Effect of storage and frying times on stability of acrylamide and 5-hydroxymethylfurfural in fresh and frozen curry puff skins

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Abstract. Acrylamide and 5-hydroxymethylfurfural (HMF) are potential compounds that are known to be neurotoxic, mutagenic, and carcinogenic when exposed to humans. These components are formed during Maillard reaction at which sugar is reduced and specific amino acids react at high temperature, and thus producing brown colour and flavour in food. Therefore, the aim of this study was to observe the formation level of acrylamide and HMF in fresh and frozen curry puff skins. This study investigated the effects of frozen storage and frying times on the formation of acrylamide and HMF in curry puff skin. Frozen curry puff skins were stored at -18°C for 0, 7, 14, and 28 days. The curry puff skins were fried at 180 °C for 2, 3, 5, and 7 min. Before that, the frozen curry puff skins were thawed at room temperature for 2 h. The changes in colour, moisture, and texture were measured as indicators to Maillard reaction. Frozen curry puff skins reduced the level of acrylamide and HMF to 70 % and 50 %, respectively after 28 days of storage. The colour development of frozen curry puff skins demonstrated less vividness as the storage time increased as compared to fresh curry puff skins. The fresh and frozen curry puff skins exhibited similar firmness and texture profile with no significant differences during the 4 weeks of storage.

Keywords: Acrylamide, Hydroxymethylfurfural (HMF), Maillard reaction, Frozen storage, Non-enzymatic browning

INTRODUCTION

Curry puff is a popular tea time snack in Southeast Asia (Leong-Salobir, 2019). Due to the changes in lifestyle, consumer prefers convenient food for on the go consumption rather than preparing everything from scratch. Preference to pastry consumption like curry puff has also been increasing, and thus creates the interest for food manufacturers to produce ready-made frozen

curry puff product. Frozen technology provides several advantages, namely prolonging the food shelf life and facilitating transportation. Curry puff is consumed after deep frying and spoils easily due to its soft texture during storage and thawing (Hussain *et al.*, 2018). Kaewthong *et al.* (2019) reported that fluctuations of temperature may reduce its shelf life and affect the product

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quality. The fluctuations of temperature during freezing storage will cause re-crystallisation, destroy gluten structure, accumulate moisture and sugar, and decrease the quality of pastry dough that contributes to the level of reducing sugar and amino acids and directly influences acrylamide and HMF formation rate (Naito *et al.*, 2004; Olsson *et al.*, 2004; Deep *et al.*, 2008).

Extreme temperature ($>170^{\circ}\text{C}$) is commonly used for thermal processing, such as frying process to achieve the requirements of food production (Friedman, 2003; Koszucka and Nowack, 2019). During heating at high temperature, a specific chemical reaction known as Maillard reaction or non-enzymatic browning is responsible for the development of food colour and flavour (Parisi and Luo, 2018). The reaction occurs when sugar reduce reacts with amino acids, especially in foods that have a high amount of carbohydrates. However, Maillard reaction is also the precursor to the development of harmful products such as acrylamide and 5-hydroxymethylfurfural (HMF) (Nguyen and Boekel, 2017). Besides, Maillard reaction alters the flavour and functionality of food. In addition, other indicators to Maillard reaction are changes in water activity, moisture content, and slight modification in texture (Zhao *et al.*, 2013).

Semla *et al.* (2016) reported that acrylamide is a very reactive compound that has mutagenic and carcinogenic properties. Acrylamide may pose dire risks, such as cancers and neurological damages if exposed to a high level (Ciesarová *et al.*, 2009). In contrast, many research opposed to this idea, as low concentration of acrylamide in food may not be harmful to consumers. However, repetitive and long-term exposures to acrylamide are suspected to cause adverse health problems, which have raised concern among food researchers in the present days (Meulenaer *et al.*, 2016). Similarly, HMF in food has raised concerns among researchers, as this compound is also identified as a possible carcinogenic (Miao *et al.*, 2013). The discovery of acrylamide and HMF in food urged the researchers to investigate various factors involved in the formation process, including frying times (Gokmen *et al.*, 2006). The Commission Regulation (EU) established the benchmark level of acrylamide and HMF in flour-based product with 350 $\mu\text{g}/\text{kg}$ and 40 mg/kg , respectively. Therefore, the work aimed to

observe the formation of acrylamide and HMF in curry puff skins. Fresh and frozen curry puffs were used to measure the acrylamide and HMF formations at different frying times and temperatures. Physicochemical properties such as colour, texture, moisture content, and water activity were also determined as indicators that contribute to Maillard reaction.

MATERIALS AND METHODS

Curry puff skins preparation and frying conditions

The curry puff skin dough was prepared according to the formulation stated in Table 1 below, where the dough was made of wheat flour (59.74 %), water (21.51 %), oil (14.93 %), butter (3.58 %), and salt (0.24 %). The ingredients were mixed at room temperature for 5 min in a lab-scale stand mixer. Next, the dough was allowed to leave at room temperature for 30 min and rolled to a thickness of 0.3 cm. Then they were manually shaped into individual curry puffs. The curry puffs were then separated into two batches with replications, where one was inserted into an air-blast freezer at -20°C for 2 hours. The frozen curry puffs were kept in a chest freezer (-18°C) for the period of 0, 7, 14, and 28 days before frying and analysis. The samples were deep-fried using sunflower oil as the frying medium. Before that, frozen curry puffs were just leave at ambient temperature for 2 hours for thawing process until the required texture was observed. The sunflower oil was added into a deep fryer and was set to 180°C . The samples were added gently into the oil and fried at different frying times for 2, 3, 5, and 7 min, respectively. The samples were duplicated for each frying time and temperature. After frying, the excess oil was drained and samples were let cooled down before analysis.

Table 1. Formulation of curry puff skin dough.

Ingredients	Formulation	Percentage (%)
Wheat Flour (g)	1000	59.74
Butter (g)	57	3.58
Water (mL)	355	21.51
Oil (mL)	327	14.93
Salt (g)		0.24

Colour measurement

The colour measurement of the fresh and frozen curry puff samples was evaluated using a chromameter according to the CIELab (the $L^*a^*b^*$ colour space). The CIELab system gave three readings of colour component, namely luminosity L^* (-black to +white components) and chromaticity coordinates, a^* (+red to -green components), and b^* (+yellow to -blue components). The colour difference (ΔE) was evaluated by comparing the results of different frying temperatures and times using the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where, ΔL^* is the brightness difference, Δa^* is the redness difference, and Δb^* is the yellowness difference.

Moisture content analysis

Moisture content analysis was determined using a drying oven according to the method from the Association of Official Analytical Chemists (AOAC, 2005). Aluminium dishes were pre-dried in the oven at 105 °C for 3 h and cooled down in a desiccator. The empty cooled dishes were weighed and recorded. The curry puff skins were finely ground using a pestle and mortar. Two-gram samples were weighted and spread to form an even layer on an empty dish. The samples were dried for 24 h at 100 °C with a hold time until the sample reached a constant weight for three consecutive readings. The samples were then moved into a desiccator and allowed to cool before taking the final weight. All the samples and data collected were duplicated. Moisture content was calculated using the following formula:

$$\text{Percentage of Moisture (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where W_1 = Weight of sample before drying (g) and W_2 = Weight of sample after drying (g).

Water activity analysis

Water activity (a_w) was determined by methods from Landrock and Procter (1951). The analysis was performed using AQUALAB 4TE Benchtop Water Activity Meter from Meter Group Inc., USA.

Textural profile analysis (TPA)

The texture analysis of the curry puff skins was performed using a texture analyser (TA-XT2, Stable Micro Systems Ltd., UK) equipped with a cylindrical probe of 36 mm diameter, 1.0 mm/s test speed, and 25 kg compression load. The crust of the samples was removed, and the sample was sliced into equal squares (2 cm x 2 cm). The textural profiles of the samples were determined using Texture Expert 1.05 software (Stable Micro Systems). The parameters observed were hardness, firmness, and springiness. Each texture profile analysis was duplicated.

Quantification of acrylamide using high-performance liquid chromatography (HPLC)

Acrylamide was determined based on Nur Fatimah and Razinah (2018) method with slight modifications. The fried curry puff skins were ground prior to extraction process. One gram of the ground sample was placed in a 50 mL Erlenmeyer flask and added with 20 mL of deionised water at 50 °C and 5 mL of petroleum ether to remove fats in the sample. The mixture was agitated using an orbital shaker at 250 rpm for 30 min. Next, the mixture was centrifuged at 3000 rpm for 20 min. The mixture formed a fat layer, where the layer was removed. The remaining layer was added with 1 mL of Carrez I and Carrez II solutions each. The mixture was re-agitated for 30 min and centrifuged at 3000 rpm for 20 min. Lastly, three layers were formed, namely protein (upper), acrylamide (middle), and sediment layers. The middle layer was purified using 1 mL of Carrez I and Carrez II solutions each. The fat layer was removed once again and the remaining layer was added with Carrez I and Carrez II solutions. The sample was filtered through a 0.45 µm filter and sonicated before analysis. The acrylamide content was measured using a high-performance liquid chromatography (HPLC) system equipped with a diode array detector and an analytical C18 column steel. A 7 % (v/v) acetonitrile in deionised water was used as the mobile phase. The quantification of acrylamide was performed by measurement of peak area at 215 nm wavelength and 7.5 min acrylamide retention time. The amount of acrylamide content was determined by comparison with the calibration curve in which the injection volume was set at 10 µL and the flow rate was set at 1 mL/min.

Quantification of HMF using ultraviolet-visible (UV-Vis) spectrophotometer

The HMF content was measured using spectrophotometric method based on Zappala *et al.* (2005) method without modification. The fried samples were finely ground for analysis. Five grams of sample were dissolved in 25 mL of distilled water, and was then transferred into a 50 mL volumetric flask. In the flask, 0.5 mL of Carrez I and 0.5 mL of Carrez II were added. Next, distilled water was added to make a 50 mL solution. The solution was filtered using a 0.45 µm filter paper whereby the first 10 mL of the filtrate was rejected. Finally, 5 mL of the remaining filtrates were added with 5 mL of distilled water (sample solution) in which pure deionised water was used as a reference solution. A stock solution of HMF was prepared at 1000 µg/kg concentration. The absorbance of the solutions was determined using a VARIAN mod (UV-Vis (UV2600, Shimadzu Scientific Instruments, Europe) at the wavelength of 336 nm. The HMF was quantified using the formula obtained from the standard calibration curve.

Statistical analysis

The raw data obtained were analysed using Minitab Version 16 (Minitab, LLC). All analyses were done in duplication and data were presented in mean and standard deviation. Comparison study was conducted using ANOVA – Analysis of Variance (Fit General Linear Model) with the significance level set at $P < 0.05$ (Tukey's test).

RESULTS AND DISCUSSION

Colour development

Colour development is one of the positive effects of Maillard reaction. The crust of the curry puff skins turned brownish after the frying process, which indicated the presence of melanoidins in the samples (Izydorczyk, 2005). The development

of the colour in curry puff skins varied according to the exposure time and high temperature during frying. In this study, the frying temperature used was 180 °C and the frying time varied between 2, 3, 5, and 7 min.

The colour differences (ΔE) were calculated in this study in order to represent the browning process (Ciesarová *et al.*, 2009). The increase in frying time showed no significant difference in fresh curry puff skin colour. Fresh curry puff skins showed lower ΔE than fresh frozen curry puff skins. The development of brown colour varied when frozen curry puffs were fried at different storage and frying times. At 2 min of frying time, the frozen curry puff skins showed the highest ΔE at 0 day. As the storage time increased to 28 days, the ΔE also decreased. However, these changes were not significant ($P > 0.05$) and the frying time was short. At this point, the frying time may not be significant to allow proper browning, as the lightness (L^*) also showed marginal changes. As the frying time increased, the pattern of ΔE started to change in which longer storage time showed an increased ΔE . Longer frying time and low storage temperature may be the contributing factor towards browning (Olsson *et al.*, 2003; Jin *et al.*, 2016). Moreover, longer storage time up to 28 days did not affect the curry puff skin colour significantly. Jin *et al.* (2016) reported that the potato chips colour became dark brown or black when the potato was processed directly after storage at low temperature. The darkening formation was directly correlated with the accumulation of sugar reduce during frozen storage. However, the reduction of brown colour was observed after reconditioning at room temperature for thawing process. The findings also suggested that the browning was strongly associated with the prolongation of frying time. However, frozen storage and prolonged storage time intensified the browning which may be due to the excessive loss of moisture content during frying (Table 2).

Table 2. The water activity, a_w and moisture content in the fresh and curry puff skins at different frying times.

Type of product	Frying times (min ²)	Parameter ¹	Fresh	Frozen (0 day)	Frozen (7 days)	Frozen (14 days)	Frozen (28 days)
Curry puff skin	2	Water activity	0.85±0.004 ^{Aa}	0.82±0.001 ^{Aab}	0.79±0.004 ^{Aabc}	0.59±0.008 ^{Abc}	0.55±0.012 ^{Ac}
		Moisture content	46.80±4.39 ^{Aa}	36.01±2.31 ^{Aa}	33.29±1.69 ^{Aab}	11.04±0.99 ^{Ab}	9.38±0.96 ^{Ab}
	3	Water activity	0.77±0.002 ^{Aa}	0.75±0.003 ^{Aab}	0.7±0.001 ^{Aabc}	0.49±0.01 ^{Abc}	0.46±0.05 ^{Ac}
		Moisture content	42.05±0.93 ^{Aa}	29.77±1.65 ^{Aa}	26.13±1.86 ^{Aab}	8.51±0.49 ^{Ab}	5.98±0.37 ^{Ab}
	5	Water activity	0.73±0.007 ^{Aa}	0.63±0.004 ^{Aab}	0.59±0.08 ^{Aabc}	0.34±0.03 ^{Abc}	0.32±0.001 ^{Ac}
		Moisture content	33.92±3.27 ^{Aa}	24.20±0.45 ^{Aa}	18.82±0.38 ^{Aab}	6.30±0.78 ^{Ab}	4.63±0.70 ^{Ab}
	7	Water activity	0.68±0.009 ^{Aa}	0.55±0.014 ^{Aab}	0.46±0.001 ^{Aabc}	0.25±0.012 ^{Abc}	0.36±0.001 ^{Ac}
		Moisture content	22.52±8.48 ^{Aa}	12.55±0.12 ^{Aa}	9.97±1.80 ^{Aab}	4.28±0.14 ^{Ab}	8.09±0.68 ^{Ab}

¹mean values ± standard deviation (n=2, n= number of the same kind of product)²storage time of product^Adifferent letters indicate significance differences (p<0.05) for difference frying times^{a-b}within the same parameter, different letters indicate significance differences (p<0.05) for difference storage conditions

Moisture content and water activity (a_w)

The moisture content and water activity were related to the browning and HMF formations in curry puff skins. The trend of moisture loss in both fresh and frozen curry puffs can also be observed in their water activity analysed (Table 2). The moisture content in fresh and frozen curry puff skins showed that the moisture content decreased as the duration of frying decreased. The moisture content of fresh curry puff decreased significantly ($P < 0.05$) from 46.80 % to 22.52 % from 2 min to 7 min, respectively. These results were in correspondence with the results reported by other researchers whereby the moisture content of common pastries such as bread ranged between 35–45 % after undergoing heat treatment at a very high temperature (Hass *et al.*, 1975; Capuano *et al.*, 2009; Ciesarová *et al.*, 2009). However, the frozen curry puff showed even greater decrease in moisture content, and thus suggesting that longer frozen storage time leads to greater moisture loss as opposed to the fresh curry puff. Frozen storage at 14 days

onwards showed the most significant decrease in moisture loss, with 5 % to 10 % of moisture content after frying.

The water activity of both fresh and frozen curry puffs showed a similar trend with the moisture content, and thus indicating that the frying and frozen storage lead to the migration of free water out from the curry puffs (Table 2). However, the migration of free water was more severe in frozen curry puff and longer frozen time led to more moisture loss. The reduction in moisture content and a_w in frozen curry puff skins can be related to the enlargement of ice crystal particles in the curry puff skins during freezing. The increased ice crystals size might result in protein denaturation that affects the water holding capacity of the food products. Small ice crystals and a rather large surface area of the ice-liquid interface are formed during freezing, and thus resulting in increased exposure of protein molecules to the ice-liquid interface thereby increasing protein damage, particularly when freezing at high speeds (Cao *et al.*, 2003).

Figure 1. The colour comparison (ΔE) of fresh and frozen curry puff skins at different frying times.

^Adifferent letters indicate significance differences ($p < 0.05$) for difference frying times.

^{a-b}within the same parameter, different letters indicate significance differences ($p < 0.05$) for difference storage conditions.

Figure 2. The moisture content in fresh and frozen curry puff skins after frying at different frying times.

^Adifferent letters indicate significance differences ($p < 0.05$) for difference frying times.

^{a-b}within the same parameter, different letters indicate significance differences ($p < 0.05$) for difference storage conditions.

Figure 3 The water activity (a_w) of curry puff skins after frying at different frying times.

^Adifferent letters indicate significance differences ($p < 0.05$) for difference frying times.

^{a-b}within the same parameter, different letters indicate significance differences ($p < 0.05$) for difference storage conditions.

Textural profile analysis (TPA)

TPA was carried out by the hardness, firmness, and springiness attributes (Figure 4) of both fresh and frozen curry puff skins. The curry puff skins showed similar findings for all the tested attributes. The firmness of fresh samples that were fried at 2, 3, 5, and 7 min was 5.34 N, 5.25 N, 5.26 N, and 5.51 N, respectively. On the other hand, the firmness of frozen samples was comparable to the fresh samples (ranging from 5.08 N – 5.51 N) along with the sample storage of 28 days. Hardness and springiness of the curry puff skins also displayed similar trends as the firmness, where the results ranged from 3.09 N to 3.29 N (hardness) and 9.07 % to 9.91 % (springiness). However, all these attributes showed a slight increase in value when the frying time increased from 2 min to 7 min in both fresh and frozen curry puff skins, with no significant difference. Therefore, frozen curry puff skins did

not induce any significant changes in their microstructure that in turn determined their final physical properties of the samples. The TPA has shown that both fresh and frozen curry puff skins exhibited a similar behaviour, and thus showing that there was no apparent effect of the frying time and storage period on the overall texture of the curry puff skins although there were significant changes in the moisture content and a_w . The finding was similar with Zhao *et al.* (2013) where a mild change on the texture of protein bar was observed after Maillard reaction occurred. They suggested that in the initial process of Maillard reaction, chemical changes did not cause significant changes in hardness and the progress of reactions in which a significant amount of protein was modified. In this stage, further high-molecular weight polymers formed through nonsulfide cross-links caused hardening of texture.

Figure 4. Texture profile analysis of curry puff between different storage conditions and frying times of curry puff skins. (a) Hardness (b) Firmness (c) Springiness.

^A different letters indicate significance differences ($p < 0.05$) for difference frying times.

^{a-b} within the same parameter, different letters indicate significance differences ($p < 0.05$) for difference storage conditions.

Acrylamide content

Comparison between the acrylamide formation in the fresh curry puff skins and frozen samples was analysed. A linear equation of $y = 70.65x - 108413$ was obtained from the standard calibration curve of acrylamide, with the correlation coefficient, R^2 of 0.996. Ahn *et al.* (2002) reported that the limit of detection (LOD) for acrylamide detection in toasted bread, fried chips, grilling and baking of potatoes was 2500 µg/kg. The results showed that acrylamide was found in all of the samples. The acrylamide concentrations in fresh curry puff skins were 3343 µg/kg, 3410 µg/kg, 3534 µg/kg, and 4250 µg/kg after frying at 180 °C for 2, 3, 5, and 7 min, respectively. The acrylamide content in fresh curry puff skins showed a similar amount during 2, 3, and 5 min, but the value was higher at 7 min. However, the change was not significant. Frozen samples at day 0 showed marginal acrylamide formation at 2, 3, 5, and 7 min, with the concentration of 3300 µg/kg, 3345 µg/kg, 3484 µg/kg, and 3650 µg/kg, respectively. Morales *et al.* (2008) observed that churros frying times of over 3 min at 200 °C caused excessive moisture loss and browning, and thus resulted in the loss of product quality. Interestingly, the acrylamide formation was lower in frozen curry puff skins as compared to fresh ones (Figure 2). Moreover, prolonged storage condition resulted in significant reduction in acrylamide formation ($P < 0.05$). Curry puff skins storage for 28 days showed the least acrylamide in all frying times.

The development of acrylamide in fried products is the result of simultaneous formation and elimination (Biedermann *et al.*, 2002). Since Maillard reaction and acrylamide formation are related to one another, thus the colour formation can be used as a rapid indicator of the acrylamide presence in food. However, in this case, the increased intensity of ΔE in frozen curry puff skins showed lower acrylamide formation, and thus suggesting that frozen storage and reconditioning from frozen to room temperature for thawing process reduced the sugar content which is the precursor to Maillard reaction. This result was supported by the research done by Matsuura-Endo *et al.* (2020). Significant reduction of sugars was achieved after reconditioning at room temperature following cold storage. At the storage temperature (>10 °C), starch and other sugars remained in balance with free sugars, either

being utilised in the other reaction or connected to the starch. However, below this temperature level, the reducing sugar was accumulated and contributed to a higher formation of acrylamide (Edward *et al.*, 2002; Jin *et al.*, 2016). The result reported from Silva and Simon (2005) was consistent with this study, where a decrease of glucose concentration from 2.64 % to 0.58 % was measured after tuber reconditioning to 15°C for two weeks of storage.

In past studies, Tareke *et al.* (2002) reported that acrylamide content in French fries ranged between 2200 – 3700 µg/kg, whereas the World Health Organisation (WHO) in 2005 has declared that acrylamide in French fries could have a maximum concentration of 12800 µg/kg. Other than that, the European Food Safety Authority (EFSA) had also listed acrylamide content in several food products which is processed at a very high temperature. According to the list, biscuits are found to have the highest amount of acrylamide that could reach the maximum level of 4200 µg/kg, followed by several other products that contain up to 4700 µg/kg and potato crisps at 4180 µg/kg of acrylamide. In conjunction with these studies, Tardiff *et al.* (2009) reported that a tolerable intake of acrylamide for human consumption is 2600 µg per kilogram bodyweight per day. Therefore, the findings of this study had shown that the level of acrylamide formed in both fresh and frozen curry puff samples are still in the safe range for human consumption.

HMF content

HMF is also one of the undesirable components resulted from Maillard reaction. The presence of HMF was also detected in all the samples. The HMF level in curry puff skins was calculated from the linear equation formed from the standard curve of HMF, $y = 0.0012x + 0.0399$ and correlation coefficient, $R^2 = 0.9993$. The HMF formation was also affected by the increase of frying time and storage conditions (Figure 6). The highest amount of HMF was detected in the fresh curry puff skins that were fried for 7 min at 180 °C, with a concentration of 534.93 µg/kg. The HMF levels in the curry puff skins when fried at 2, 3, and 5 min were only 488.79 µg/kg, 457.67 µg/kg, and 522.00 µg/kg, respectively. However, the fresh curry puff skins recorded the highest HMF level as compared to the frozen curry puff

skins. Abraham *et al.* (2011) reported that the highest level of HMF was found in cereals that were made from wheat such as biscuits, pastries, and bread, where the maximum level of HMF formed was 503 µg/kg. It was estimated that the daily intake of HMF was between 400 µg – 3000 µg per person a day. However, Janzowski *et al.* (2000) reported that the estimation intake for HMF was ranged between 30 to 150 mg per person.

Frozen curry puff skins showed similar trend whereby longer storage time showed lower HMF formation significantly ($P < 0.05$). However, frying times were insignificant throughout all samples in both fresh and frozen curry puff skins. Previous study by Kedzierska-Matysek *et al.* (2016) showed that frozen rapeseed honey had a lower HMF content as compared to honey stored at room temperature. Furthermore, potato slices immersed in citric acid significantly reduced HMF formation by 70% (Maan *et al.*, 2020). The freezing pretreatment method reduced HMF formation by 80% as compared to control method (Iqbal Khan *et al.*, 2017). It is due to inactivation of enzyme that triggers the formation process. Complex reaction effects like inactivation of enzymes or microorganisms are altered in the reaction rates by their temperature. Modification of cell membrane permeability and ion exchange capability, changes in cell morphology and biochemical reactions as well as protein denaturation can be considered as relevant mechanisms (Jaegar *et al.*, 2010). Besides the reducing sugar, free amino acids like asparagines that are precursor to the formation of HMF and acrylamide also show little change at low storage temperature, which may contribute to the reduction of formation rate (Sun *et al.*, 2020).

There are some actions that may help to reduce the acrylamide and HMF formations in curry puff skins like using ultrasound treatment before frying (Barutcu *et al.*, 2009), using some food additives like asparaginase, citric acid, glycine, vanadyl sulphate, or lime (Kalitha and Jayathy, 2013; Jia *et al.*, 2013; Salazar *et al.*, 2014; Sansaro *et al.*, 2015). Most of the suggested actions are highly related with lowering the formation of reducing sugars and asparagine. The usage of additives like the glycine reported is involved in the competition with asparagines along the reaction process. Organic acid like citric acid

reduces the formation of acrylamide and HMF through the protonation of asparagines amino groups at a low pH condition.

CONCLUSION

In conclusion, this study had shown that the reconditioning of storage condition from -20 °C to room temperature and the reducing of frying times showed lower formation of acrylamide and HMF as compared to those of fresh curry puff skins. The acrylamide and HMF formations in the frozen curry puff skins were significantly reduced to 70 % and 50 %, respectively after 28 days of frozen storage. These conditions were minimised as the risks were opposed by these harmful compounds. Increasing the frying time had insignificant effect towards acrylamide and HMF formations. Furthermore, physical appearances such as colour and texture had only slight differences in both fresh and frozen curry puff skins, which may not affect the overall consumer acceptability. Therefore, the study suggests that frozen storage may have multiple benefits besides prolonging shelf life and may also reduce the factors contributing to health risk by reducing acrylamide and HMF formations.

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