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Efficiency of food additives and frying durations in reducing acrylamide and 5-hydroxymethylfurfural formation in tray *kadayif* dessert

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Abstract

Acrylamide and 5-hydroxymethylfurfural (HMF), end products of Maillard reaction in heat-treated products, are known to have carcinogenic effects on human health. The present work thus investigated the effects of six different food additives (acetic acid, $CaCl_2$, glycine, NaCl, $NaHCO_3$, and sucrose), three different doses (0, 1.5, and 3%, w/w), and two frying durations (30 and 40 min) at 200°C on physicochemical properties of tray *kadayif*, a famous Turkish dessert. The lowest acrylamide formation was achieved with $CaCl_2$, glycine, and NaCl additives; and the lowest HMF formation was achieved with glycine and $NaHCO_3$ additives. Moreover, increasing frying durations from 30 to 40 min increased acrylamide and HMF levels of the control samples without any additives; but, the effects of frying durations on acrylamide and HMF levels of additive supplemented samples varied with the type and dose of additives. It was concluded that food additives and frying durations could be used as an efficient tool to control Maillard reaction in tray *kadayif*. The present work provided findings that can be effective in the optimisation of *kadayif* formulation and process conditions for large-scale industrial production of this popular dessert.

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Introduction

Desserts in syrup have an important place in the Middle Eastern and Turkish cuisines (Yildirim *et al.*, 2018). *Kadayif*, a popular dessert in syrup, is largely consumed in the Balkans, Turkey, and Middle Eastern countries (Aydin and Çakmakçi, 2014). Standard "tray *kadayif*" is made of highly soft dough prepared with flour and water, and its texture is quite similar to that of shredded wheat, which is then fried until golden colour is obtained. Tray *kadayif* is mostly produced by small companies; but, sometimes it is also produced by large companies in small quantities (Seyyedcheraghi *et al.*, 2019). For industrial production of this popular dessert, formulation and process conditions should be optimised.

Frying is the most critical process to be optimised in *kadayif* production (Maan *et al.*, 2020). Maillard reaction occurring during frying may produce some compounds with mutagenic, carcinogenic, and cytotoxic effects on the final product (Capuano and Fogliano, 2011). Acrylamide is one of these compounds that is formed by frying of carbohydrate-rich foodstuffs, and Maillard reaction between asparagine and carbonyl compounds has a significant role in this formation (Başaran *et al.*, 2020). It is a neurotoxin and genotoxin, and is listed as probably carcinogenic to humans (Group 2A) by the International Agency for Research on Cancer (IARC; Esteve *et al.*, 1994). Acrylamide is a colourless, odourless, and water-soluble compound, and susceptible to acids, bases, iron salts, and oxidising agents (Maan *et al.*, 2020). The 5-hydroxymethylfurfural (HMF) is another heat-induced compound formed as an intermediate product of Maillard reaction. It results from direct dehydration of sugars under acidic conditions during thermal processes of foodstuffs (Capuano and Fogliano, 2011). The genotoxic, cytotoxic, and carcinogenic effects of HMF were reported in previous studies (Mortas *et al.*, 2017). HMF levels are largely dependent on the type of sugar, water activity, pH, and concentration of divalent cations (Capuano and Fogliano, 2011). Therefore, frying temperature, duration, and other relevant factors should be controlled as to prevent the formation of harmful compounds such as acrylamide and HMF (Mousavi Khaneghah *et al.*, 2020).

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Temperature, duration, and moisture adjustments are classified as physical methods for reduction of acrylamide and HMF formation (Baskar and Aiswarya, 2018). However, some chemical methods including food additives such as organic acids, amino acid, salts, cations, asparagine enzyme solutions, and antioxidants are also commonly used to reduce or inhibit acrylamide and HMF formation (Friedman, 2015). Schiff base is a key intermediate in Maillard reaction, and in acrylamide formation, organic acids such as acetic acid may inhibit Schiff base formation (Mestdagh *et al.,* 2008). The mono- and divalent cations (*e.g.*, Na^+ and Ca^{2+}) are efficient acrylamide- and HMF-reducing agents due to interactions with asparagine that prevents Schiff base formation (Baskar and Aiswarya, 2018). Free amino acid such as glycine and supplementations are also suggested for reduction of acrylamide and HMF formation since they promote competitive reactions and/or covalently bind the resultant acrylamide through Michael type addition reactions (Mestdagh *et al.,* 2008).

Thus far, there were no studies on the potential use of food additives in tray *kadayif* production to reduce acrylamide and HMF formation during frying. Therefore, the present work was conducted to investigate the effects of six different food additives (acetic acid, $CaCl_2$, glycine, NaCl, $NaHCO_3$, and sucrose) and frying durations on physicochemical properties of tray *kadayif* (water activity, pH, colour parameters, acrylamide, and HMF levels).

Materials and methods

Materials

Wheat flour and other materials used in *kadayif* production were purchased from a local market (Erzurum, Turkey). Food additives, reagents, and solvents used were purchased from Merck Chemicals Co. (Germany).

Production of tray kadayif

Firstly, the *kadayif* was prepared from sifted wheat flour, water, and different six food additives (acetic acid, $CaCl_2$, glycine, NaCl, $NaHCO_3$, and sucrose) at three different doses (0, 1.5, and 3%, w/w). Then, 800 g of *kadayif* was mixed with 200 g melted butter at low temperature for 5 min. After that, it was seated on a tray with the same thickness, and a special medium-density fibreboard wood (thickness = 10 cm; weight = 10 kg) was put on it. The samples were fried at 200°C for two different durations (30 and 40 min). Finally, previously prepared syrup was added, and the upper parts of the samples were used for analyses (Aydin and Çakmakçi, 2014; Seyyedcheraghi *et al.,* 2019).

Water activity measurement

The water activity levels of tray *kadayif* samples were determined using a water activity meter (Lab Master-aw, Novasina, Switzerland).

pH measurement

The pH values of homogenised tray *kadayif* samples (3 g) in distilled water were determined using a pH-meter (Inolab pH 720, wtw 82362, Weiheim, Germany).

Acrylamide measurement

The acrylamide levels of tray *kadayif* samples were determined following a previously specified method (Han *et al.,* 2019) with minor modifications. Briefly, 10 mg/L of d3-acrylamide internal standard solution (10 µL) and deionised water (9 mL) were added to 15 mL plastic centrifuge tubes containing 1.0 g of tray *kadayif* samples, followed by supplementation of 0.5 mL of each Carrez I (prepared with dissolution of 15 g potassium hexacyanoferrate (II) trihydrate in 100 mL distilled water) and Carrez II (prepared with dissolution of 30 g zinc sulphate heptahydrate in 100 mL distilled water) solutions. The mixed solutions were shaken at 40°C for 30 min, and then centrifuged at 5,000 *g* for 10 min. Finally, the supernatant was taken for purification. The *n*-hexane (10 mL) was added to the supernatant, and shaken for another 10 min, before being removed and then followed by purification of the acrylamide using a pre-treated Waters Oasis HLB SPE column (200 mg, 30 µm). The prepared sample was centrifuged at 5,500 *g* for 10 min to obtain the supernatant, which was then filtered through 0.22 µm nylon filter, and used for liquid chromatography-mass spectrometry (LC-MS/MS) analysis. LC-MS/MS analysis was performed in an Agilent 1200 LC system (GC-MS; Agilent Technologies Inc., Santa Clara, CA, USA) equipped with a flame-ionisation detector (FID) and a DB-225 column (30 m × 0.25 mm × 0.25 µm). The nebuliser, drying, and collision gas was nitrogen. The nebuliser pressure was 40 psi, drying gas flow rate was 10 L/min (350°C), and capillary voltage was 4 kV. The analytical column was an Agilent ZORBAX Eclipse on a C_{18} column (2.1 × 150 mm, 3.5 µm)

maintained at 35°C. The mobile phase was methanol:water (5:95, v/v) mixture with a flow rate of 0.2 mL/min, running for 15 min. The injection volume was 2 µL, with *m/z* 72.2 → 55.4 and *m/z* 75.3 → 58.4 transitions for acrylamide and d3-acrylamide, respectively. The limit of detection (LOD) in samples was 6 µg/kg, and the limit of quantification (LOQ) was 16 µg/kg.

Hydroxymethylfurfural (HMF) measurement

The analysis of HMF was carried out following a previously established method (Han *et al.*, 2019) with minor modifications. Briefly, 2 g of sample powder in plastic centrifuge tube was supplemented with 8 mL of deionised water, and 0.5 mL of each Carrez I and Carrez II solutions. The mixtures were vortexed for 3 min, and then shaken for 30 min at 40°C, subsequently, centrifuged at 5,000 *g* for 10 min to obtain clear supernatants. The HMF in supernatants was purified by applying the Waters Oasis HLB SPE cartridges (200 mg, 30 µm). The prepared samples were filtered through 0.22 µm nylon filter, and then analysed with HPLC. Instrumental analysis was performed using a Shimadzu HPLC system (Shimadzu, Kyoto, Japan) consisting of a CBM-20A system controller, two LC-20AT pumps, a DGU-20A degasser, an LC-20A UV detector, and a CTO-20AT column oven. The analysis system was equipped with a Thermal ODS C_{18} analysis Nucleosil $5C_{18}$ column (250 × 4.6 mm; Hichrom, Reading Berkshire, England). The temperature of the column oven was set to 35°C. The UV detection wavelength was 280 nm. The mobile phase was acetonitrile:water (10:90, v/v) at a flow rate of 0.6 mL/min, and a run time of 20 min per sample. The injection volume was 20 µL. The LOD and LOQ of the samples were 0.06 mg/kg and 0.15 mg/kg, respectively.

Colour measurement

The colour parameters (L*, a*, and b*) of *kadayif* samples were determined using a colorimeter (CR-410 Minolta Chroma Meter, Minolta Camera Co., Osaka, Japan) based on CIELab colour space.

Statistical analysis

Data were expressed as the mean ± standard deviation (SD) for three samples of each raw material. Experimental data were subjected to analysis of variance (One-way ANOVA) with the use of SPSS for Windows version 22.0 (SPSS Inc., Chicago, IL, USA). Significant means were compared with the use of Duncan's test at $p < 0.05$ significance level.

Results and discussion

Water activity measurement

The regulation of sensory parameters such as water activity is a critical way to control the progress of Maillard reaction and the formation of browning compounds in the system (Ames, 1990). Table 1 presents the results of analysis of variance for water activity levels under different additives, additive levels, and frying durations. The effects of additive type, additive level, and frying durations on water activity levels of tray *kadayif* were found to be highly significant ($p \leq 0.01$).

As shown in Figure 1a, the lowest water activity levels were obtained from acetic acid and glycine supplemented samples, and the highest water activity level was obtained from $NaHCO_3$ supplemented samples. Water acidity levels significantly ($p < 0.05$) decreased with increasing frying durations (Table 2).

pH measurement

pH is another key parameter to control the rate of Maillard reaction and the nature of the coloured products (Capuano and Fogliano, 2011). As presented in Table 1, the effects of additive type, additive level, and frying durations on pH level of tray *kadayif* were highly significant ($p \leq 0.01$). The lowest pH (5.44 ± 0.48) was obtained from acetic acid supplemented samples, and the highest pH (7.48 ± 1.27) was obtained from $NaHCO_3$ supplemented samples (Figure 1b). However, no significant difference ($p > 0.05$) was observed among the pH levels of the other additives. Complying with the present findings, Anese (2010) reported that the addition of salts such as CH_3COOK, $CaCl_2$, and $MgCl_2$ to biscuit formulations caused no significant difference in pH levels. It was also reported that acrylamide and HMF levels were only influenced by salt type. As can be inferred from Table 2, the pH level of control samples (without additive) significantly ($p < 0.05$) increased with increasing frying durations. Nevertheless, the effects of frying durations on pH levels varied with the type of additive.

Acrylamide measurement

The analysis of variance for acrylamide levels under different additives, additive levels, and frying

Table 1. Analysis of variance of water activity, pH, acrylamide, and HMF levels of tray *kadayif* dessert samples under different additives, additive levels, and frying times.

SOV	SD	Water activity	pH	Acrylamide	HMF
		F	F	F	F
Additive type (A)	5	412.58**	2998.73**	2.97*	238.93**
Additive level (L)	2	135.47**	106.02**	0.01*	86.97**
Frying time (T)	1	83.63**	14.39**	0.01*	508.42**
A × L	10	188.18**	902.77**	2.45*	83.19**
A × T	5	5.07**	40.88**	1.54*	68.06**
L × T	2	4.56*	140.98**	0.01*	17.14**
A × L × T	10	2.54*	14.27**	3.61**	31.15**
Error	72	0.00012	0.002	138.71	0.50

Significance: *$p < 0.05$ and **$p < 0.01$.

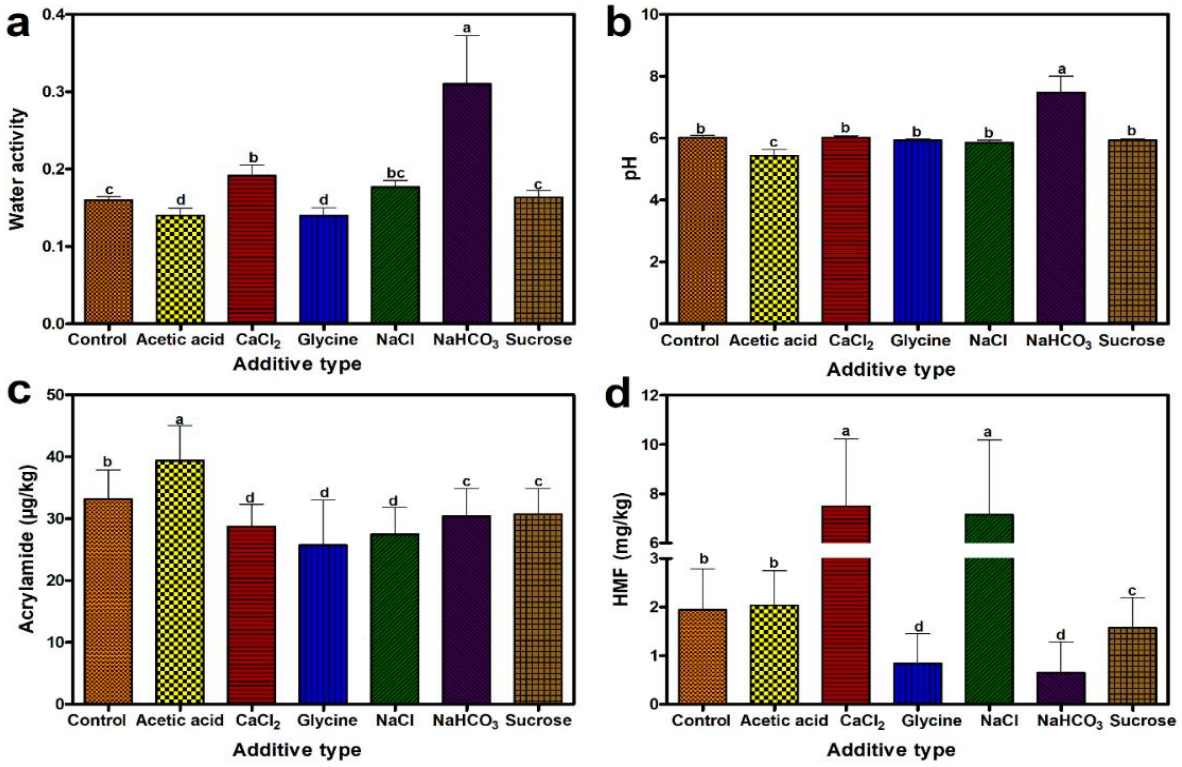

Figure 1. Means of **(a)** water activity, **(b)** pH, **(c)** acrylamide, and **(d)** HMF of tray *kadayif* samples under different additives. Data are mean ± standard deviation of triplicate ($n = 3$). Means followed by different lowercase letters are significantly different ($p < 0.05$) by the Duncan's test.

Table 2. Water activity and pH levels of tray *kadayif* dessert samples under different additives, additive levels, and frying times.

Additive type	Additive level (%)	Frying time (min)	Water activity	pH
Acetic acid	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.131 ± 0.004^{a}	5.24 ± 0.04^{b}
		40.0	0.115 ± 0.004^{b}	5.31 ± 0.04^{a}
	3.0	30.0	0.163 ± 0.010^{a}	5.10 ± 0.02^{a}
		40.0	0.113 ± 0.011^{b}	4.93 ± 0.03^{b}
$CaCl_2$	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.234 ± 0.048^{a}	6.09 ± 0.02^{a}
		40.0	0.193 ± 0.006^{b}	6.07 ± 0.00^{ab}
	3.0	30.0	0.226 ± 0.006^{a}	6.06 ± 0.01^{a}
		40.0	0.179 ± 0.001^{b}	5.86 ± 0.00^{b}
Glycine	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.150 ± 0.009^{a}	5.83 ± 0.00^{ab}
		40.0	0.148 ± 0.001^{a}	5.88 ± 0.00^{a}
	3.0	30.0	0.110 ± 0.009^{a}	5.85 ± 0.00^{b}
		40.0	0.109 ± 0.12^{a}	5.97 ± 0.00^{a}
NaCl	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.184 ± 0.000^{b}	5.85 ± 0.01^{ab}
		40.0	0.206 ± 0.007^{a}	5.92 ± 0.13^{a}
	3.0	30.0	0.185 ± 0.022^{a}	5.65 ± 0.00^{ab}
		40.0	0.161 ± 0.000^{b}	5.69 ± 0.02^{a}
$NaHCO_3$	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.300 ± 0.007^{a}	7.93 ± 0.15^{a}
		40.0	0.245 ± 0.002^{b}	7.28 ± 0.03^{b}
	3.0	30.0	0.541 ± 0.004^{a}	9.04 ± 0.08^{a}
		40.0	0.480 ± 0.001^{b}	8.58 ± 0.02^{b}
Sucrose	0	30.0	0.168 ± 0.002^{a}	5.88 ± 0.00^{b}
		40.0	0.152 ± 0.006^{b}	6.17 ± 0.00^{a}
	1.5	30.0	0.193 ± 0.002^{a}	5.77 ± 0.01^{b}
		40.0	0.160 ± 0.005^{b}	5.98 ± 0.00^{a}
	3.0	30.0	0.175 ± 0.014^{a}	5.91 ± 0.06^{a}
		40.0	0.125 ± 0.000^{b}	5.87 ± 0.08^{b}

Data are mean ± standard deviation of triplicate (n = 3). Means followed by different lowercase superscripts are significantly different ($p < 0.05$) by the Duncan's test.

durations revealed that the effects of all parameters on acrylamide formation were significant ($p \leq 0.05$) (Table 1). As depicted in Figure 1c, the lowest acrylamide levels were obtained from $CaCl_2$, glycine, and NaCl supplemented samples. Complying with the present findings, Mestdagh *et al.* (2008) reported that glycine and $CaCl_2$ additives significantly decreased acrylamide formation in potatoes. Moreover, it was reported that the addition of $CaCl_2$ to cookies yielded a decrease in acrylamide formation (Açar *et al.*, 2012). This decrease in acrylamide formation by free amino acids such as glycine could be attributed to the competition of these compounds with asparagine to react with reducing sugars in the Maillard reaction (Maan *et al.*, 2020). Furthermore, decreasing acrylamide levels by the addition of salts can also be attributed to inhibition of Schiff base as a key intermediate in acrylamide formation by cations such as Ca^{2+} or Na^{+} (Keramat *et al.*, 2011). Moreover, acetic acid supplemented samples had highest level of acrylamide (39.40 ± 13.76 µg/kg). As presented in Table 3, increasing frying durations significantly ($p < 0.05$) increased acrylamide formation of the control samples. According to Maan *et al.* (2020), there is a direct correlation between frying duration and acrylamide formation level. However, change in acrylamide values largely depends on type and dose of additives. In the present work, the acrylamide levels of acetic acid supplemented samples at both levels significantly ($p < 0.05$) decreased with increasing frying durations. Additionally, acrylamide formation in 1.5% $CaCl_2$, glycine, and sucrose supplemented samples decreased with increasing frying durations. But acrylamide levels of 3% NaCl and $NaHCO_3$ supplemented samples significantly decreased with increasing frying durations. Complying with the present findings, Liu *et al.* (2020) reported that soaking raw potato wedges into acetic acid solution caused a decrease in acrylamide formations due to extraction of asparagine and reducing sugars by acetic acid solution.

Hydroxymethylfurfural (HMF) measurement

The effects of additive type, additive level, and frying durations on HMF levels of tray *kadayif* samples were found to be highly significant ($p \leq 0.01$) (Table 1). As shown in Figure 1d, the lowest HMF levels were obtained from glycine and $NaHCO_3$ supplemented samples, and the highest levels were obtained from $CaCl_2$ and NaCl supplemented samples. Similar with the present findings, Açar *et al.* (2012) reported that the addition of $CaCl_2$ decreased acrylamide formation but increased HMF formation of cookies, due to the change of reaction path from the Maillard reaction toward dehydration of glucose. Moreover, it was reported that $CaCl_2$ and NaCl additions increased HMF levels of cookies (Kocadağlı and Gokmen, 2016) and biscuits (Van Der Fels-Klerx *et al.*, 2014). Furthermore, in the present work, HMF formation in the control sample significantly ($p < 0.05$) increased with increasing frying durations (Table 3). The HMF levels of 1.5% acetic acid, 3% glycine, and 1.5 and 3% $NaHCO_3$ supplemented samples significantly decreased with increasing frying durations. However, the HMF levels of the other samples significantly ($p < 0.05$) increased with increasing frying durations.

Colour measurement

The colour of food products such as desserts is an important key property for consumers. The L* colour parameter specifies the lightness (vary between 0 and 100), a* is related to red-green axis, and b* is related to yellow-blue axis. The results of analysis of variance for colour parameters under different additives, additive levels, and frying durations are provided in Table 4. The effects of additive type, additive level, and frying durations on colour parameters (L*, a*, and b*) were found to be highly significant ($p \leq 0.01$). The lowest L* value (35.30 ± 11.06) was obtained from glycine supplemented samples, and the highest (55.27 ± 7.07) from $CaCl_2$ supplemented samples (Figure 2a). In was reported that $CaCl_2$ additions significantly increased L* values of cookies (Açar *et al.*, 2012) and biscuits (Anese, 2010). As can be seen in Table 5, increasing frying durations decreased L* values of *kadayif* samples, except for glycine and $NaHCO_3$ supplemented samples. Such a case could be explained by more intense browning development with increasing frying durations, thus causing formation of coloured compounds such as melanoidins. The lowest a* value (5.55 ± 3.06) was obtained from $CaCl_2$ supplemented samples, and the highest (12.54 ± 3.99) from glycine supplemented samples (Figure 2b). Açar *et al.* (2012) also reported decreased a* values of cookies with $CaCl_2$ additions. The a* parameter of the *kadayif* samples in the present work, except for 1.5% acetic acid, 1.5 and 3.0% glycine, and 3% $NaHCO_3$ supplemented

Table 3. Acrylamide and HMF levels of tray *kadayif* dessert samples under different additives, additive levels, and frying times.

Additive type	Additive level (%)	Frying time (min)	Acrylamide (µg/kg)	HMF (mg/kg)
Acetic acid	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	47.46 ± 10.30[a]	3.73 ± 0.39[a]
		40.0	43.39 ± 3.62[b]	2.91 ± 0.264[b]
	3.0	30.0	56.47 ± 4.87[a]	0.00 ± 0.00[b]
		40.0	22.77 ± 6.32[b]	1.70 ± 0.03[a]
$CaCl_2$	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	34.79 ± 3.44[a]	3.79 ± 0.81[b]
		40.0	25.61 ± 12.68[b]	15.09 ± 3.81[a]
	3.0	30.0	20.04 ± 13.27[b]	5.69 ± 0.20[b]
		40.0	25.49 ± 5.80[a]	16.50 ± 0.16[a]
Glycine	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	52.07 ± 16.92[a]	0.04 ± 0.01[b]
		40.0	10.42 ± 1.97[b]	0.77 ± 0.00[a]
	3.0	30.0	10.06 ± 0.71[b]	0.30 ± 0.42[a]
		40.0	15.45 ± 5.96[a]	0.07 ± 0.09[b]
NaCl	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	16.02 ± 4.35[b]	4.47 ± 0.82[b]
		40.0	17.65 ± 2.05[a]	7.36 ± 0.47[a]
	3.0	30.0	34.54 ± 19.24[a]	5.64 ± 0.63[b]
		40.0	30.21 ± 0.52[b]	21.52 ± 0.52[a]
$NaHCO_3$	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	18.92 ± 7.01[b]	0.00 ± 0.00[b]
		40.0	38.44 ± 25.10[a]	0.00 ± 0.00[b]
	3.0	30.0	38.43 ± 36.25[a]	0.00 ± 0.00[b]
		40.0	20.25 ± 7.10[b]	0.00 ± 0.00[b]
Sucrose	0	30.0	22.67 ± 3.84[a]	0.04 ± 0.04[b]
		40.0	43.66 ± 19.56[b]	3.84 ± 0.32[a]
	1.5	30.0	23.93 ± 4.21[a]	0.07 ± 0.07[b]
		40.0	21.68 ± 15.90[b]	1.27 ± 0.24[a]
	3.0	30.0	29.33 ± 8.90[b]	1.36 ± 0.02[b]
		40.0	43.13 ± 17.73[a]	2.87 ± 0.33[a]

Data are mean ± standard deviation of triplicate (n = 3). Means followed by different lowercase superscripts are significantly different ($p < 0.05$) by the Duncan's test.

Table 4. Analysis of variance of colour parameters of tray *kadayif* dessert samples under different additives, additive levels, and frying times.

SOV	SD	L*	a*	b*
		F	F	F
Additive type (A)	5	45.55**	32.94**	65.56**
Additive level (L)	2	2.60**	20.58**	19.64**
Frying time (T)	1	54.58**	58.49**	12.14**
A × L	10	13.66**	9.44**	20.33**
A × T	5	0.55**	2.09**	3.10**
L × T	2	10.35**	7.77**	2.12**
A × L × T	10	0.70**	2.27*	1.48*
Error	72	18.75	3.51	4.84

Significance: *$p < 0.05$ and **$p < 0.01$.

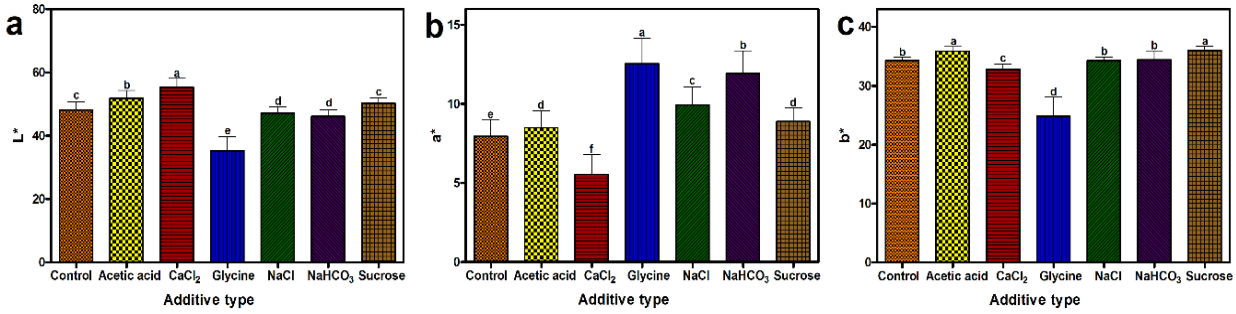

Figure 2. Means of **(a)** L*, **(b)** a*, and **(c)** b* colour parameters of tray *kadayif* samples under different additives. Data are mean ± standard deviation of triplicate ($n = 3$). Means followed by different lowercase letters are significantly different ($p < 0.05$) by the Duncan's test.

Table 5. Colour parameters of tray *kadayif* dessert samples under different additives, additive levels, and frying times.

Additive type	Additive level (%)	Frying time (min)	L*	a*	b*
Acetic acid	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	53.25 ± 2.19^{a}	9.21 ± 1.70^{a}	37.59 ± 0.72^{a}
		40.0	49.73 ± 4.66^{b}	8.26 ± 2.01^{b}	34.91 ± 0.34^{b}
	3.0	30.0	61.63 ± 6.23^{a}	5.57 ± 3.31^{b}	36.42 ± 2.13^{b}
		40.0	49.97 ± 3.52^{b}	12.07 ± 0.93^{a}	37.97 ± 2.27^{a}
$CaCl_2$	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	58.21 ± 1.43^{a}	1.68 ± 1.09^{b}	29.45 ± 2.16^{b}
		40.0	55.87 ± 3.56^{b}	7.32 ± 0.50^{a}	35.04 ± 2.77^{a}
	3.0	30.0	63.55 ± 5.12^{a}	3.10 ± 3.46^{b}	31.27 ± 1.38^{b}
		40.0	57.64 ± 3.68^{b}	5.29 ± 0.85^{a}	32.51 ± 2.74^{a}
Glycine	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	33.50 ± 0.20^{a}	16.50 ± 0.76^{a}	25.20 ± 1.96^{a}
		40.0	30.91 ± 1.69^{b}	14.93 ± 0.30^{b}	21.48 ± 2.29^{b}
	3.0	30.0	25.95 ± 2.13^{a}	14.63 ± 1.21^{a}	18.19 ± 1.07^{a}
		40.0	25.10 ± 1.00^{a}	13.25 ± 1.75^{b}	15.42 ± 2.61^{b}
NaCl	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	51.11 ± 3.38^{a}	8.53 ± 1.95^{b}	34.76 ± 2.63^{b}
		40.0	49.56 ± 6.10^{b}	10.11 ± 1.23^{a}	36.06 ± 2.61^{a}
	3.0	30.0	44.10 ± 4.64^{a}	11.12 ± 1.45^{b}	33.19 ± 1.90^{a}
		40.0	41.74 ± 6.45^{b}	13.96 ± 0.86^{a}	33.18 ± 6.15^{a}
$NaHCO_3$	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	50.70 ± 0.75^{a}	12.16 ± 1.53^{b}	39.70 ± 1.79^{a}
		40.0	45.70 ± 1.13^{b}	14.56 ± 0.54^{a}	36.45 ± 0.48^{b}
	3.0	30.0	41.14 ± 2.10^{b}	15.05 ± 0.12^{a}	33.44 ± 1.66^{a}
		40.0	42.76 ± 14.18^{a}	13.76 ± 0.93^{b}	28.29 ± 1.63^{b}
Sucrose	0	30.0	53.94 ± 2.98^{a}	5.57 ± 2.84^{b}	35.59 ± 1.89^{a}
		40.0	42.42 ± 3.42^{b}	10.33 ± 1.56^{a}	32.88 ± 1.65^{b}
	1.5	30.0	54.30 ± 1.93^{a}	7.45 ± 0.74^{b}	37.69 ± 1.84^{a}
		40.0	48.61 ± 6.85^{b}	10.04 ± 2.35^{a}	35.61 ± 2.93^{b}
	3.0	30.0	52.02 ± 1.14^{a}	8.70 ± 1.00^{b}	37.27 ± 0.36^{a}
		40.0	50.16 ± 6.23^{b}	11.24 ± 2.49^{a}	36.93 ± 3.29^{b}

Data are mean ± standard deviation of triplicate (n = 3). Means followed by different lowercase superscripts are significantly different ($p < 0.05$) by the Duncan's test.

samples, significantly ($p < 0.05$) increased with increasing frying durations. As displayed in Figure 2c, the lowest b* value (24.79 ± 8.05) was obtained from glycine supplemented samples, and the highest values (35.89 - 36.00) were obtained from acetic acid and sucrose supplemented samples. The b* values of control samples significantly ($p < 0.05$) decreased with increasing frying durations. The b* values of 3% acetic acid, 1.5 and 3.0% $CaCl_2$, and 1.5% NaCl supplemented samples increased with increasing frying durations. However, b* values of the other samples decreased with increasing frying durations.

Conclusion

Generally, water activity, pH, acrylamide, and HMF levels in all samples with different additives were in acceptable ranges. However, as compared to other additives, $CaCl_2$, glycine, and NaCl were found to be more effective in controlling acrylamide formation. Moreover, glycine and $NaHCO_3$ additives had higher inhibition activity against HMF formation. In terms of colour parameters, $CaCl_2$-supplemented samples had the highest L* and coloured Maillard reaction products. The present work provided findings that can be effective in the optimisation of *kadayif* formulation and process conditions for large-scale industrial production of this popular dessert.

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