}	3.72±1.51^{b}	3.36±1.55^{c}	3.40±1.68^{c}	3.36±1.66^{c}
Sorbitol	6.48±0.96^{a}	6.60±1.08^{a}	6.68±1.22^{a}	6.72±0.98^{a}	6.68±0.85^{a}	6.60±0.82^{a}

[a,b,c,d] Mean within columns with differing superscripts are significantly different at $p < 0.05$

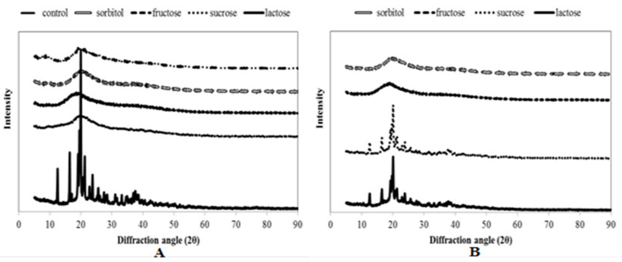

Figure 2. X-ray diffractogram of sweet-dried chicken meat prepared with different sugar types before frying (A) and after frying (B)

Note: control, meat without sugar; sorbitol, meat prepared with sorbitol; fructose, meat prepared with fructose; sucrose, meat prepared with sucrose; lactose, meat prepared with lactose

within the protein network during Maillard reaction development (Rich and Foegeding, 2000).

The sensory scores of sweet-dried chicken meat after frying in color, tenderness and overall acceptance attributes (Table 3) are corresponding to the shear force values and brown color of samples (Figure 1, Table 1 and 2). Shear values of samples prepared with fructose and lactose were higher than those of sucrose and sorbitol ($p < 0.05$) which concordant with the lowest tenderness in sensory evaluation ($p < 0.05$) (Table 3). Color of sample prepared with sucrose and sorbitol showed in light brown color while fructose samples were dark brown because of the high nonenzymatic browning reaction rate of fructose. Sample prepared from lactose displayed in opaque brown color which might be due to protein denaturation and no interaction of protein-lactose complex. The sweet-dried chicken meat prepared with sucrose and sorbitol had the lowest shear values and highest sensory scores in glossy, color, tenderness, taste and overall acceptance attributes (Table 3). In contrast, the sweet-dried chicken meat prepared with fructose and lactose showed the lowest sensory scores in all attributes.

The X-ray diffraction patterns of sweet-dried chicken meat containing sucrose, fructose and sorbitol as well as the sample without sugar before frying are amorphous as measured by X-ray diffraction (Figure 2A). The crystallization of sugar ingredients in sweet-dried chicken meat was hindered by the composition of muscle protein. The amorphous characteristic was observed in barely strong crystalline structure (Barrett et al., 2000). While, sample prepared with lactose showed crystalline structure (Figure 2A). The predominant peak position at 2θ=12.48º, 16.43º, 19.13º, 19.53º, 19.98º and 20.08° were observed in lactose sample. It was supported to the study of Barhama *et al*. (2006) who indicated that the features of β-lactose showed the small peak at 2θ=10.5°, peaks of α-lactose monohydrate showed at 2θ=12.5° and 16.4º. Moreover, this result was coincident to the investigation of Jouppila *et al.* (1998) and Barhama *et al.* (2006). The predominant crystalline peak of sweet-dried chicken meat before frying probably due to lactose sugar cannot dissolve homogeneously with chicken meat. The dissolution of lactose sugar might be flocculated into crystal, and then showed more order of crystalline structure (Figure 2A). Figure 2B displayed the X-ray diffraction patterns of sweet-dried chicken meat after frying with various sugar types, it was found that crystalline of sucrose and lactose sample were prominent. The peak intensities of lactose after frying in diffractogram was decreased compared to the sample before frying might be due to the sugar loss during frying. The crystallinity of sucrose sample after frying was remarkable at 2θ=11.63º, 13.13º, 18.78º, 19.58º and 24.73° (Figure 2B). The X-ray diffraction patterns of sucrose were concordant to the study of Li *et al.* (2009) who revealed several peaks for sucrose at 11.7°, 13.2°, 18.9°, 19.6°, and 24.8°. The predominance of sucrose crystallinity was probably due to lower moisture content during frying resulting in moisture migration to surface layer and sucrose formed agglomerated matrix particles into crystallization (Li *et al*., 2009). As consider to the results of crystalline structure and glossy attributes, the crystalline structure feature of sample prepared from sucrose after frying was observed (Figure 2B) which was coinciding to the highest glossy of the sensory score (Table 3). However, sample prepared with lactose showed a high order of crystalline structure (Figure 2B) which was contrasted to the lowest glossy attributes in sensory score (Table 3). This was probably due to the dissolution of lactose crystal in the sample was detected. In addition, the sweet-dried chicken meat prepared with sorbitol and fructose showed amorphous structure both before and after frying might be because of sorbitol and fructose is easily to dissolve (Jouppila, 2006).

Conclusion

Sweet-dried chicken meat prepared with different sugar types had different color, texture, and overall acceptance. Product prepared with fructose caused darker brown color compared to sucrose, lactose, and sorbitol. The sweet-dried chicken meat prepared with sucrose and sorbitol had the lowest shear values and highest sensory scores in all attributes. Sample prepared with sucrose had the highest sensory score in glossy attribute which was coinciding to the ordered crystalline structure in X-ray diffraction pattern.

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Reference

Ajandouz, E.H., Desseaux, V., Tazi, S. and Puigserver, A. 2008. Effects of temperature and pH on the kinetics of caramelization, protein cross-linking and Maillard reactions in aqueous model systems. Food Chemistry 107 (3): 1244-1252.

AOAC. 1999. Official Methods of Analysis of the Association of Official Analytical Chemists. 16th edn. Washington DC: The Association of Official Analytical Chemists, Inc.

Arakawa, T., Prestrelski, S. J., Kenney, W. C. and Carpenter, J. F. 2001. Factors affecting short-term and long-term stabilities of proteins. Advanced Drug Delivery Reviews 46 (1-3): 307–326.

Barhama, A. S., Haque, M. K., Roos, Y. H. and Hodnett, B. K. 2006 Crystallization of spray-dried lactose/protein mixtures in humid air. Journal of Crystal Growth 295 (2): 231–240.

Barrett, A., Tsoubeli, M., Maguire, P., Tan, N. B., Conca, K., Wang, Y., Porter, B. and Taub, I. 2000. Textural stability of intermediate-moisture extrudates: Effect of formulation. Cereal Chemistry 77 (6): 784-790.

BeMiller, J. N. and Whistler, R. L. 1996. Carbohydrate. In Fennema, O. R. (Eds). Food Chemistry, p. 157-224. New York: Marcel Dekker.

Bosch, L., Alegría, A., Farré, R. and Clemente, G. 2007. Fluorescence and color as markers for the Maillard reaction in milk–cereal based infant foods during storage. Food Chemistry 105 (3): 1135–1143.

Brands, C. M. J. and van Boekel, M. A. J. S. 2001. Reactions of monosaccharides during heating of sugar-casein systems: building of a reaction network model. Journal of Agricultural and Food Chemistry 49 (10): 4667-4675.

Chen, W. S., Liu, D. C. and Chen, M. T. 2002. Effects of High Level of Sucrose on the Moisture Content, Water Activity, Protein Denaturation and Sensory Properties in Chinese-Style Pork Jerky Australasian Journal of Animal Sciences 15 (4): 585-590.

Esse, R. and Saari, A. 2004. Shelf-life and moisture management. In Steele, R. (Eds). Understanding and Measuring the Shelf-life of Food, p. 24-41. Boca Raton: CRC Press.

Grosso, C. R. F., Bobbio, P. A. and Airoldi, C. 2000. Effect of sugar and sorbitol on the formation of low methoxyl pectin gels. Carbohydrate Polymers 41 (4): 421–424.

Huang, T. C. and Nip, W. K. 2001. Intermediate-moisture meat and dehydrated meat. In Hui, Y. H., Nip, W. K., Rogers, R. W. and Young, O. A. (Eds). Meat Science and Applications, p. 403-441. New York: Marcel Dekker.

Iseya, Z., Kubo, T. and Saeki, H. 2000. Effect of sorbitol on moisture transportation and textural change of fish and squid meats during curing and drying processes. Fisheries Science 66 (6): 1144–1149.

Jing, H. and Kitts, D. D. 2002. Chemical and biochemical properties of casein–sugar Maillard reaction products. Food and Chemical Toxicology 40 (7): 1007–1015.

Jouppila, K. 2006. Mono- and disaccharides: selected physiochemical and functional aspects. In Eliasson, A. (Eds). Carbohydrated in Foods, p. 41-88. Boca Raton: CRC Press.

Jouppila, K., Kansikas, J. and Roos, Y. H. 1998. Crystallization and X-ray diffraction of crystals formed in water-plasticized amorphous lactose. Biotechnology Progress 14 (2): 347-350.

Kroh, L. W. 1994. Caramelisation in food and beverages. Food Chemistry 51 (4): 373-379.

Kwak, E. J. and Lim, S. I. 2004. The effect of sugar, amino acid, metal ion, and NaCl on model Maillard reaction under pH control. Amino Acids 27 (1): 85–90.

Laroque, D., Inisan, C., Berger, C., Vouland, É., Dufossé, L. and Guérard, F. 2008. Kinetic study on the Maillard reaction. Consideration of sugar reactivity. Food Chemistry 111 (4): 1032-1042.

Lee, J. C. and Timasheff, S. N. 1981. The stabilization of proteins by sucrose. Journal of Biological Chemistry 256: 7193-7201.

Li, T., Zhou, P. and Labuza, T. P. 2009. Effects of sucrose crystallization and moisture migration on the structural changes of a coated intermediate moisture food. Frontiers of Chemical Science and Engineering 3 (4): 346–350.

Morales, F. J. and Jiménez-Pérez, S. 2001. Free radical scavenging capacity of Maillard reaction products as related to colour and fluorescence. Food Chemistry 72 (1): 119-125.

Naranjo, G. B., Malec, L. S. and Vigo, M. S. 1998. Reducing sugars effect on available lysine loss of casein by moderate heat treatment. Food Chemistry 62 (3): 309-313.

Nezzal, A., Aerts, L., Verspaille, M., Henderickx, G. and Redl, A. 2009. Polymorphism of sorbitol. Journal of Crystal Growth 311 (15): 3863–3870.

Ngadi, M., Li, Y. and Oluka, S. 2007. Quality changes in chicken nuggets fried in oils with different degrees of hydrogenatation. LWT - Food Science and Technology 40 (10): 1784–1791.

Nummer, B., Harrison, J. A., Harrio, M. A., Kendall, P., Sofos, J. N. and Andress, E. L. 2004. Effects of preparation methods on the microbiological safety of home-dried meat jerky. Journal of Food Protection 67 (10): 2337-2341.

Pearson, A. M. and Young, R. B. 1989. Composition and structure. In Pearson, A. M. (Eds). Muscle and Meat Biochemistry, p. 1-33. San Diego: Academic Press.

Pegg, R. B., Amarowicz, R. and Code, W. E. 2006. Nutritional characteristics of emu (*Dromaius* *novaehollandiae*) meat and its value-added products. Food Chemistry 97 (2): 193-202.

Quintas, M., Guimarães, C., Baylina, J., Brandão, T. R. S. and Silva, C. L. M. 2007. Multiresponse modelling of the caramelisation reaction. Innovative Food Science and Emerging Technologies 8 (2): 306–315.

Ramírez, M. R. and Cava, R. 2005. Changes in colour, lipid oxidation and fatty acid composition of pork loin chops as affected by the type of culinary frying fat. LWT - Food Science and Technology 38 (7): 726–734.

Rich, L. M. and Foegeding, E. A. 2000. Effects of sugars on whey protein isolate gelation. Journal of Agricultural and Food Chemistry 48 (10): 5046-5052.

Roos, Y. H. 2001. Water activity and plasticization. In Eskin, N. A. M. and Robinson, D. S. (Eds). Food Shelf Life Stability: Chemical, Biochemical, and Microbiological Changes, p. 3-36. Boca Raton: CRC Press.

Semenova, M. G., Antipova, A. S. and Belyakova, L. E. 2002. Food protein interactions in sugar solutions. Current Opinion in Colloid and Interface Science 7 (5-6): 438-444.

Silván, J. M., van de Lagemaat, J., Olano, A. and Del Castillo, M. D. 2006. Analysis and biological properties of amino acid derivates formed by Maillard reaction in foods. Journal of Pharmaceutical and Biomedical Analysis 41 (5): 1543–1551.

Tsai, P. J., Yu, T. Y., Chen, S. H., Liu, C. C. and Sun, Y. F. 2009. Interactive role of color and antioxidant capacity in caramels. Food Research International 42 (3): 380-386.

Yoo, B. and Lee, C. M. 1993. Thermoprotective effect of sorbitol on proteins during dehydration. Journal of Agricultural and Food Chemistry 41 (2): 190-192.