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Acrylamide Formation In Cake Baked In Different Utensils And Novel Intervention Strategies

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Abstract

Humans are exposed to high levels of acrylamide (AA) through consumption of grilled and fried food. The present study represents the effect of using different common seven baking utensils on AA content in the cake as well as evaluation of two mitigation strategies: lining-based fruit by-products and steam at household levels. Orange and banana peels, parchment paper (pp), and traditional way as control (ghee +wheat flour) were used as lining materials. Total phenols, flavonoids, antioxidant capacity and thickness were measured in fruits by-product. AA, moisture and sensory evaluations were determined in cakes. The results revealed the following descending order of AA in studied molds: Pyrex, tinfoil, aluminum, pottery, silicon, Teflon, and galvanized molds. Current mitigation approach revealed that both fruits by product lining and pp as well as steam technique were significantly reducing AA in cake however, orange peels was the best among tested lining. Moreover, using orange peel+pp resulted in reduction of AA to the lowest level in cakes baked in lining tinfoil and aluminum utensils. Lining with orange peels and steam baking prevent the excessive brownness on the crust of cakes. In conclusion, these results can introduce cost-effective in economical, recycled, and easily practice methods for reducing AA formation at household-prepared foods using available utensils.

Keywords: Acrylamide ; Cake; Fruit by-products; Steam: Baking utensils.

1 Introduction

Various cooking utensils have been used in a very wide range all over the world; the use of specific materials in the manufacture of suitable cooking utensils depends on various characteristics; thermal conductivity and heat transfer which important physical properties are used to identifying of choice of cookware in order to reduce acrylamide (AA) formation. Schmid, [1]ordered different materials descending according to thermal conductivity as follow; copper (393 W/mK), aluminum (222 W/mK), titanium (17 W/mK) ceramics (10-17 W/mK) and plastics (0.1-0.4 W/m K). This ranking shows why materials such as aluminum and copper are usually used as heat sink materials. AA is formed in food as a by-product of the Millard reaction between the amino group of the free amino acid asparagine and the carbonyl group of reducing sugars (as glucose) during frying, baking and roasting especially starch rich food [2]. Kepekci et al., [3] reported that European Chemicals Agency (ECHA) (2010) reclassified AA as a probable carcinogenic substance to humans. National and international regulatory agencies have been focused their attention on the detection of AA in food. Ruiz el al., [4] depending on Codex commission WHO/FAO/ 72 [5] recommended that 0.01 mg of AA /kg body weight (bw)/day was the oral minimal risk level (MRL) for acute-duration exposure (≤ 14 day). Oral MRL for 15- 364 days of 0.001 mg/kg bw/day AA has been administrated for intermediate duration exposure. The average recorded intake of AA for the general population including children was 0.004 mg/ Kg b.w./ day; which considered high consumption. Due to AA toxicity; since 2002 more than hundreds of scientific papers have been done to classify the mitigation and/ or elimination of AA in food depending on type of food, precursors and pathway of AA formation. Anese et al. [6]; Anese et al., [7]; Gökmen, [8]; Pal et al., [9], and Xu et al., [10], summarized the reducing intervention strategies into three different categories. Firstly, select materials are low in AA precursors to reduce the AA in the final

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product. Secondly, modify the process conditions, in order to decline the amount of AA formation which concerns on technological strategies. Thirdly, post-process intervention could be used to reduce AA levels. The initial mitigation methods involved the control of processing conditions; for example, lowering pH, decreasing cooking temperature and shortening the processing time [11]. Although, these methods were achieved an effective reduction of AA, it's not widely applicable on household levels and sensory properties of the food were compromised.

Some food wastes considered as functional food through its constituents of bioactive compounds as dietary fibers, antioxidants and phenolic compounds. Eskicioglu et al., [12] reported that, orange flavedo contains higher vitamin C, carotenoid in addition to flavones, while the albedo is rich in phenols, flavanones, and antioxidant activity. Banana peels also had higher flavonoids than pulp. Peels dietary fibers was 81.5 g/100 g DM with antioxidant activity (1.5-6.9µmol Trolox eq. /g). Keramat et al., [13] and Summa et al., [14] concluded that, vitamin E, flavonoids, green tea extract, olive and bamboo leaves reduced AA contents; depending on antioxidant activity of food matrices. In addition, antioxidants could block the oxidation of acrolein to a certain extent and hence mitigation of AA.

Numerous AA researches focused on the risk of some factors affecting AA formation, mitigate AA in preparation; but few of them study the correlation of physical properties of utensils "thickness" and AA formation, or using by-products as filling and the correlation between. Current study aimed to evaluate the effect of different Egyptian utensils on AA formation in cake, also to reduce AA levels by using fruits by-product (banana and orange peels) as lining layer compared to tradition method ghee + flour or Parchment Paper (pp), and by increasing humidity in baked cake.

2 Materials and Methods

Method

Seven utensils with different materials used for baking cakes including silicon, pottery, borosilicate glass (Pyrex), aluminum alloy 3003, tinfoil, Teflon (polytetrafluoroethylene (PTFE) or tefal) and galvanized utensils were purchased from local super market in Egypt.

Methods:This study has two aspects:

2.2.1. The first aspect: to study the effect of different type of baking utensils on AA formation in baked cakes

2.2.2. The second aspect: to evaluate two strategies on household level to reduce AA formation in the most Egyptian utensils cause high AA formation:

2.2.2.a. Using fruits by-product as lining layer compared with tradition method (ghee and flour) or (pp).

2.2.2.b. Increasing humidity in baked cake

2.2.3. Preparation of cakes: cakes were prepared using fresh ingredients, from local supermarket in Cairo, included sugar (32.06%), oil (8.33%), eggs (13.86%), milk (16.64%) and vinegar (0.55%) were whipped then mixed together with dry ingredients included wheat flour (27.73%) and baking powder (0.83%).

2.2.4. Study the effect of baking utensils material on the acrylamide formation in cakes: Cakes were baked in the seven utensils coated with ghee and flour in a convection oven at 180 °C for 35 min. After baking; cakes were kept at room temperature to cool for one hour before performing the analysis (AAand moisture). Two types of the most common utensils (Aluminum alloy 3003 and tinfoil) which showed high level of AA formation in cakes were used in the second aspect of the study.

2.2.5. Mitigation strategies: Two applied methods at household levels were used to reduce acrylamide level in cakes.

2.2.5.a. **Method 1:** Fruits peels based lining. Aluminuim alloy 3003 and tinfoil utensils were lined with orange, banana peels and orange peel+ pp in compare with traditional lining (ghee and flour). Orange peels were carefully washed under running water then minced using food processing machine and formed in one layer with 0.3 mm. thicknesses. While banana peels were used on natural form after washing on running water. Either orange or banana peels covered all the inside surface of baking utensils before pour the batter of cake (Figure 1), then baked in a convection oven at 180°C for 35 min.

2.2.5.b. **Method 2:** increasing humidity in backed cakes. Cakes' dough divided between tinfoil and aluminium alloy 3003 utensils which lined with ghee + wheat flour. 150 to 200g of hot water placed in utensils in the bottom surface of the oven in order to be a source of vapour water steam. Cake samples in different utensils baked in a convection gas oven without forced air at 180°C for 35 min. In the last 10 min of baking, the temperature was measured in the cakes at depths of 2mm from the surface of the cakes.

Figure 1:Preparation of orange peels as lining based material before baking cakes

2.2.5. Chemical analysis

2.2.6.a. **Moisture determination:** Moisture of fresh baked cakes was determined by measuring the weight difference before and after drying for 15 h at 110°C using an air oven (LABEC, PSW, Germany) [15].

2.2.6.b. **Determination of AAby GC/MS/MS:** The AA were analyzed in mixture of cakes' crust and inner according to Biedermann et al.,[16] using GC-(Agilent technologies 7890A) interfaced with a mass-selective delector (MSD, Agilant 7000) equiped with an apolar HP- 5ms (5% phenyl amethyl poly siloxane) capillary colunm (30m × 0.25 mm i.d. and 0.25 µm film thickness). The carruer gas was helium with the linear velocity of 1 ml/min., Cake crusts and inner parts were hemogonized and swelled by adding amount of water approximately 3 times the weight of the samples (more for exceptionally dry samples). 10 g of the homogenate was prepared and weighed into a 100 ml centrifuge glass with a screw cap and thoroughly mixed with 40 ml of 1-propanol.

2.2.6.c. **Total phenols content:** were analyzed in raw orange and banana peels by Folin-Ciocalteu method [17] using gallic acid as standard. The results were expressed as mg of gallic acid equivalent per 100 milliliters (mg GAE/ 100 g).

2.2.6.d. **Total antioxidant capacity:** were determined in raw fruits peels using the phosphomolybdenum method [18] Ascorbic acid was used as standard. The results were expressed as mg ascorbic acid equivalent per 100 milliliters (mg AAE / 100 g).

2.2.6.e. **Flavonoids content:** were determined in fruits peels by the aluminum chloride colorimetric assay [19]. Total flavonoids recorded as expression of g quercetin (QE) equivalent / 100g sample.

2.2.6.f. **Thickness measurements:** Thickness of baked utensils and lining material was measured using Vernier caliper.

2.2.7. Organoleptic evaluation of cakes: Sensory evaluation of the cake samples was carried out as described by Iwe [20] using 20 members of panelists who selected randomly from the Regional Center for Food and Feed community. Samples were valued on a scale of 10 (1, 2: bad, 3,4: poor, 5,6: fair, 7,8: good and 9,10: excellent). Judges were placed in different places in order to minimize and avert confusion for the testers. They were also provided with potable water to rinse their mouth after evaluating each sample to avoid taste interference. The samples were presented in transparent dishes with coded letter. The sensory quality attributes of the samples were color, taste, odor, texture and over all acceptability.

2.2.8. Statistical analysis: Data were statistically analyzed in completely randomized design in factorial arrangement [21] and the treatments means of 3 replicats were compared by Least Significant Differences ($P \leq 0.05$) Duncan multiple range using Costate software (version 6.4, Cohort software(USA).

3 Results & Discussion

3.1 Effects of baking utensils materials on the AA formation in cakes

Table 1 present the mean ± S.E. of AA content (ppm) in baked cakes using different utensils in descending order. Pyrex resulted in the highest AA content (207.75ppm) in cake followed by tinfoil, aluminum and pottery, while the galvanized utensils was the lowest (62.67 ppm). It worthy to note that there is no significant difference in AA content in cakes baked in silicon, teflon and galvanized molds ($P \leq 0.05$). The varied AA contents in different cooking molds can be explained by knowing the main factors affecting heat transition from cookware metals to food ingredients are thermal conductivity, heat capacity and thickness of cooking pan [22]. Low thermal conductive materials extended time consumed for cooking temperature while high pan thickness lead to reducing top surface temperature. Glass cookware (Aluminosilicate glasses) had low thermal expansion and high softening temperature properties; this can tolerate high temperature [23]. It is believed that the higher temperature and duration of the heat treatment are most critical factors of AA formation. These results were agreed with Sedighi, [24]who approved that when the first layer or crust exposed to the heat source with highly conductive metal, then temperature will arrive lower on the non-heated surface and vice versa.

Table 1: AA levels in baked cake using different utensils

Utensil types	AA content (ppm) (mean± S.E)
Pyrex	207.75 ± 1.98[a]
Tinfoil	148.88 ± 1.69[b]
Aluminum	94.20 ± 0.40[c]
Pottery	89.27 ± 1.00[d]
Silicon	63.34 ± 0.97[e]
Tefal	63.24 ± 1.5[e]
Galvanized	62.67 ± 0.87[e]

Values in the same column with the same letter are not statistically significant at P ≤0.05.

Maskepatil et al., [22] and Shieh et al., [25] reported that steel thickness had positive varying in temperature on the top surface. Unfortunately, low thermal conductivity means a lot of energy needs to be imparted to the bottom of the steel, in order to get the top hot. Therefore, utensils made of a low thermally conductive material will take a longer time to reach cooking temperatures which aid to reduce acrylamide accumulation in foods. On the other view Dardashti et al., [26]emphasized that using multi-layer structure cooking molds can be effects on improving the quality of temperature distribution including uniformity, temperature magnitude and thermal conductivity for different metals.

Current mitigation strategies were applied on tintinfoil and aluminum molds as most used at Egyptian household with low and middle income and had high AA formation in its cakes.

3.2 Mitigation strategies

Two mechanisms that can be applied at household levels and affect AA formations were selected: 1) lining- based materials using fruit peels and 2) using steam on the surrounding environment.

3.2.1. Effect of using fruit peels as lining-based materials on reducing AA contents in baked cakes

Table 2 illustrate the effect of tinfoil and aluminium molds, different lining materials and their interactions on the acrylamide content in cakes. Tinfoil usually used as outdoor disposal utensils in bakeries markets, while aluminum utensils are mostly used for baking cakes at household levels. Higher AA levels was recorded for tinfoil and aluminum molds based with ghee and flour (148.8 and 94.2 ppm) respectively. .Data revealed that fruits peels were more effective in lowering AA content than pp in cakes baked in both molds comparing with control. Using pp has very little effect on lowering AA content (4.83%) in cakes baked in aluminum compared with other lining materials, meanwhile pp recorced pronounced reduction of AA level (80.37%) as used tinfoil utensils for baking comparing with control.

The AA contents for both tinfoil and aluminum utensils by using different fruit peels were arranged in descending order as banana peels (23.90 and 37.02 ppm), mashed orange peel (16.94 and 31.43 ppm) and orange peel with pp (8.25 and 13.19 ppm), respectively. It can be suggested that; using fruits by-products as lining based materials caused significant effect in reducing AA formation in baked cakes. These reductions ranged from 83.94% to 94.46% and 60.70% to 86% for tinfoil and aluminum utensils, respectively.

Table 2. Acrylamide levels (ppm) in baked cake using different lining-based materials

Treatments	Tin foil	Reduction ratio	Aluminum	Reduction ratio
Ghee + flour (control)	148.8± 5.69 [a]	-	94.20±1.38 [b]	-
Parchment paper (pp)	29.22± 2.76 [e]	80.37%	89.65±3.93 [c]	4.83%
Banana peels	23.90±0.87 [f]	83.94%	37.02± 1.21 [d]	60.70%
Orange peels	16.94±1.16 [g]	88.62%	31.43 ±3.90 [e]	66.63%
Orange peels + pp	8.25 ±0.22 [i]	94.46%	13.19±0.06 [h]	86.0%

Each value represents the mean ± S.E (Standard Error). Values in the same column with the same letter aren't significant at p≤0.05

AA is a natural contaminant always generated during the heat treatment of carbohydrate-rich foods. Many studies have showed that AA is formed from the Millard reaction between amino acids, mainly asparagine, and reducing sugars under high temperature conditions [27] The high AA levels in cakes by using ghee and flour as based materials may be due to that; the total carbohydrates content of the outer layer of baked cakes were increased which lead to more reaction between reducing sugars and amino acids under the high oven temperature causing high AA level and excess browning. On the other hand, use fruits by-products can prevent the excessive browning on the crust of baked cakes **(Figure 2)** causing low AA formation compared with pp and typically traditional base. On the other hand, Lingnert et al., [28] reported that glycerol is degraded to acrolein when oil is heated at temperatures over the smoke point. (Acrolein is a very probable precursor of acrylamide), (the unpleasant acrid black and irritating smoke). Oils with a higher content of saturated fatty acids and lower content of polyunsaturated acids have a higher smoke point. The smoke points for some ofthe main fats and oils are: palm 240°C, peanut 220°C, olive 210°C, corn 160°C, margarine 150°C and butter 110°C. Usually, the smoke begins to appear on the surface of heated oils before their temperature exceed 175°C.

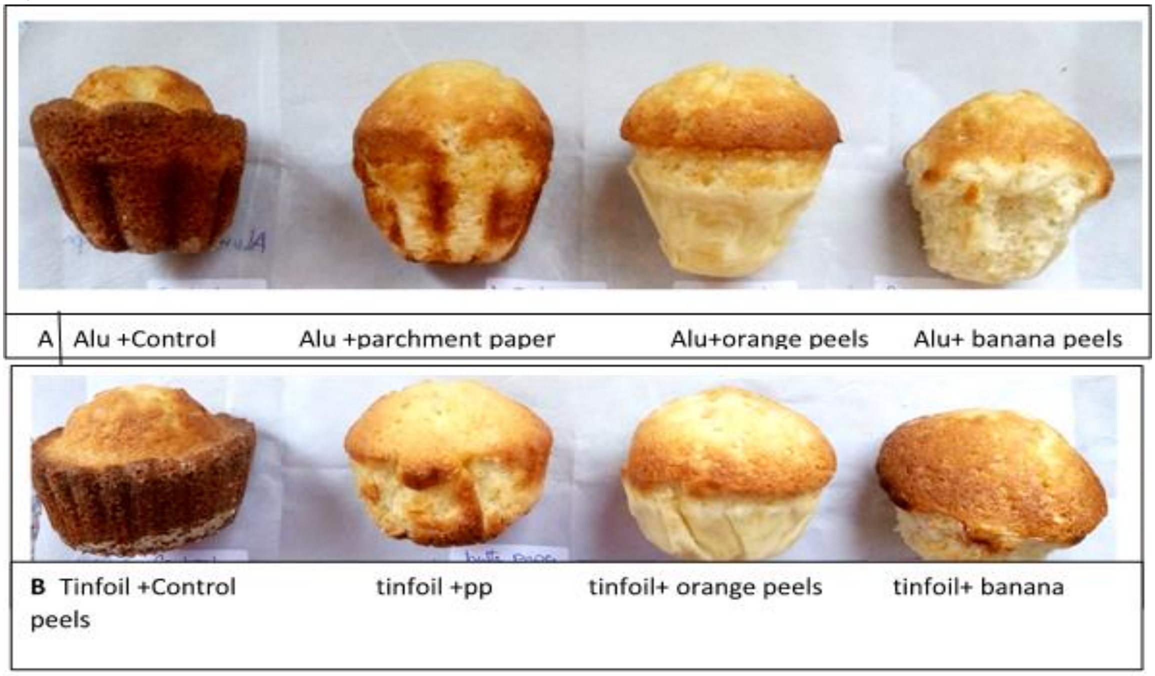

Figure 1: Side color of baked cake using Aluminum mold (A) and Tinfoil mold (B) with different lined materials

The possible pathways by which fruits by-products reduce AA formation in cakes baked in both tinfoil and aluminum molds have been studied in details concerning within three vitl factors a) moisture contents on the baked cake, b) phytochemical contents of peels lining and c) thickness of inner surface of molds.

3.2.1.a. ***Effect of use some utensils and lining materials on the moisture content of baked cakes***

The effects of use tinfoil and aluminum utensils and different lining materials on the moisture content of the final cakes are listed in **Table (3)**. Generally, use tinfoil molds in baking cakes were significantly increased the moisture content of the final product compared with using aluminum ones. Lining utensils with pp, orange and banana peels caused increments on the moisture content of the cake samples than control. The highest increase in the moisture content was recorded from orange peels lining in tinfoil followed by aluminum molds (28.96 and 25.99 g/100 gm of baked samples respectively). These results revealed that moisture content of cakes can be affected by the kind of utensil's material and lining materials. These findings can also explain the reduction of AA formation by using fruits by-products as shown in **Table 2**.

Table 3. Mean moisture content (gm/100gm of baked cake samples).

Lining materials / Utensils	Control	Parcment paper	Orange peels	Banana peels
Tinfoil	22.89 [c]	25.81 [b]	28.96 [a]	26.86 [b]
Aluminum	20.97 [d]	22.99 [c]	25.99 [b]	24.12 [c]

Each value represents the mean ± S.E (Standard Error). Values in the same row with the same letter aren't significant at $p\leq0.05$

Table 4. Phytochemical contents on banana and orange peels

Fruits by- product / Phytochemical compounds	Banana peels	Orange peels
Total Antioxidant activity(mg AAE / 100 g)	19804.17	15485.83
Total Phenols (mg GAE/ 100 g)	13834.17	11276.67
Total flavonoids (g QE equivalent / 100g)	1036.5	1512.12

3.2.1.b. *phytochemical components in by-product fruits and its effect on AA levels*

Fruit by-products have been used in many issues in food and feed due to their high content of many phytochemicals in addition of its health benefits for human. **Table 4** numarate the antioxidant capacity, phenols and flavonoids contents in orange and banana peels. It has been found that banana peels contain higher antioxidant and phenol (19804.17 and 13834.17 mg GAE/ 100 g), respectively than orange peels (15485.83 and 11276.67mg GAE/ 100g), respectively. Conversely, flavonoid contents were higher in orange peels than banana peels. Crawford et al.,[29] and Gökmen, [8] also used by-products especially vegetables and fruits peels in powder forms to reduce AA in baked food as a rich source of phytochemicals especially antioxidants and anti-inflammatory compounds. They explain that through two mechanisms: the first one is refers to the effect of antioxidant on preventing lipid oxidation, which leads to deformation of AA; the second is the effect of carbonyl functional groups in some phenolic antioxidants that may react with asparagine which decreasing the risk of acrylamide formation. Although, banana peels are rich in phenols with high antioxidant activity compared to orange peels, using orange peels as a lining –based material was more effective in reducing the AA level in baked cakes. These findings refer to the reduction on AA was not only regarding to the phytochemicals effect but it may be related to the high fiber content in orange peels than banana peels. Zoair et al**.,** [30] showed that fiber content in orange and banana peels were 12% and 10%, respectively. Also, Eskicioglu et al., [12] reported that orange peels have high dietary fiber content (71.62 g/100 g dry matter).

*3.2.1.c. **Effect of the thickness of utensils with different lining–based materials on reducing AA in baked cakes***

Figure 3 revealed that using fruits by-product whether orange or banana peels as lining material increase the thickness of the inner layer of aluminum and tintinfoil utensils than control and/or pp. The increased thickness by fruits peels can decline the direct interaction between batter cakes and the ambient temperature in the oven, in addition; it will lead to retain more moisture content in the final cakes compared with using ghee and flour and pp (**Table 3**). At higher temperature, more pertain to heat processes, considerably lower water activity has been shown to be favorable to the Millard reaction. The fundamental reason for an optimum reaction rate at an intermediate water activity, as a low water activity as the mobility of reactants is limited, despite their presence at increased concentrations [31].

It could be concluded that as the thickness of lining materials increased, the retain moisture increased in cakes and AA formation reduced.

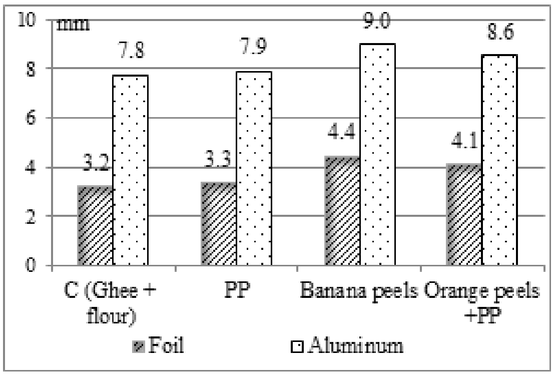

Figure 3: Thickness of tinfoil and aluminum utensils with different lining materials

3.3 Effect of steam baking on AA levels and moisture content in baked cakes

Data in **Table 5** revealed that forced steam during baking can reduce the AA formation in the crust of the cakes compared with no steam usage in both tinfoil or aluminum utensils. This effect was more pronounced with pp lining than traditional lining of ghee and flour. **Figure 4** presented the moisture contents in cake samples baked with or without steam. Generally, using tintinfoil molds with steam baking was significantly increased the moisture content of the product compared with aluminum. Lining utensils with pp caused increments in the moisture content of the cake samples than control (ghee and flour). These results revealed that moisture content of cakes can be affected by lining material in addition to steam baking. Crust temperature after baking cakes was shown in Also, Blank et al., [33] mentioned that in aqueous systems, the Schiff base may hydrolyze to the Amadori compound, which is not an efficient precursor in AA formation. However, it was not agreed with Dessev et al., [34] who found that high amount of AA in the crust with the steam level and cellar temperature. However, a slight decrease in AA level was observed, when the steaming is high (300 ml) and the temperature is above 200C˚. Howevere recent mitigation technique aimed to reduce temprature and cooking time as a sucssesful strategy to reduce AA in food [35].

Figure (5) and the results revealed that low crust temperature achieved by using steam baking especially in tinfoil's cakes. Our results in accordance with the result reported by Ahrné et al., [32]which proved reduction on AA concentration reached 50% in the crust of baked bread as using steam baking in the last 10 min, although there is no increment on moisture content on the crust of baked bread. Xu et al., [10]explained the influence of moisture on the Millard reaction via restricting the mobility of reaction with evidence on no AA is found in boiled food. Many researches emphasized on initial and maintaining a certain levels of moisture had a significant effect on reducing AA in high fat and dried foods. The steaming caused a reduction in moisture loss from the crust, which helps to reduce the crust temperature and lowering the AA level.

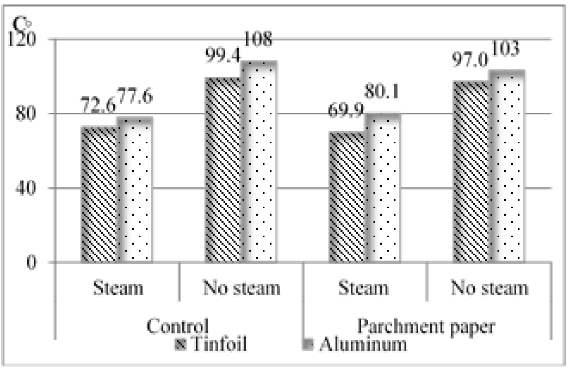

Figure 5:Crust temperature (C°) in cakes with/ without using steam baking

Table 5. Acrylamide contents (ppm) in cakes after steam baking using tinfoil and Aluminum mold

Steaming	Control (ghee+ flour)		Parchment paper (PP)	
Utensils	**Steam**	**No steam**	**Steam**	**No steam**
Tinfoil	18.57 ± 0.66	148.88 ± 1.69	13.75± 0.40	25.19± 0.73
Aluminum	28.32± 0.69	94.20 ± 0.40	23.90 ± 0.25	31.43 ± 1.13

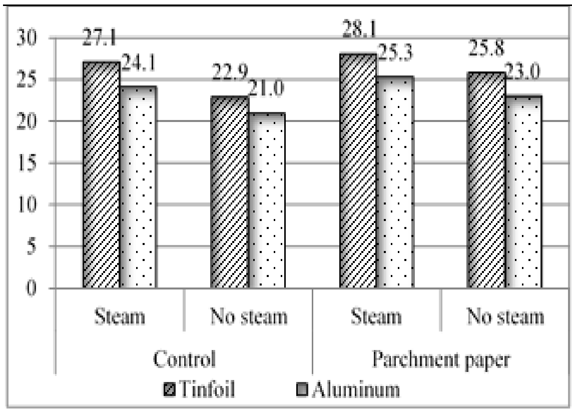

Figure 4: moisture content (gm/100gm) of cake baked with/ without steam.

4 Sensory evaluation

Table 6 presented the sensory properties for cakes baked in utensils lined with different materials of pp, orange and banana peels. No significant ($P \leq 0.05$) differences were observed in top and sides color, texture and over all acceptable among control cakes and pp lining. However, use orange and banana peels in lining the cake's utensils caused a significant decrease in the top and sides color and texture compared with control. Conversely in taste, treatment with orange peels recorded the highest scores over other treatments. Over all acceptability results revealed that control cake was more favorable to consumers, but other cake still have considerable satisfaction degree.

Table 6. Sensory evaluation of different cake samples

Cakes	Top surface color	Sides & bottom surface color	Texture	Taste	Over all acceptability
Control	8.50 [a]	8.60 [a]	8.40 [a]	8.15 [b]	8.41 [a]
PP	8.02 [a]	8.00 [a]	7.87 [a]	7.90 [bc]	7.95 [a]
Orange peels	6.10 [c]	7.05 [c]	6.00 [c]	9.22 [a]	7.09 [b]
Banana peels	6.87 [b]	7.52 [bc]	7.02 [b]	7.55 [c]	7.24 [b]

4. Conclusions

It can be concluded that kind of utensils material have a big role in reducing the AA formation. Temperature, moisture and thickness are the main factors affecting the accumulation of AA. Current study aimed to apply effective, costly wise, healthy, tasty and helpful baking modifications for low and medium income households, for reduce acrylamide accumulation in cakes. Lining utensils with fruit by-products especially orange peels and steam baking were significantly reduced AA in cakes. Among the different practices that were used for decline the AA formation in cakes at household levels, steam baking procedure reduce the almost AA content in cakes with more superbly than use different lining- based materials. Further researches on different cooking techniques could be conducted for reduce the acrylamide content in foods.

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