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Effect of polyols and chitosan on shelf-life extension of Thai taro custard

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Abstract

Taro custard is a popular dessert in Thailand, but it is highly perishable. The effects of adding polyols (glycerol, xylitol, and sorbitol) in combination with chitosan (0.01 and 0.05%) were assessed on changes in quality and shelf-life extension of Thai taro custard stored at refrigerated condition of 2 - 4°C. Results indicated that xylitol was an effective additive in reducing the water activity (a_w) value of the custards, with reduction in number of total plate count and increased shelf-life of the products. The incorporation of chitosan and polyols led to stability of L* and b* values, and retarded decrease in adhesiveness during storage. A combination of xylitol (60%) and chitosan (0.05%) (X60C0.05 recipe) was the most effective blend additive for improving qualities of the custards including sensory attributes and shelf-life extension. The X60C0.05 recipe gave a longer shelf-life (49 d) than the control (C recipe, 3 d). The use of a blended additive comprising 60% xylitol and 0.05% chitosan showed potential to be an alternative for shelf-life extension of Thai taro custard, with acceptable sensorial quality instead of using preservatives.

Introduction

Thai taro custard is one of the most popular desserts in Phetchaburi Province, Thailand. Typical ingredients for Thai taro custard are coconut milk, whole egg, coconut palm sugar, taro, and tapioca flour. However, the product normally has a short shelf-life of 1 d or less at ambient temperature (25 - 30°C), with only a few days at refrigerated temperature (2 - 4°C); due to high water activity (a_w) and the intrinsic nature of its compositions resulting in a high rate of microbial spoilage induced by both pathogenic and non-pathogenic strains. Hurdle technology can be used to extend the shelf-life of Thai taro custard by adjusting the a_w, pH, and temperature levels.

Water activity value is an important factor that controls food spoilage caused by the growth of microorganisms, and this is related to physical, chemical, and enzymatic degradation (Maltini *et al.,* 2003). Microorganisms can be effectively inhibited if the a_w value is decreased to a lower level for a given water content. Polyols or sugar alcohols can be used as humectants to decrease the a_w value and to inhibit microbial growth. Several studies have used polyols to increase the shelf-life of specific food, including the addition of glycerol in fresh noodles (Li *et al.,* 2011), sorbitol in vacuum packaged Chinese-style sausage (Wang, 2000), and xylitol in *dadih* (Mohd Thani *et al.,* 2016). As well as reducing the a_w value, polyols can also serve as sweeteners and bulking agents, with slightly less sweetness and lower caloric value than sucrose. According to the U.S. Food and Drug Administration, the use of polyols allows for a reduction in nutritional input at 2.4 kcal/g for xylitol and 2.6 kcal/g for sorbitol when compared with 4.0 kcal/g for sucrose. The capacity to decrease a_w value makes polyols an attractive alternative to sugar (Ghosh and Sudha, 2012).

In this health-conscious age, consumers prefer foods without chemical preservatives. Chitosan has, therefore, received increasing attention as a potential food preservative with new and natural antimicrobial agents. Chitosan is a modified, natural carbohydrate polymer derived through the deacetylation of chitin, a major component of the exoskeletons of crustaceans that is also found in various insects, worms, and mushrooms. Chitosan inhibits a wide variety of pathogenic and spoilage bacteria and fungi (No *et al.,* 2007). The antimicrobial mechanism of chitosan involves

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electrostatic interactions between positively charged chitosan molecules and negatively charged bacterial cell membranes. Electrostatic interactions stimulate changes in cell wall permeability, and internal osmotic imbalances are activated with subsequent inhibition of bacterial cell growth. Electrostatic interaction leads to hydrolysis of peptidoglycans in Gram-positive bacteria, resulting in leakage of intracellular electrolytes such as glucose, proteins, nucleic acids, and potassium ions. Chitosan also binds with bacterial DNA and this causes inhibition of mRNA and protein synthesis. Many reports have investigated shelf-life extension using chitosan for juice (Barbosa *et al.,* 2015), meat (No *et al.,* 2007), and cake products (Sangsuwan *et al.,* 2015).

Vinegar is designated and approved by the Federal Drug Administration (FDA) as a generally recognised as safe (GRAS) substance. Vinegar contains natural antimicrobials that are widely used in food applications to reduce thermal death time of microorganisms and inhibit pathogenic microorganisms such as *Listeria monocytogenes, Salmonella Typhimurium,* and *Escherichia coli* O157:H7, which can penetrate and acidify cell contents and subsequently lead to instability in the bacterial cell membrane (Keener *et al.,* 2004). Vinegar can also be used to prolong the shelf-life of fresh beef cuts (Jamilah *et al.,* 2008) and unpeeled shrimp (Attala, 2012).

To the best of our knowledge, this is the first study to investigate the use of polyols in combination with chitosan to extend the shelf-life of Thai taro custard. Changes in moisture content, a_w, pH values, microbial loads, surface colour, texture, and sensory properties were examined over time while samples were kept at refrigerated condition.

Materials and methods

Preparation of Thai taro custard samples

Thai taro custard samples comprised of egg (38.86%), coconut milk (30.43%), taro (11.51%), tapioca flour (0.87%), and coconut palm sugar (18.33%). The preparation process involved mixing whole egg with sweetener, tapioca flour, and coconut milk before filtering through cheesecloth, and adding mashed taro. This mixture was poured into aluminium foil cups, and baked in an oven at 150°C. After the taro custard surface turned brown, oven temperature was reduced to 110°C, and baking was continued for another 30 min. The taro custard was packed in hermetically sealed containers using a packaging machine until further analysis.

Addition of polyols to Thai taro custard

Three polyols (glycerol, sorbitol, and xylitol) were used to study their effect on the a_w value by replacing coconut palm sugar with 20, 40, and 60% (w/w) polyols. The custards with added polyols were measured in terms of a_w value in relation to the control recipe (100% coconut palm sugar).

Addition of polyols and chitosan in Thai taro custard

Chitosan solutions (0.1 and 0.5%; food-grade with deacetylation of 95% minimum; molecular weight (Mw) of 500,000 to 1,000,000; BFM, Bangkok, Thailand) were prepared in 1% vinegar (v/v) using 5% distilled vinegar (Diamond Preserved Food Co., Ltd.), stirred until completely dissolved, and then autoclaved. The control sample and the lowest a_w sample were added with 0.1% vinegar solution, while chitosan solutions were added at concentrations of 0.01 and 0.05%. All the samples were stored at refrigerated temperature, and the effects of polyol and chitosan were evaluated on the custard in terms of moisture content, a_w value, pH, microbial loads, surface colour, texture, and sensory evaluation. Triplicate samples were analysed every other day for the first 7 d, and then at 7-d intervals until spoilage occurred.

Determination of moisture content

Three aluminium dishes were weighed, and 3 to 5 g of the samples were added to each dish and reweighed. The samples were dried in an oven at 105°C for 3 h, then taken out and placed in a desiccator to cool for 30 min before reweighing. Moisture content (M_i) on a wet weight basis was determined using Eq. 1.

$$M_i = (W_M - W_D) / W_M \qquad \text{(Eq. 1)}$$

where, W_M is the initial weight of the sample, and W_D is the weight after drying.

Determination of aw value

The samples were minced into small pieces and placed in disposable sample cups. The a_w value was determined in triplicate using an Aqualab water activity meter (model series 4TE, Decagon Devices, Pullman, Washington, USA).

Determination of pH value

A 2 g aliquot of the samples was homogenised with 2 mL of distilled water, and the pH value was measured in triplicate using a Docu pH Meter (Sartorius, USA).

Determination of microbial loads

The microbial loads of the samples were investigated by Total Plate Count (TPC), and Yeast and

Mould Count (YMC). Briefly, each treatment was aseptically opened on the sampling days in triplicate samples. A 25 g aliquot of the samples was aseptically transferred into a sterile stomacher bag before 225 mL of sterile 0.85% NaCl (w/v) was added, and the mixture was homogenised for 1 min using a stomacher (Masticator, IUL instrument, Barcelona, Spain). A 1 mL solution of 10-fold serial dilutions was poured and evenly spread on Petri dishes. The TPC was enumerated in triplicate using plate count agar (HiMedia Laboratories Pvt. Ltd., Mumbai, India), and incubated aerobically at 35°C for 24 - 48 h. The YMC was enumerated using potato dextrose agar (PDA) (HiMedia Laboratories Pvt. Ltd., Mumbai, India), and incubated at 24°C for 3 - 5 d. Microbial counts were expressed as colony-forming units per gram of sample (CFU/g).

Determination of surface colour

Surface colour of the samples was measured in terms of L* (lightness), a* (red/green), and b* (yellow/blue) values using a Hunter Lab Colorimeter (Ultrascan, VIS-Hunter Associates Lab., USA). All measurements were performed in triplicate.

Determination of texture

Hardness and adhesiveness of the samples were measured using a TA.XT plus Texture Analyzer (Stable Micro Systems, UK). Each sample was transferred onto a stage with a fixed height of 15 mm. Perspex probe (P/0.5) with a 10 mm diameter was compressed twice into the samples at a defined rate of 2 min to a depth of 15 mm. Data collection and calculations were performed using the texture exponent software of the instrument.

Sensory evaluation

The organoleptic evaluation was performed by 40 panellists. Samples were evaluated for colour, flavour, taste, texture, and overall acceptability using a structured 9-point hedonic scale ranging from 1 (Dislike it very much) to 9 (Liked it very much). A sensory score of 4 was taken as the limit of acceptability. All samples were determined after 1 d of refrigerated storage.

Statistical analysis

Three independent replicates were conducted, and mean values were reported. Statistical analysis of all data was performed using SPSS Version 16.0 (SPSS Inc., USA). Duncan's multiple range comparison was used to ascertain the level of significant differences ($p < 0.05$).

Results and discussion

Effect of polyols on a_w values of the samples

The a_w levels of custard samples with coconut palm sugar substituted by various polyols at 0, 20, 40, and 60% are shown in Figure 1. Replacing coconut palm sugar with 40% glycerol and 60% xylitol, respectively, significantly reduced the a_w values to 0.938 - 0.948, which was lower than the control recipe (C recipe, 100% coconut palm sugar; 0.964 a_w). Coconut palm sugar is composed of 70% sucrose, and the MW of sucrose (342.3 g/mol) is higher than glycerol (92 g/mol) and xylitol (152 g/mol). When replacing coconut palm sugar with polyols, the amount of solute remained the same, but the gross MW derived from all the ingredients decreased with polyol substitution. This then led to an increase in osmotic pressure and subsequently decreased the a_w value of the resulting custard samples (Ko, 2006).

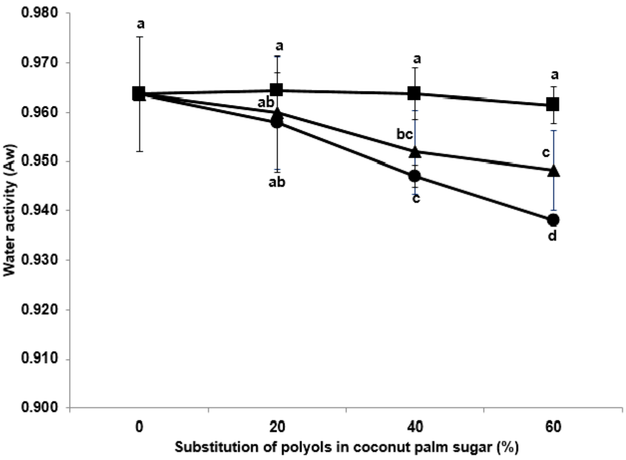

Figure 1. The water activity (a_w) of Thai taro custard with different substitutions of coconut palm sugar: sorbitol (■), glycerol (▲), and xylitol (●).

The 60% xylitol recipe (X60) yielded the lowest a_w value (0.938), followed by the 40% xylitol recipe (X40; 0.947) and the 60% glycerol recipe (G60; 0.948). Xylitol and glycerol are sugar alcohols containing high contents of hydroxyl groups that form hydrogen bonds with water molecules, and act as effective humectants. Many factors including lower MW and liquid state leads to glycerol being more effective in decreasing the a_w value than xylitol. However, here, xylitol yielded a lower a_w value than glycerol largely because xylitol has a higher polar surface area and can be more easily dissolved in Thai taro custard. Xylitol has been used to reduce the a_w value in other food products such as chocolate cake (Cauvain and Cyster, 1996) and *pesto* spread (Mitić-Ćulafić *et al.,* 2014), while glycerol is often used to reduce the a_w value in Kha Nom Pia (Chinese cake) (Kanto, 2002).

When replacing coconut palm sugar with 20 - 60% sorbitol, no significant differences in a_w values were observed as compared to the C recipe. This occurred because glycerol and xylitol have high moisture adsorption properties, while sorbitol has moderate moisture adsorption properties. Jang *et al.* (2015) showed that the a_w value in semi-dried jerky was reduced by 2.5 and 5% concentrations with glycerol and xylitol, respectively, but not by similar concentrations of sorbitol. Hence, the X60 recipe which had the lowest a_w value among those treatments was selected to further investigate the effect of polyol in combination with chitosan on the shelf-life and quality of Thai taro custard.

Effect of xylitol and chitosan on Thai taro custard quality

Moisture content

Custard samples with coconut palm sugar replaced by xylitol (X60-based recipes) had significantly higher moisture content (58.04 - 58.50%) than the C-based recipes (56.20 - 56.87%) (data not shown). However, no significant differences were observed in moisture content among C-based recipes or X60-based recipes. This result implied that xylitol had a major impact on the moisture content, with the capacity to absorb and hold water. Xylitol plasticised and expanded the protein network which became loosely packed in the custard and favoured the adsorption of water molecules. By contrast, the aggregated protein in C-based recipes acted as a barrier to rehydration (Sorapukdee *et al.,* 2016). This result concurred with Sorapukdee *et al.* (2016) who reported that glycerol increased absorption, while the control with no added humectants slightly decreased absorption of jerky made from spent hen meat. Changes in moisture contents were recorded until spoilage occurred. All recipes showed no significant difference in moisture content throughout the storage period at refrigerated temperature because they were packaged in hermetically sealed containers that prevented moisture diffusion.

a_w value

The X60-based recipes yielded significantly lower a_w values (0.932 - 0.937) than the C-based recipes (0.962 - 0.968) (data not shown). This result demonstrated that xylitol had significant effect in reducing the a_w, while vinegar and chitosan had none. During storage at refrigerated temperature, all recipes showed no significant difference in a_w throughout the storage period, which showed a similar trend to the moisture content.

pH value

The C and X60 recipes treated with vinegar, with or without chitosan, showed significantly lower pH values (6.66 - 6.77) than the C and X60 recipes without vinegar at 7.35 and 7.53, respectively (Table 1). Moreover, there was no significant difference in pH values between recipes treated with vinegar and recipes treated with chitosan. This indicated that the pH reduction was a result of the natural acidity of vinegar and not from addition of xylitol or chitosan. The pH values of the C and CV recipes significantly increased after 3 and 5 d of storage at the refrigerated temperature. A slight change in pH value was observed in the CC0.01 and CC0.05 recipes throughout the storage period, starting from day 1 until day 35, and ranging from 6.66 - 6.76 and 6.73 - 6.84, respectively. Increases in pH values of the X60 and X60V recipes

Table 1. Changes in pH values of Thai taro custard during storage at refrigerated temperature.

Storage time (day)	Recipe							
	C	CV	CC0.01	CC0.05	X60	X60V	X60C0.01	X60C0.05
1	7.35 ± 0.07^{Bc}	6.67 ± 0.07^{CDc}	6.66 ± 0.10^{CDb}	6.73 ± 0.06^{Cb}	7.53 ± 0.11^{Ad}	6.70 ± 0.13^{Cc}	6.77 ± 0.02^{Cb}	6.76 ± 0.08^{Cb}
3	7.49 ± 0.01^{b}	6.66 ± 0.02^{b}	6.74 ± 0.02^{ab}	6.73 ± 0.01^{b}	7.60 ± 0.02^{cd}	6.77 ± 0.04^{bc}	6.77 ± 0.05^{b}	6.76 ± 0.03^{b}
5	7.71 ± 0.05^{a}	6.81 ± 0.06^{a}	6.68 ± 0.06^{ab}	6.73 ± 0.04^{b}	7.81 ± 0.05^{a}	6.83 ± 0.04^{ab}	6.82 ± 0.04^{a}	6.84 ± 0.05^{ab}
7		6.78 ± 0.02^{a}	6.74 ± 0.03^{ab}	6.77 ± 0.07^{ab}	7.77 ± 0.07^{a}	6.90 ± 0.01^{a}	6.88 ± 0.07^{ab}	6.87 ± 0.02^{a}
14		6.82 ± 0.04^{a}	6.74 ± 0.04^{ab}	6.81 ± 0.05^{ab}	7.73 ± 0.03^{ab}	6.85 ± 0.05^{a}	6.81 ± 0.03^{ab}	6.82 ± 0.01^{ab}
21		6.77 ± 0.01^{a}	6.70 ± 0.01^{ab}	6.82 ± 0.08^{ab}	7.77 ± 0.04^{a}	6.86 ± 0.02^{a}	6.83 ± 0.04^{ab}	6.87 ± 0.02^{a}
28			6.68 ± 0.04^{ab}	6.84 ± 0.07^{a}	7.67 ± 0.06^{bc}	6.84 ± 0.04^{a}	6.82 ± 0.01^{ab}	6.78 ± 0.06^{b}
35			6.76 ± 0.03^{a}	6.84 ± 0.07^{a}	7.63 ± 0.04^{bc}	6.83 ± 0.02^{ab}	6.82 ± 0.01^{ab}	6.78 ± 0.03^{b}
42					7.66 ± 0.05^{bc}	6.85 ± 0.03^{a}	6.83 ± 0.01^{ab}	6.82 ± 0.01^{ab}
49					7.67 ± 0.08^{bc}	6.76 ± 0.03^{c}	6.79 ± 0.01^{b}	6.78 ± 0.04^{b}

Control recipe (C) was treated with 0.1% vinegar (CV), 0.01% chitosan (CC0.01), and 0.05% chitosan (CC0.05). X60 recipe (X60) was treated with 0.1% vinegar (X60V), 0.01% chitosan (X60C0.01), and 0.05% chitosan (X60C0.05). Uppercase superscript letters indicate significant differences in pH of Thai taro custard after 1 d of storage ($p < 0.05$). Lowercase superscript letters indicate significant differences in pH of each recipe throughout the storage days ($p < 0.05$).

were observed after 5 d. The X60C0.01 and X60C0.05 recipes had pH values ranging from 6.77 - 6.88 and 6.76 - 6.87, respectively, and these remained almost constant during 49 d of storage at the refrigerated temperature. This result indicated that chitosan delayed the increased in pH value. Generally, pH values should decline throughout the storage period as a result of microbial growth producing acids from carbohydrate breakdown (Jariyawaranugoon and Akesowan, 2010). However, in the present work, pH values of Thai taro custards increased or remained stable throughout the storage period. This can be explained because glucose, acetic acid, certain amino acids, urea, and water-soluble proteins were catabolised by bacteria. The subsequent production of alkaline radicals (ammonia and amines) contributed to the increase in pH values (Nychas *et al.,* 2008). This result agrees with Dias *et al.* (2013) who reported that the pH value of pork sausages increased linearly during storage. Moreover, chitosan also increased the pH value based on its acid-binding properties (Martín-Diana *et al.,* 2009).

Microbial loads

The Thai Industrial Standards Institute (TISI) has specified that a level of log 6.0 CFU/g in Thai taro custard can be considered as the cut-off point between spoiled and unspoiled. Thus, analysis of the samples was terminated when TPC exceeded this level. Changes in TPC of Thai taro custard samples stored at refrigerated temperature are shown in Figure 2. The TPC of the C recipe rapidly increased during 5 d of storage, mainly due to conducive a_w and pH values (Leistner, 1985). Thus, the C recipe had a shelf-life of only 5 d. By contrast, the CV recipe had a longer shelf-life (21 d) because of its acidity and bactericidal properties of vinegar (Solieri and Giudici, 2009). The addition of vinegar led to cytoplasmic acidification and subsequent failure in energy production and regulation parameters that resulted in the accumulation of free acid anions to a toxic limit. This reduced growth and extended the lag phase or killed the microorganisms (Sohaib *et al.,* 2016). Vinegar has been used to increase the shelf-life of meats (fresh beef cuts and chicken retail cuts) (Desai *et al.,* 2014) and vegetables (sweet basil) (Changsawake *et al.,* 2015); however, no reports have dealt with prolonging the shelf-life of desserts. Here, shelf-life increased up to 35 d for the CC0.01 and CC0.05 recipes due to the synergistic effects of vinegar and chitosan. Meanwhile, several studies have examined prolonging the shelf-life of desserts and beverages using only chitosan, including white rice cake and wet noodles (Lee *et al.,* 2000), orange juice (Martín-Diana *et al.,* 2009), and using acetic acid in

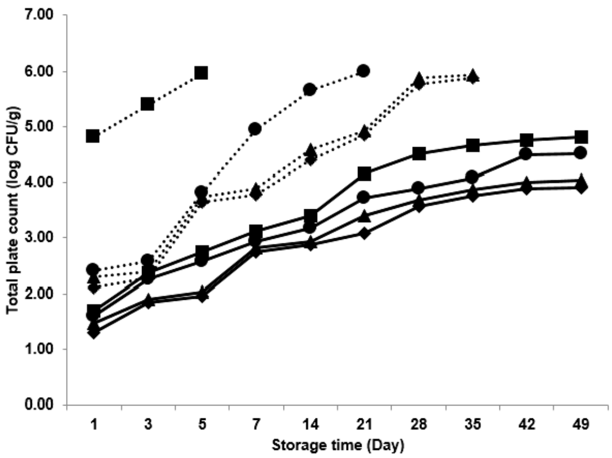

Figure 2. Changes in TPC of Thai taro custard during storage at refrigerate temperature. C recipe (··■··), CV recipe (··●··), CC0.01 recipe (··▲··), CC0.05 recipe (··◆··), X60 recipe (—■—), X60V recipe (—●—), X60C0.01 recipe (—▲—), and X60C0.05 recipe (—◆—).

combination with chitosan for mayonnaise and mayonnaise-based shrimp salads (Roller and Covill, 2000). In the present work, similar TPCs were observed in the CC0.01 and CC0.05 recipes, consistent with Lee *et al.* (2000) who extended the shelf-life in rice cake but found that TPCs among samples treated with 1 and 2% chitosan showed no significant difference. When chitosan concentration increased, interaction between the cationic chitosan and anionic bacterial cell membrane decreased because the cationic chitosan aggregated and could not bind with the bacterial cell membrane (Assis and Pessoa, 2004).

In addition to improving bacterial stability, prolonging the shelf-life of Thai taro custard was observed in the X60-based recipes. These had a TPC of less than log 6.0 CFU/g (log 3.91 - 4.81 CFU/g) at the end of the storage period and a longer storage time (49 d) than the C recipe (5 d). This may be due to the a_w lowering property of xylitol which played an important role in enhancing the beneficial effects of chitosan and vinegar in terms of extending the shelf-life. Xylitol promotes the inhibition of several bacterial strains (Tapiainen *et al.,* 2001) via the inhibition of bacterial stress proteins and phosphotransferase systems, and its effects have been tested in several food products such as *pesto* spread (Mitić-Ćulafić *et al.,* 2014) and *dadih* (Mohd Thani *et al.,* 2016). Moreover, xylitol contributes to higher microbial stability and also increases the lag phase, while decreasing bacterial growth rate and stationary phase level (Gliemmo *et al.,* 2004). In the present work, no moulds and yeasts were observed in all recipes either visually or by plate counts during the storage time (data not shown) because the Thai taro custards were packaged in hermetically sealed containers. No oxygen entered the containers and this inhibited the growth of yeast and mould.

Surface colour of Thai taro custard

As an indicator of freshness, colour is critical to consumers' purchase decisions. The a* and b* values of C and X60 recipes treated with vinegar or chitosan were higher than those of C and X60 non-treated recipes (Table 2). No significant differences were recorded in values between C and X60 recipes treated with vinegar and C and X60 recipes treated with chitosan. Furthermore, the L* and b* values of C and X60 recipes treated with vinegar and chitosan were higher than for C and X60 recipes treated with vinegar and chitosan, while the a* values were lower in each case. These results indicated that increase in

Table 2. Changes in surface colours of Thai taro custard during storage at refrigerated temperature.

Storage time (day)	Recipe							
	C	**CV**	**CC0.01**	**CC0.05**	**X60**	**X60V**	**X60C0.01**	**X60C0.05**
L* values								
1	41.91 ± 3.78^{Cns}	42.88 ± 3.88^{BCab}	43.31 ± 2.01^{BCa}	43.76 ± 2.24^{BCb}	44.90 ± 5.56^{Ba}	47.59 ± 2.97^{Aa}	47.78 ± 4.13^{Aa}	48.60 ± 1.57^{Aa}
3	41.63 ± 2.63^{ns}	42.44 ± 2.18^{ab}	42.44 ± 2.18^{ab}	43.57 ± 3.88^{b}	41.52 ± 3.42^{bc}	42.60 ± 1.26^{b}	46.33 ± 1.10^{ab}	47.02 ± 2.92^{ab}
5	41.78 ± 1.95^{ns}	41.92 ± 2.57^{ab}	43.02 ± 1.80^{a}	43.61 ± 1.99^{b}	39.44 ± 2.96^{c}	43.01 ± 1.15^{b}	46.09 ± 2.71^{ab}	46.09 ± 1.18^{b}
7		44.12 ± 1.74^{a}	41.83 ± 0.92^{ab}	42.49 ± 2.09^{b}	39.54 ± 3.63^{c}	41.99 ± 2.40^{ab}	46.72 ± 3.33^{ab}	45.88 ± 1.04^{b}
14		43.84 ± 0.13^{a}	42.10 ± 1.37^{ab}	43.04 ± 1.39^{b}	39.87 ± 1.31^{c}	43.33 ± 2.53^{b}	46.42 ± 0.67^{ab}	47.46 ± 1.61^{ab}
21		41.51 ± 1.31^{b}	41.24 ± 3.57^{b}	42.27 ± 3.38^{b}	41.45 ± 2.22^{bc}	41.76 ± 1.08^{bc}	45.32 ± 1.72^{b}	47.23 ± 0.95^{ab}
28			42.30 ± 1.11^{ab}	42.30 ± 2.40^{b}	39.47 ± 2.93^{c}	42.15 ± 1.99^{bc}	45.85 ± 1.73^{ab}	47.76 ± 4.70^{ab}
35			41.04 ± 2.22^{b}	48.30 ± 1.86^{a}	45.65 ± 3.54^{a}	42.65 ± 2.43^{bc}	44.99 ± 1.10^{b}	48.97 ± 2.11^{a}
42					43.51 ± 2.44^{ab}	40.66 ± 1.36^{c}	46.02 ± 3.70^{ab}	47.91 ± 1.67^{ab}
49					43.26 ± 5.40^{ab}	42.97 ± 0.62^{b}	47.34 ± 1.42^{ab}	46.28 ± 0.76^{b}
a* values								
1	7.02 ± 0.96^{Cns}	10.25 ± 1.09^{Aab}	10.88 ± 0.85^{Aa}	10.47 ± 1.12^{Aa}	5.83 ± 0.88^{Dd}	8.17 ± 1.36^{Bb}	8.82 ± 1.70^{Bc}	8.24 ± 0.89^{Bc}
3	7.05 ± 1.41^{ns}	9.06 ± 1.56^{ab}	10.57 ± 1.24^{ab}	11.01 ± 1.27^{a}	8.28 ± 2.07^{a}	10.08 ± 0.91^{a}	10.50 ± 1.12^{a}	9.97 ± 0.73^{a}
5	7.65 ± 0.70^{ns}	9.18 ± 0.67^{ab}	10.11 ± 1.17^{abc}	10.22 ± 0.63^{a}	7.56 ± 1.29^{ab}	9.62 ± 0.79^{a}	9.93 ± 0.93^{ab}	9.35 ± 0.66^{ab}
7		8.50 ± 0.88^{b}	9.65 ± 0.63^{c}	10.14 ± 0.32^{a}	7.05 ± 0.21^{bc}	8.18 ± 1.10^{b}	8.23 ± 2.26^{c}	9.55 ± 0.46^{ab}
14		10.12 ± 1.08^{a}	9.90 ± 1.13^{bc}	10.57 ± 1.21^{a}	6.79 ± 0.40^{bcd}	8.35 ± 1.17^{b}	9.19 ± 0.65^{bc}	9.37 ± 1.09^{ab}
21		9.97 ± 0.65^{a}	9.54 ± 0.42^{c}	10.49 ± 0.62^{a}	6.76 ± 1.13^{bcd}	8.19 ± 0.78^{b}	8.77 ± 0.66^{c}	8.32 ± 0.73^{c}
28			10.04 ± 1.19^{bc}	8.73 ± 1.08^{b}	7.01 ± 0.89^{bc}	8.10 ± 0.81^{b}	8.43 ± 0.94^{c}	8.26 ± 1.28^{c}
35			9.65 ± 0.61^{c}	8.15 ± 1.24^{b}	6.34 ± 0.56^{cd}	8.55 ± 0.69^{b}	9.15 ± 0.51^{bc}	8.60 ± 0.98^{bc}
42					6.12 ± 1.15^{cd}	7.42 ± 0.42^{c}	8.29 ± 1.47^{c}	8.46 ± 0.52^{bc}
49					6.06 ± 1.17^{cd}	7.95 ± 0.76^{bc}	8.20 ± 1.57^{c}	8.51 ± 0.76^{bc}
b* values								
1	9.98 ± 3.50^{Db}	12.79 ± 2.05^{Bb}	13.67 ± 2.33^{Bab}	13.76 ± 2.61^{Bab}	12.56 ± 2.98^{BCa}	17.49 ± 2.42^{Aa}	18.23 ± 2.79^{Aab}	19.16 ± 1.60^{Aa}
3	9.02 ± 1.44^{b}	13.07 ± 1.45^{b}	14.36 ± 2.01^{a}	14.39 ± 1.46^{a}	12.91 ± 3.65^{a}	16.10 ± 0.70^{ab}	18.10 ± 1.71^{ab}	18.54 ± 1.85^{ab}
5	13.36 ± 1.86^{a}	13.83 ± 2.95^{ab}	13.43 ± 2.52^{ab}	14.59 ± 2.64^{a}	12.27 ± 2.42^{a}	16.73 ± 2.31^{a}	18.37 ± 2.26^{ab}	17.65 ± 0.84^{b}
7		15.56 ± 1.37^{a}	12.67 ± 0.87^{ab}	12.50 ± 0.37^{ab}	10.34 ± 0.42^{ab}	15.33 ± 0.36^{ab}	17.55 ± 1.53^{b}	17.88 ± 1.84^{ab}
14		15.18 ± 1.90^{a}	12.10 ± 1.69^{b}	13.35 ± 1.76^{ab}	12.44 ± 1.93^{a}	15.84 ± 1.11^{ab}	19.45 ± 1.62^{a}	18.05 ± 1.03^{ab}
21		15.00 ± 1.44^{a}	13.63 ± 1.88^{ab}	14.31 ± 1.77^{a}	12.52 ± 1.60^{a}	14.31 ± 1.38^{b}	17.21 ± 2.32^{b}	18.78 ± 1.74^{ab}
28			13.61 ± 1.69^{ab}	12.01 ± 1.02^{b}	10.30 ± 1.04^{ab}	14.39 ± 0.79^{b}	17.90 ± 1.05^{ab}	17.88 ± 2.23^{ab}
35			12.88 ± 2.06^{ab}	13.54 ± 1.06^{a}	12.76 ± 2.57^{a}	15.89 ± 1.70^{ab}	17.34 ± 1.58^{b}	19.01 ± 2.37^{ab}
42					10.53 ± 1.59^{ab}	16.31 ± 1.64^{ab}	16.65 ± 2.96^{b}	17.75 ± 1.29^{ab}
49					9.41 ± 1.79^{b}	16.77 ± 2.65^{a}	18.21 ± 1.37^{ab}	17.74 ± 1.60^{ab}

Control recipe (C) was treated with 0.1% vinegar (CV), 0.01% chitosan (CC0.01), and 0.05% chitosan (CC0.05). X60 recipe (X60) was treated with 0.1% vinegar (X60V), 0.01% chitosan (X60C0.01), and 0.05% chitosan (X60C0.05). ^{ns} = no significant difference in surface colours of each recipe throughout the storage days ($p > 0.05$). Uppercase superscript letters indicate significant differences in surface colours of Thai taro custard after 1 d of storage ($p < 0.05$). Lowercase superscript letters indicate significant differences in surface colours of each recipe throughout the storage days ($p < 0.05$).

L* and b* values resulted from the addition of xylitol and vinegar but not chitosan. The C-based recipes were mainly composed of sucrose (70%) that can undergo hydrolysis to glucose and fructose with heat processing, leading to Maillard reaction (Wongwiwat and Wattanachant, 2015). By contrast, the X60-based recipes consisting of 60% xylitol, a non-reducing sugar, gave no Maillard reaction. Addition of xylitol also decreased non-enzymatic browning development (Gliemmo *et al.,* 2008). This result concurs with Triyannanto and Lee (2016) who reported that duck jerky samples treated with 10% sorbitol had higher L* values than samples treated with honey and rice syrup. Meanwhile, chitosan had no effect on the L*, a*, and b* values, corresponding with the findings observed in tofu by Boonpan *et al.* (2011).

After storage at the refrigerated temperature, the L* value of the C recipe showed no significant differences across all storage times, while L* values of the other C-based recipes remained fairly stable. Interestingly, the X60 recipe showed a decrease in L* value after 3 d before subsequently increased after 35 d, while the X60V recipe showed a slight decrease in L* value throughout the storage period. However, the L* values of the X60C0.01 and X60C0.05 recipes remained stable during the storage period, indicating that chitosan improved the stability of the L* value in the X60-based recipes. This result is consistent with Hernández-Muñoz *et al.* (2008) who reported that chitosan reduced L* value changes in strawberries during refrigerated storage.

The C recipe showed no significant differences in a* value, while the a* value of the CV recipe remained fairly constant (8.50 - 10.25). The a* values of CC0.01 and CC0.05 reduced, with ranges of 9.54 - 10.88 and 8.15 - 11.01, respectively. This result implied that chitosan reduced the a* value during storage. A similar trend was reported by Chaparro-Hernandez *et al.* (2015) who observed tilapia fillet immersed in 2% chitosan. Meanwhile, the X60-based recipes showed a different a* value trend, with their a* values significantly increasing after 3 d before subsequently decreasing.

The b* values of the C and CV recipes increased throughout the storage period, while there were no clear changes in the other recipes. These results correspond with Zhelyazkov *et al.* (2014) who reported that a chitosan coating maintained the b* value of fresh-cut apple cubes.

Texture analysis

The initial hardness of the X60-based recipes (2.12 - 2.47 N) was higher than that of the C-based recipes (1.71 - 1.79 N; Table 3), with the X60C0.05 recipe showing the highest hardness value. This result implied that xylitol and chitosan at high concentration level (0.05%) increased the hardness of Thai taro custard. Here, xylitol increased the hardness of Thai taro custard because of its humectant property. This finding concurs with Sangale and Datta (2014) who noted that increase in tablet hardness was caused by diffusion of xylitol in the tablets. Furthermore, Boonpan *et al.* (2011) reported increased hardness in tofu with a high level of chitosan as a result of its cationic nature. After soybean protein was denatured through heat treatment, the denatured protein became anionic and bound with the cationic chitosan. This led to coagulation and possessed a neutral charge. Afterward, the neutrally charged molecules bonded with each other through hydrophobic interaction and, consequently, formed a network. Similarly, Thai taro custard samples consisted of approximately 38.86% of egg. The protein in the egg was denatured and coagulated during baking leading to an increase in hardness. During storage at refrigerated temperature, increase in hardness in the C and CV recipes was observed after 3 to 5 d, while hardness values of the CC0.01 and CC0.05 recipes slightly decreased during the first 7 d before subsequently increasing at day 14, indicating that chitosan retarded starch retrogradation of Thai taro custard due to interruption in the starch network. This result concurs with Klinmalai *et al.* (2017) who reported that chitosan retarded increase in hardness of rice flour gel during storage at 30°C for 5 d. The hardness of the X60 recipe significantly increased after 14 d of storage. Surprisingly, the X60V, X60C0.01, and X60C0.05 recipes decreased in hardness after 3 to 5 d, and subsequently, increased after 14 d, suggesting that combination of xylitol and vinegar or chitosan resulted in a decrease in hardness during the first period of storage. Klinmalai *et al.* (2017) reported that acetic acid decreased the hardness of cooked rice because the acid promoted water adsorption of amylopectin by rice starch granules and dissolved proteins at the rice starch granular surface.

The adhesiveness of the X60 recipes treated with vinegar and chitosan was significantly lower than that of the X60 recipe (Table 3). A decrease in adhesiveness was observed in the C recipe after 3 to 5 d of storage, while that of the CV, CC0.01, and CC0.05 recipes slowly decreased after 14 to 21 d. Similarly, adhesiveness of the X60 and X60V recipes significantly decreased after 7 and 14 d, respectively, while the X60C0.01 and X60C0.05 recipes exhibited a slower decline in adhesiveness. This result suggested that chitosan retarded decrease in adhesiveness in the X60-based recipes.

Table 3. Changes in textures of Thai taro custard during storage at refrigerated temperature.

Storage time (day)	Recipe							
	C	CV	CC0.01	CC0.05	X60	X60V	X60C0.01	X60C0.05
Hardness (N)								
1	1.71 ± 0.06^{Db}	1.78 ± 0.01^{CDc}	1.79 ± 0.10^{CDc}	1.79 ± 0.12^{Cc}	2.12 ± 0.14^{Bb}	2.15 ± 0.27^{Bd}	2.12 ± 0.29^{Bb}	2.47 ± 0.06^{Ab}
3	1.71 ± 0.23^{b}	1.84 ± 0.07^{b}	1.67 ± 0.09^{cd}	1.78 ± 0.20^{cd}	1.87 ± 0.09^{b}	2.11 ± 0.10^{d}	2.32 ± 0.24^{b}	1.70 ± 0.24^{c}
5	2.49 ± 0.18^{a}	1.87 ± 0.11^{b}	1.67 ± 0.06^{cd}	1.54 ± 0.05^{d}	1.99 ± 0.07^{b}	1.56 ± 0.04^{e}	1.53 ± 0.04^{c}	1.56 ± 0.19^{c}
7		1.81 ± 0.34^{b}	1.58 ± 0.04^{d}	1.62 ± 0.04^{d}	1.94 ± 0.04^{b}	1.75 ± 0.18^{e}	1.71 ± 0.11^{c}	1.66 ± 0.10^{c}
14		2.87 ± 0.20^{a}	2.14 ± 0.05^{b}	2.90 ± 0.05^{b}	2.88 ± 0.15^{a}	2.58 ± 0.14^{c}	2.78 ± 0.11^{a}	3.20 ± 0.04^{a}
21		2.97 ± 0.30^{a}	2.01 ± 0.13^{b}	2.74 ± 0.15^{b}	2.79 ± 0.14^{a}	2.49 ± 0.11^{c}	2.22 ± 0.06^{a}	2.92 ± 0.15^{a}
28			2.66 ± 0.17^{a}	3.62 ± 0.23^{a}	2.92 ± 0.03^{a}	2.50 ± 0.12^{c}	2.84 ± 0.10^{a}	2.98 ± 0.22^{a}
35			2.50 ± 0.18^{a}	3.88 ± 0.35^{a}	2.76 ± 0.07^{a}	2.89 ± 0.17^{b}	2.78 ± 0.10^{a}	3.13 ± 0.20^{a}
42					2.87 ± 0.07^{a}	2.98 ± 0.30^{b}	2.92 ± 0.09^{a}	3.11 ± 0.50^{a}
49					3.05 ± 0.44^{a}	3.15 ± 0.07^{a}	2.82 ± 0.16^{a}	3.05 ± 0.32^{a}
Adhesiveness (N·mm)								
1	-4.08 ± 0.48^{Aa}	-4.15 ± 1.61^{Aa}	-4.13 ± 0.97^{Aa}	-5.26 ± 0.53^{ABa}	-4.31 ± 0.90^{Aa}	-5.68 ± 1.44^{Ba}	-5.52 ± 1.14^{Bab}	-5.95 ± 0.24^{Bab}
3	-5.52 ± 1.47^{b}	-4.47 ± 0.71^{a}	-4.30 ± 1.41^{a}	-5.60 ± 0.77^{a}	-4.51 ± 0.72^{a}	-5.81 ± 0.36^{a}	-5.06 ± 0.58^{ab}	-5.87 ± 0.55^{ab}
5	-8.03 ± 0.92^{c}	-4.98 ± 0.98^{a}	-4.95 ± 0.90^{a}	-4.79 ± 0.80^{a}	-4.28 ± 0.67^{a}	-5.61 ± 0.16^{a}	-4.19 ± 0.16^{ab}	-4.20 ± 0.08^{a}
7		-3.55 ± 1.00^{a}	-4.73 ± 1.11^{a}	-5.28 ± 0.22^{a}	-6.14 ± 0.47^{b}	-5.30 ± 0.33^{a}	-4.70 ± 0.14^{ab}	-4.39 ± 0.30^{a}
14		-8.31 ± 1.25^{b}	-5.31 ± 0.64^{a}	-10.36 ± 0.86^{b}	-7.95 ± 0.55^{c}	-7.84 ± 0.96^{b}	-6.10 ± 0.47^{b}	-5.88 ± 1.38^{ab}
21		-7.59 ± 1.25^{b}	-7.23 ± 1.15^{b}	-10.89 ± 0.56^{b}	-7.84 ± 0.44^{c}	-8.07 ± 0.13^{b}	-5.95 ± 0.47^{b}	-6.64 ± 0.25^{bc}
28			-7.38 ± 1.39^{b}	-13.91 ± 1.49^{c}	-8.99 ± 1.59^{cd}	-7.99 ± 1.22^{b}	-9.04 ± 0.97^{c}	-7.53 ± 1.90^{bc}
35			-8.85 ± 0.93^{c}	-13.46 ± 1.49^{c}	-9.09 ± 1.07^{cd}	-8.89 ± 0.67^{b}	-8.23 ± 1.17^{c}	-7.68 ± 1.43^{bc}
42					-8.24 ± 1.24^{cd}	-9.20 ± 0.63^{b}	-8.21 ± 0.94^{c}	-7.03 ± 0.73^{bc}
49					-9.51 ± 0.35^{d}	-9.59 ± 0.61^{b}	-8.40 ± 2.40^{c}	-8.56 ± 1.57^{c}

Control recipe (C) was treated with 0.1% vinegar (CV), 0.01% chitosan (CC0.01), and 0.05% chitosan (CC0.05). X60 recipe (X60) was treated with 0.1% vinegar (X60V), 0.01% chitosan (X60C0.01), and 0.05% chitosan (X60C0.05). Uppercase superscript letters indicate significant differences in texture of Thai taro custard after 1 d of storage ($p < 0.05$). Lowercase superscript letters indicate significant differences in texture of each recipe throughout the storage days ($p < 0.05$).

Table 4. Changes in sensory qualities of Thai taro custard during storage at refrigerated temperature.

Storage time (day)	Recipe							
	C	CV	CC0.01	CC0.05	X60	X60V	X60C0.01	X60C0.05
Colour								
1	7.15 ± 1.29^{ABa}	7.51 ± 1.17^{Aa}	7.23 ± 1.58^{ABa}	7.08 ± 1.58^{Aa}	7.31 ± 1.32^{Aa}	7.38 ± 1.28^{Aa}	7.18 ± 1.32^{Aa}	6.63 ± 1.70^{ABab}
3	6.31 ± 1.14^{b}	6.95 ± 1.18^{a}	6.90 ± 1.33^{ab}	6.84 ± 1.07^{ab}	6.58 ± 0.90^{ab}	7.11 ± 1.10^{a}	7.21 ± 1.18^{a}	6.94 ± 1.14^{a}
5	5.10 ± 1.29^{c}	6.00 ± 0.72^{b}	6.40 ± 1.64^{abc}	6.06 ± 0.57^{b}	5.45 ± 1.15^{c}	7.25 ± 1.02^{a}	6.35 ± 1.39^{a}	6.06 ± 1.03^{abc}
7		6.10 ± 1.17^{b}	6.00 ± 1.19^{bcd}	6.05 ± 1.85^{b}	5.70 ± 1.17^{bc}	7.00 ± 1.49^{a}	6.20 ± 1.36^{abc}	6.25 ± 0.87^{abc}
14		6.00 ± 1.08^{b}	5.30 ± 2.70^{cd}	6.12 ± 1.58^{ab}	5.00 ± 1.37^{c}	5.16 ± 1.37^{c}	6.25 ± 1.07^{abc}	6.25 ± 0.55^{abc}
21		5.01 ± 1.70^{c}	5.60 ± 1.57^{cd}	6.71 ± 1.11^{ab}	5.20 ± 1.62^{c}	5.42 ± 1.17^{b}	6.30 ± 1.42^{ab}	6.45 ± 1.64^{ab}
28			5.00 ± 0.86^{d}	6.47 ± 1.02^{ab}	5.11 ± 1.12^{c}	5.15 ± 1.14^{c}	5.30 ± 1.95^{bc}	5.65 ± 1.93^{bcd}
35			5.55 ± 0.61^{cd}	6.89 ± 1.03^{ab}	5.95 ± 1.19^{bc}	5.30 ± 0.66^{b}	5.28 ± 1.82^{bc}	5.65 ± 1.66^{bcd}
42					5.95 ± 0.85^{bc}	5.94 ± 0.57^{b}	5.25 ± 1.86^{c}	5.35 ± 1.79^{cd}
49					5.93 ± 1.03^{bc}	5.89 ± 0.93^{b}	5.01 ± 1.80^{c}	5.01 ± 0.90^{d}
Flavour								
1	6.97 ± 1.14^{NSa}	6.95 ± 1.32^{NSa}	6.85 ± 1.46^{NSa}	6.79 ± 1.30^{NSns}	6.82 ± 1.28^{NSa}	7.08 ± 1.20^{NSa}	7.13 ± 1.24^{NSa}	7.13 ± 1.30^{NSa}
3	6.05 ± 1.23^{b}	6.40 ± 1.54^{ab}	6.00 ± 1.69^{a}	6.18 ± 0.95^{ns}	5.25 ± 2.00^{bc}	6.25 ± 1.29^{bcd}	6.25 ± 1.16^{abc}	6.10 ± 1.33^{c}
5	3.99 ± 0.69^{c}	6.00 ± 0.89^{b}	6.45 ± 1.28^{a}	6.11 ± 0.60^{ns}	5.90 ± 0.72^{b}	6.50 ± 0.95^{abc}	6.30 ± 0.80^{abc}	6.00 ± 0.75^{c}
7		6.15 ± 1.04^{ab}	6.90 ± 1.62^{a}	6.25 ± 1.36^{ns}	5.80 ± 1.08^{bc}	7.00 ± 0.97^{a}	6.05 ± 1.32^{bc}	6.15 ± 0.88^{ab}
14		6.45 ± 0.83^{ab}	6.90 ± 0.97^{a}	6.00 ± 0.82^{ns}	5.07 ± 0.88^{bc}	6.11 ± 1.13^{cd}	6.00 ± 1.39^{bc}	6.00 ± 0.86^{c}
21		3.95 ± 1.61^{c}	5.01 ± 1.38^{b}	6.45 ± 0.83^{ns}	5.80 ± 1.01^{bc}	6.85 ± 1.18^{ab}	6.65 ± 1.09^{ab}	6.80 ± 1.06^{abc}
28			5.07 ± 1.68^{b}	6.44 ± 0.98^{ns}	5.00 ± 1.17^{c}	5.20 ± 1.20^{f}	5.50 ± 1.40^{cd}	6.20 ± 1.64^{bc}
35			5.00 ± 0.96^{b}	5.95 ± 1.47^{ns}	5.80 ± 1.24^{bc}	5.70 ± 0.47^{def}	6.80 ± 1.24^{ab}	6.89 ± 1.32^{abc}
42					5.94 ± 0.66^{b}	5.95 ± 1.10^{cde}	5.00 ± 1.59^{d}	7.00 ± 0.71^{ab}
49					5.92 ± 0.76^{b}	5.35 ± 0.67^{f}	5.00 ± 0.73^{d}	6.15 ± 1.31^{bc}
Taste								
1	7.13 ± 1.32^{NSa}	7.55 ± 1.06^{NSa}	7.51 ± 1.21^{NSa}	7.11 ± 1.50^{NSa}	7.23 ± 1.18^{NSa}	7.56 ± 1.23^{NSa}	7.39 ± 1.20^{NSa}	6.95 ± 1.58^{NSns}
3	6.12 ± 1.22^{a}	6.77 ± 1.20^{ab}	6.79 ± 1.20^{ab}	6.20 ± 1.24^{ab}	5.75 ± 1.59^{b}	6.74 ± 1.10^{ab}	6.35 ± 1.14^{ab}	6.11 ± 1.49^{ns}
5	5.05 ± 1.05^{c}	6.10 ± 0.32^{b}	6.35 ± 1.35^{bcd}	6.08 ± 0.68^{b}	5.90 ± 0.79^{b}	5.65 ± 0.88^{bc}	6.11 ± 0.78^{bc}	6.14 ± 0.69^{ns}
7		6.00 ± 1.52^{b}	6.50 ± 0.76^{bc}	6.70 ± 1.03^{ab}	5.79 ± 1.12^{b}	5.75 ± 0.50^{bc}	6.40 ± 1.14^{ab}	6.35 ± 1.42^{ns}
14		5.75 ± 2.07^{b}	6.40 ± 0.68^{bcd}	6.08 ± 0.29^{b}	5.30 ± 1.34^{b}	5.45 ± 1.57^{c}	6.00 ± 0.82^{bcd}	6.25 ± 1.21^{ns}
21		5.00 ± 2.00^{c}	5.75 ± 1.33^{cde}	6.95 ± 1.40^{ab}	5.94 ± 1.03^{b}	5.71 ± 1.80^{bc}	6.43 ± 0.79^{ab}	6.25 ± 1.03^{ns}
28			5.40 ± 1.57^{e}	6.55 ± 1.47^{ab}	5.45 ± 1.32^{b}	5.65 ± 1.46^{bc}	6.45 ± 1.28^{ab}	6.40 ± 2.14^{ns}
35			5.60 ± 1.10^{de}	6.93 ± 0.62^{ab}	5.94 ± 0.80^{b}	5.10 ± 1.12^{c}	6.40 ± 1.76^{ab}	6.10 ± 1.77^{ns}
42					6.00 ± 0.74^{b}	6.00 ± 1.00^{bc}	5.10 ± 1.12^{cd}	6.45 ± 2.26^{ns}
49					6.00 ± 0.63^{b}	5.50 ± 0.83^{c}	5.00 ± 1.08^{d}	6.21 ± 1.54^{ns}
Texture								
1	6.97 ± 0.98^{NSa}	7.48 ± 1.20^{NSa}	7.46 ± 1.32^{NSa}	7.08 ± 1.40^{NSa}	7.03 ± 1.28^{NSa}	7.23 ± 1.22^{NSa}	7.38 ± 1.33^{NSa}	7.03 ± 1.46^{NSns}
3	6.00 ± 1.38^{b}	6.47 ± 1.47^{b}	6.65 ± 1.14^{bc}	5.80 ± 1.64^{b}	5.65 ± 1.50^{b}	6.53 ± 1.22^{bc}	6.35 ± 1.14^{bc}	6.05 ± 1.40^{ns}
5	5.20 ± 0.70^{c}	6.00 ± 0.75^{b}	6.55 ± 1.00^{bc}	5.40 ± 0.68^{b}	5.50 ± 0.95^{b}	6.05 ± 1.05^{bc}	6.20 ± 0.89^{bc}	6.06 ± 0.94^{ns}
7		6.45 ± 1.19^{b}	6.83 ± 0.94^{ab}	5.89 ± 0.33^{b}	5.70 ± 1.53^{b}	6.85 ± 0.81^{a}	6.35 ± 1.39^{bc}	6.30 ± 1.34^{ns}
14		6.25 ± 0.64^{b}	6.93 ± 0.59^{ab}	5.40 ± 0.88^{b}	5.35 ± 1.09^{b}	5.40 ± 1.50^{cd}	6.00 ± 0.54^{c}	6.00 ± 1.50^{ns}
21		5.00 ± 1.56^{c}	5.90 ± 1.12^{cd}	5.91 ± 1.04^{b}	5.89 ± 0.96^{b}	5.89 ± 0.60^{bcd}	6.85 ± 1.35^{abc}	7.00 ± 1.34^{ns}
28			5.15 ± 1.46^{d}	5.88 ± 0.86^{b}	5.70 ± 1.13^{b}	5.45 ± 1.57^{d}	6.25 ± 1.33^{ab}	6.90 ± 1.62^{ns}
35			5.20 ± 1.11^{d}	6.00 ± 0.97^{b}	5.85 ± 0.99^{b}	5.10 ± 1.12^{d}	6.90 ± 0.72^{ab}	6.94 ± 1.00^{ns}

42					5.95 ± 1.22^{b}	6.00 ± 0.77^{bc}	5.23 ± 1.14^{d}	7.00 ± 0.78^{ns}
49					6.00 ± 0.71^{b}	5.25 ± 0.55^{cd}	5.15 ± 1.04^{d}	6.65 ± 1.27^{ns}
Overall acceptability								
1	7.70 ± 0.81^{NSa}	7.68 ± 1.02^{NSa}	7.41 ± 1.43^{NSa}	7.43 ± 1.36^{NSa}	7.50 ± 1.32^{NSa}	7.79 ± 1.03^{NSa}	7.48 ± 1.47^{NSa}	7.25 ± 1.75^{NSa}
3	6.10 ± 1.21^{b}	6.95 ± 1.43^{b}	6.90 ± 0.85^{a}	6.55 ± 1.00^{bc}	5.95 ± 1.32^{b}	6.79 ± 1.03^{b}	6.70 ± 1.08^{bc}	6.55 ± 1.32^{b}
5	4.85 ± 0.75^{c}	6.00 ± 0.50^{c}	6.75 ± 1.30^{ab}	6.10 ± 0.72^{c}	5.75 ± 1.02^{bc}	6.25 ± 1.02^{bc}	6.12 ± 0.86^{c}	6.00 ± 0.94^{b}
7		6.00 ± 0.80^{c}	7.00 ± 0.78^{a}	6.75 ± 0.85^{abc}	5.95 ± 1.18^{b}	6.93 ± 1.10^{b}	6.40 ± 0.88^{bc}	6.15 ± 1.18^{b}
14		6.15 ± 0.75^{c}	7.00 ± 0.39^{a}	6.00 ± 0.92^{c}	5.05 ± 1.00^{c}	5.70 ± 1.26^{cd}	6.25 ± 1.16^{bc}	6.10 ± 1.45^{b}
21		4.75 ± 1.30^{d}	6.00 ± 1.08^{bc}	6.70 ± 1.03^{bc}	6.00 ± 0.91^{b}	5.88 ± 1.25^{c}	7.00 ± 0.54^{ab}	7.00 ± 1.10^{ab}
28			5.30 ± 1.42^{c}	6.55 ± 1.36^{bc}	5.25 ± 1.45^{bc}	5.45 ± 1.23^{cd}	6.35 ± 1.42^{bc}	6.80 ± 1.40^{ab}
35			5.40 ± 1.23^{c}	6.90 ± 1.05^{ab}	5.95 ± 0.91^{b}	5.05 ± 1.32^{d}	6.55 ± 1.19^{bc}	6.70 ± 1.34^{ab}
42					6.00 ± 0.85^{b}	5.94 ± 0.68^{c}	5.05 ± 0.51^{d}	6.94 ± 0.77^{ab}
49					6.00 ± 0.63^{b}	5.60 ± 0.60^{cd}	5.10 ± 0.55^{d}	6.00 ± 1.08^{b}

Control recipe (C) was treated with 0.1% vinegar (CV), 0.01% chitosan (CC0.01), and 0.05% chitosan (CC0.05). X60 recipe (X60) was treated with 0.1% vinegar (X60V), 0.01% chitosan (X60C0.01), and 0.05% chitosan (X60C0.05). ^{NS} = no significant difference in sensory scores of Thai taro custard after 1 day of storage ($p > 0.05$). ^{ns} = no significant difference in sensory scores of each recipe throughout the storage days ($p > 0.05$). Uppercase superscript letters indicate significant differences in sensory scores of Thai taro custard after 1 d of storage ($p < 0.05$). Lowercase superscript letters indicate significant differences in sensory scores of each recipe throughout the storage days ($p < 0.05$).

Sensory analysis

Sensory evaluation is frequently applied to estimate the quality of Thai taro custard and correlates with microbiological activities. Results revealed no significant differences in flavour, taste, texture, and overall acceptability between all recipes after 1 d of storage (Table 4). Rapid reduction in the colour scores of C recipes without chitosan was due to the Maillard reaction in the product, whereas slight decreases in colour scores were observed in the C and X60 recipes treated with chitosan. These results supported the roles of xylitol and chitosan as delaying the colour change of the product (Gliemmo *et al.,* 2008; Zhelyazkov *et al.,* 2014). A decline in the flavour scores was noticed and related to spoilage in C and CV recipes after 5 and 21 d, respectively, together with an off-odour. The X60 recipe had a lower flavour score than 6.00 after 3 d, with loss of natural fragrance from reducing the amount of coconut palm sugar. However, the X60-based recipes were acceptable throughout the storage time. Taste scores for all recipes followed a similar trend to the flavour scores, except for the X60C0.05 recipe that showed no significant difference in taste score. Results of overall acceptability indicated that the panellists rejected the C and CV recipes on days 5 and 21, whereas the C recipes treated with chitosan (CC0.01 and CC0.05) and X60-based recipes gained acceptance throughout the 35 and 49 d, respectively. Our findings suggested that X60C0.05 was the optimal recipe with superior sensory qualities.

Conclusions

Xylitol played an important role in reducing a_w value and total plate count. High concentration of chitosan had a positive impact on L* and b* values, adhesiveness, and sensory quality, while X60-based recipes had a longer shelf-life than C-based recipes. The X60C0.05 recipe gave excellent results in terms of quality characteristics, microbiological, and panellist acceptance after storage at refrigerated temperature for 49 d.

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References

Assis, O. B. G. and Pessoa, J. D. C. 2004. Preparation of thin films of chitosan for use as edible coatings to inhibit fungal growth on sliced fruits. Brazilian Journal of Food Technology 7(1): 17-22.

Attala, O. A. 2012. Impact of using organic acids and sodium sulfite on the quality of unpeeled shrimp. World Journal of Fish and Marine Sciences 4(3): 284-289.

Barbosa, I. C., Stamford, T. C. M., Berger, L. R. R., Melo, N. F. C., Pintado, M. and Stamford, T. L. M. 2015. Potential of chitosan as an Acerola (*Malphighia glabra* L.) juice natural preservative. International Journal of Current Microbiology and Applied Sciences 4(8): 929-942.

Boonpan, A., Pongswat, S., Pongthai, P. and Saijai, S. 2011. The effect of chitosan on quality and extension of shelf life of tofu. Science and Technology RMUTT Journal 1(1): 45-57.

Cauvain, S. P. and Cyster, J. 1996. Sponge cake technology. United Kingdom: Campden and Chorleywood Food Research Association (CCFRA).

Changsawake, K., Krusong, W., Laosinwattana, C. and Teerarak, M. 2015. Use of ambient upland rice fermented vinegar vapor to extend shelf life of sweet basil (*Ocimun basilicum* Linn.). International Journal of Agricultural Technology 11(8): 2249-2256.

Chaparro-Hernandez, S., Ruiz-Cruz, S., Marquez-Rios, E., Ocano-Higuera, V. M., Valenzuela-Lopez, C. C., Ornelas-Paz, J. J. and Del-Toro-Sanchez, C. L. 2015. Effect of chitosan-carvacrol edible coating on the quality and shelf of tilapia (*Oreochromis niloticus*) fillets stored in ice. Food Science and Technology 35(4): 734-741.

Desai, M. A., Kurve, V., Smith, B. S., Campano, S. G., Soni, K. and Schilling, M. W. 2014. Utilization of buffered vinegar to increase the shelf life of chicken retail cuts packaged in carbon dioxide. Poultry Science 93(7): 1850-1854.

Dias, F. S., Ramos, C. L. and Schwan, R. F. 2013. Characterization of spoilage bacteria in pork sausage by PCR-DGGE analysis. Food Science and Technology 33(3): 468-474.

Ghosh, S. and Sudha, M. L. 2012. A review on polyols: new frontiers for health-based bakery product. International Journal of Food Sciences and Nutrition 63(3): 372-379.

Gliemmo, M. F., Calviño, A. M., Tamasi, O., Gerschenson, L. N. and Campos, C. A. 2008. Interactions between aspartame, glucose and xylitol in aqueous systems containing potassium sorbate. LWT - Food Science and Technology 41(4): 611-619.

Gliemmo, M. F., Campos, C. A. and Gerschenson, L. N. 2004. Effect of sweet humectants on stability and antimicrobial action of sorbates. Journal of Food Science 69(2): FMS39-FMS44.

Hernández-Muñoz, P., Almenar, E., Valle, V. D., Velez, D. and Gavara, R. 2008. Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria* × *ananassa*) quality during refrigerated storage. Food Chemistry 110(2): 428-435.

Jamilah, M. B., Abbas, K. A. and Abdul Rahman, R. 2008. A review on some organic acids additives as shelf life extenders of fresh beef cuts. American Journal of Agricultural and Biological Sciences 3(3): 566-574.

Jang, S.-J., Kim, H.-W., Hwang, K.-E., Song, D.-H., Kim, Y.-J., Ham, Y.-K., ... and Kim, C.-J. 2015. Effects of replacing sucrose with various sugar alcohols on quality properties of semi-dried jerky. Korean Journal for Food Science of Animal Resources 35(5): 622-629.

Jariyawaranugoon, U. and Akesowan, A. 2010. Effect of thyme and lemongrass extracts on quality characteristics of Thai coconut cream custard dips during storage. Journal of Applied Sciences Research 6(11): 1596-1602.

Kanto, P. 2002. Shelf life extension of Kha Nom Pia (Chinese cake) by using humectant and packaging. Thailand: Kasetsart University, MSc thesis.

Keener, K. M., Bashor, M. P., Curtis, P. A., Sheldon, B. W. and Kathariou, S. 2004. Comprehensive review of *Campylobacter* and poultry processing. Comprehensive Reviews in Food Science and Food Safety 3(2): 105-116.

Klinmalai, P., Hagiwara, T., Sakiyama, T. and Ratanasumawong, S. 2017. Chitosan effects on physical properties, texture, and microstructure of flat rice noodles. LWT - Food Science and Technology 76(Part A): 117-123.

Ko, J. S. 2006. Food processing. Korea: Yuhan Munhwasa.

Lee, J.-W., Lee, H.-H. and Rhim, J.-W. 2000. Shelf life extension of white rice cake and wet noodle by the treatment with chitosan. Korean Journal of Food Science and Technology 32(4): 828-833.

Leistner, L. 1985. Hurdle technology applied to meat products of the shelf stable product and intermediated moisture food types. In Simatos, D. and Multon, J. L. (eds). Properties of Water in Foods, p. 309-329. Netherlands: Springer.

Li, M., Zhu, K., Guo, X., Peng, W. and Zhou, H. 2011. Effect of water activity (a*w*) and irradiation on shelf-life of fresh noodles. Innovative Food Science and Emerging Technologies 12(4): 526-530.

Maltini, E., Torreggiani, D., Venir, E. and Bertolol, G. 2003. Water activity and the preservation of plant foods. Food Chemistry 82(1): 79-86.

Martín-Diana, A. B., Rico, D., Barat, J. M. and Barry-Ryan, C. 2009. Orange juices enriched with chitosan: optimisation for extending the shelf-life. Innovative Food Science and Emerging Technologies 10(4): 590-600.

Mitić-Ćulafić, D. S., Pavlović, M., Ostojić, S. and

Knezević-Vukčević, J. 2014. Antimicrobial effect of natural food preservatives in fresh basil-based *pesto* spreads. Journal of Food Processing and Preservation 38(3): 1298-1306.

Mohd Thani, N., Mustapa Kamal, S. M., Taip, F. S. and Awang Biak, D. R. 2016. Evaluation on safety and sensory analysis of xylitol substituted *dadih*. International Food Research Journal 23(Suppl): S203-S208.

No, H. K., Meyers, S. P., Prinyawiwatkul, W. and Xu, Z. 2007. Application of chitosan for improvement of quality and shelf life of foods: a review. Journal of Food Science 72(5): R87-R100.

Nychas, G.-J. E., Skandamis, P. N., Tassou, C. C. and Koutsoumanis, K. P. 2008. Meat spoilage during distribution. Meat Science 78(1-2): 77-89.

Roller, S. and Covill, N. 2000. The antimicrobial properties of chitosan in mayonnaise and mayonnaise-based shrimp salads. Journal of Food Protection 63(2): 202-209.

Sangale, P. B. and Datta, S. 2014. Phase transition method: a novel technique for mouth dissolving tablet. International Journal of PharmTech Research 6(3): 969-981.

Sangsuwan, J., Rattanapanone, N. and Pongsirikul, I. 2015. Development of active chitosan films incorporating potassium sorbate or vanillin to extend the shelf life of butter cake. International Journal of Food Science and Technology 50(2): 323-330.

Sohaib, M., Anjum, F. M., Arshad, M. S. and Rahman, U. U. 2016. Postharvest intervention technologies for safety enhancement of meat and meat based products; a critical review. Journal of Food Science and Technology 53(1): 19-30.

Solieri, L. and Giudici, P. 2009. Vinegars of the world. Italy: Springer-Verlag Mailand.

Sorapukdee, S., Uesakulrungrueng, C. and Pilasombut, K. 2016. Effects of humectant and roasting on physicochemical and sensory properties of jerky made from spent hen meat. Korean Society for Food Science of Animal Resources 36(3): 326-334.

Tapiainen, T., Kontiokari, T., Sammalkivi, L., Ikaheimo, I., Koskela, M. and Uhari, M. 2001. Effect of xylitol on growth of *Streptococcus pneumonia* in the presence of fructose and sorbitol. Antimicrobial Agents and Chemotherapy 45(1): 166-169.

Triyannanto, E. and Lee, K. T. 2016. Evaluation of honey and rice syrup as replacements for sorbitol in the production of restructured duck jerky. Asian-Australasian Journal of Animal Sciences 29(2): 271-279.

Wang, F. S. 2000. Effects of three preservative agents on the shelf life of vacuum packaged Chinese-style sausage stored at 20°C. Meat Science 56(1): 67-71.

Wongwiwat, P. and Wattanachant, S. 2015. Color characteristics and Maillard reactions of chicken meat jerky with different sweeteners during storage. Walailak Journal of Science and Technology 13(3): 141-155.

Zhelyazkov, S., Zsivanovits, G., Brashlyanova, B. and Marudova-Zsivanovits, M. 2014. Shelf-life extension of fresh-cut apple cubes with chitosan coating. Bulgarian Journal of Agricultural Science 20(3): 536-540.