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Research Article

Thermal inactivation of major food pathogens in air fryer cooking of lahmacun: A traditional Turkish fast food

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ABSTRACT

Lahmacun is a popular traditional fast-food style dish, widely consumed in Turkey and served in many restaurants in the EU countries. However, there are no data and standards on the thermal inactivation of pathogens when cooking lahmacun in an air fryer, which appears to be healthy because it is fast, convenient and uses less oil. This study aimed to obtain standardised data on cooking times and temperatures of lahmacun in the air fryer and to determine the thermal inactivation of *Escherichia coli O157:H7, Listeria monocytogenes*, *Salmonella* Typhimurium in an experimental environment. For this purpose, pathogen-contaminated lahmacuns were cooked in an air fryer at 180, 190 and 200°C for 3, 5 and 8 minutes each. Then, *the counts of E. coli O157:H7, L. monocytogenes, and S. Typhimurium* were determined. It was found that *E. coli O157:H7, L. monocytogenes*, and *S.* Typhimurium bacterial counts were reduced (approximately 5 log) and became edible when lahmacun was cooked in an air fryer at 180, 190 and 200°C (5 and 8 min). However, it was found that cooking at these temperatures (3 min) did not reduce *E. coli O157:H7, L. monocytogenes* and *S.* Typhimurium counts by < 1.0 log10, although the lahmacun became sensory edible. The results of this study will assist the food industry in ensuring lahmacun's microbiological safety. This study highlights the importance of validating thermal processes in new devices under home and food service use conditions to ensure consumer food safety.

Keywords: Lahmacun, *Escherichia coli O157:H7, Listeria monocytogenes, Salmonella* Typhimurium, Thermal inactivation

Introduction

People's lifestyles have changed due to increasing globalisation and industrial progress. With these changes, the demand for products that are easy to prepare and take less time (fast food) has increased instead of the traditional diet (Wang et al., 2016; İncili et al., 2020). The variety of fast-food products is increasing daily, and different fast-food products are becoming more popular in different countries. It has been reported that the most consumed fast-food meat product in China is meat burgers (Khan et al., 2019), while the most preferred fast-food meat product in Turkey is lahmacun (Arslan et al., 2023).

Although fast-food diets are increasing daily, they continue to be a concern regarding food safety. In particular, fast-food meat products can be exposed to microbial contamination during production, processing, distribution and preparation. Contaminated meat and meat products may be microbiologically spoiled due to the activity of different saprophytic microorganism species. They may also cause foodborne infections and poisoning due to contamination with pathogenic microorganisms (*Escherichia coli O157: H7, Listeria monocytogenes*, *Salmonella spp*., etc.) (Bingöl et al., 2018; Šovljanski et al., 2022). Foodborne diseases affect millions of people annually and are reported to cause about 5000 deaths (Lee & Yoon, 2021). Foods containing raw or undercooked ground beef in fast food restaurants cause significant outbreaks of salmonellosis and *E. coli* infections. In recent years, there has been an increasing trend in reporting outbreaks and sporadic cases associated with meat and meat products contaminated with pathogenic bacteria (Matle et al., 2020).

Lahmacun is a popular traditional fast-food style food. It is widely consumed in Türkiye and served in many EU restaurants. It is also available as a frozen ready meal in large chain markets. Lahmacun is a fast-food style meat product obtained by mixing the filling prepared from the mixture of minced meat, parsley, onion, garlic, black pepper, salt and spices such as isot on the dough made by mixing flour, yeast, salt and water, rolled out in an oval shape and cooking it. Its name comes from 'Lahm-i acun' (meat and dough), which means meat dough in Arabic. The history of lahmacun, also called Turkish pizza, dates back to the Babylonian period (Durmaz et al., 2019; Altun et al., 2020). Lahmacun, which many consumers prefer due to its fast and practical consumption, can cause foodborne diseases in consumers due to uncontrolled production, keeping the lahmacun filling for several days under inappropriate conditions, especially in restaurants, and the lack of a standard application regarding cooking time and temperature. Therefore, lahmacun can be considered risky regarding infections caused by *E. coli O157:H7*, *L. monocytogenes*, *S. Typhimurium*, and other pathogens.

The most important antibacterial barrier in lahmacun production is the cooking process. Indeed, it is well known that foodborne pathogenic microorganisms can survive in undercooked meat and meat products and cause foodborne outbreaks. Cooking is a critical control point in the food processing industry (Öksüztepe et al., 2013). Cooking of lahmacun varies depending on the chef's experience, consumer preference (medium or well done), oven temperature, production speed, cooking time and cooking method.

Air fryer cooking is when hot air is circulated evenly around the food, using less or no oil (Cano et al., 2022). This method has recently become popular due to the proliferation of air fryers in the market and consumers looking for alternatives to healthier cooking methods (Zaghi et al., 2019). The air fryer achieves high convection velocities through an air blower, radiant heat transfer and high transfer rates between air and food using specially designed cooking chambers. The air fryer cooking method is widely used because it is fast, convenient, low in oil and looks healthy. People use the air fryer to cook and consume frozen food (fast food), which they practically buy from the market. However, since the air fryer is a new household appliance, very few studies have investigated the inactivation of pathogens that may be present in food using this technology in the home environment (Rao et al., 2020).

In literature searches regarding this product, no published data exists on the thermal inactivation of *E. coli O157:H7, L. monocytogenes, S.* Typhimurium or other pathogens in lahmacun in an air fryer. In addition, the lack of any standard for lahmacun production reveals the risk of contamination with these pathogens. Therefore, the main objective of this study is to obtain standardised data on cooking time and temperatures of lahmacun, which will be consumed as fast food, in an air fryer, and to determine the thermal inactivation of *E. coli O157:H7, L. monocytogenes, S.* Typhimurium in an air fryer in an experimental environment.

Materials and Methods

Lahmacun Preparation

All ingredients used in the lahmacun mixture, and the dough were obtained from the local market in Şanlıurfa province.

Then, the ingredients were brought to the laboratory in a sterile and cold chain, and lahmacun was produced. The formulation of the lahmacun mixture was as follows: 500 gr raw ground beef, 200 g onion, 10 g isot spice, 120 g pepper paste (Öncü Salça, Turkey), 20 g parsley, 25 g garlic, 100 mL sunflower oil (Yudum, Turkey), 5 g black pepper (Bağdat, Baharat, Turkey), 20 g salt (Billur Tuz, Turkey). The dough was formulated: 700 g wheat flour, 280 mL water, 10 g salt (Billur Tuz, Turkey) and 10 g sugar (Torku, Turkey). After inoculating pathogenic bacteria, as mentioned above, 100 g of the dough was taken and rolled out as an oval with a diameter of 15 cm and a thickness of 3 mm. On the dough, 100 g of lahmacun mortar was spread to cover the entire surface. On the test day of each repetition, 10 lahmacuns were prepared after the materials were obtained. A total of 30 lahmacuns were prepared in the study.

Preparation of Inoculum of Pathogenic Bacteria

E. coli O157:H7 (ATCC 35150, 43984 and 43895), *Salmonella* Typhimurium (NCTC 74, 12416 and ATCC 14028), and *L. monocytogenes* (N 7144, RSKK 474 and 476) reference strains were used in this study. All strains were incubated for growth in Tryptic Soy Broth (Merck, Darmstadt, Germany) at 37°C. After incubation, the liquids were centrifuged (Nuve, NF 400, Turkey) at 4200xg for 10 minutes, and the supernatants were discarded. After centrifugation, the pellets were washed twice with sterile 0.1% peptone water (PW) (Merck, Darmstadt, Germany), mixed in a tube, and the final volume was adjusted to 10 mL using 0.1% sterile PW (Merck, Darmstadt, Germany). The tube was used as a stock inoculation cocktail. It was diluted decimally with PW to reach approximately 6.0 log10 for inoculation of the lahmacun mixture and doughs.

Experimental Contamination of Lahmacuns and Preparation of Treatment Groups

On the day of the experiment, lahmacun mixture was prepared under sterile conditions and 10 mL of *E. coli O157:H7, S.* Typhimurium and *L. monocytogenes* cocktail was added to the lahmacun dough (approximately 1 kg) and mixed by hand for 5 minutes to reach a target level of approximately 6.0 log10 CFU/g (Karyotis et al., 2017) 100 g of lahmacun dough was taken and prepared in an oval shape, and 0.5 mL of diluted bacterial cocktail was added by spreading it over all surfaces of the dough. The lahmacun mixture and dough were kept at room temperature for 10 minutes to allow the bacteria to attach. Then, 100 g of lahmacun mixture was applied to cover the dough surface.

Cooking of Lahmacuns

The prepared lahmacuns were cooked in an air fryer (Karaca,153.03.06.7771, Türkiye) at 180, 190, and 200°C for 3 min, 5 min and 8 min. Each group of lahmacun is cooked separately. The internal temperature of the samples was monitored using K-type thermocouples (HI 9057 KJT Thermocouple, Hanna instruments, Portugal). Upon reaching the target time at the specified baking temperatures, the samples were removed from the oven, kept at -18°C for 2 min, and cooled to < 10°C in a deep freezer.

Analyses

Microbiological analyses

After cooling, the sample was homogenised under sterile conditions, and 25 g was taken and placed in a sterile stomacher bag. 225 mL of 0.1% peptone water (Merck, Darmstadt, Germany) was added and homogenised in a Stomacher (Stomacher 400, France) for 3 minutes to prepare a 10^{-1} dilution. From this dilution, other dilutions of the sample up to 10-7 were prepared using the same diluent and inoculated by smear plate method to determine the number of pathogenic bacteria (in grams) in the samples (USDA/FSIS, 2011).

S. Typhimurium *count*

The S. Typhimurium count was performed on Xylose Lysine Tergitol-4 (XLT-4) agar (Merck, Darmstadt, Germany) medium. *The plates were incubated at 35°C for 24-48 hours, and specific colonies (black-coloured* colonies) were counted.

L. monocytogenes count

Oxford agar (Merck, Darmstadt, Germany) medium was used for *L. monocytogenes* count. After incubating the plates at 35°C for 24-48 hours, specific colonies (blackish green, brown colonies with black zone and sunken centre) were counted.

E. coli O157: H7 count

The E. coli O157: H7 count was performed using Cefixime Tellurite sorbitol MacConkey (BT-SMAC) agar (Merck, Darmstadt, Germany) medium. The plates were incubated at 35°C for 24-48 hours, and specific colonies (white-coloured colonies) were counted.

pH analysis

The pH values (25 ±1°C) of the mince, lahmacun mixture, dough and lahmacun samples used in the composition of lahmacun were measured using a pH meter (HI 11310, Hanna Instruments, USA).

Thermal resistance (D-values) calculation

The numbers of *E. coli O157:H7*, *S.* Typhimurium and *L. monocytogenes* detected as a result of the study were converted into logarithmic units for each temperature value. Survival curves (log CFU/g vs time) were generated using Microsoft Excel 2010 software (Karyotis et al., 2017).

Statistical analysis

All analyses were performed in three separate and independent replicates. Data sets obtained from replicates after logarithm transformation of microbiological data were presented as mean ± standard error. Data were subjected to variance analysis (ANOVA) using the general linear model (GLM) in statistical analyses. Paired comparisons between the groups were determined using post-hoc Tukey's test ($P < 0.05$).

Results and Discussion

The pH value of the lahmacun mortar was 5.3±0.10, and the dough was 5.63 ±0.14. The counts of E. coli O157:H7, S. Typhimurium, and L. monocytogenes in lahmacun samples after inoculation were 5.69 ±0.08, 5.40 ±0.29, and 5.15 ±0.15 log10 CFU/g, respectively. The changes in E. coli O157:H7, S. Typhimurium, and *L. monocytogenes* counts in lahmacun samples according to the cooking process are shown in Table 1 and Figure 1.

The number of *E. coli O157:H7* decreased by 2.19, 2.29 and 3,24 logs in lahmacun samples cooked at 180, 190 and 200°C for 3 min, respectively, and decreased below 1 log at all other temperatures and times (Table 1). The number of *S.* Typhimurium decreased by 1.53, 2.97 and 3 log in lahmacun samples cooked at 180, 190 and 200 °C for 3 min, respectively, and decreased below 1 log at all other temperatures and times (Table 1). *L. monocytogenes* decreased by 1.92, 2.07 and 2.2 log in lahmacun samples cooked at 180, 190 and 200 °C for 3 min, respectively, and decreased below 1 log at all other temperatures and times (Table 1).

Heat treatment of meat and meat products is one of the most effective methods to inactivate important pathogenic microorganisms in foods and ensure food safety (Huang, 2019). Subjecting meat (including ground meat) to an internal temperature of 70°C for 2 minutes or heat treatment equivalent to 2 minutes at 70°C inactivates pathogens (5 log reduction), making the meat edible (ACMSF, 2007). In the study, except for the lahmacun samples cooked for 3 minutes at all temperatures, the number of *E. coli O157:H7*, S. Typhimurium and *L. monocytogenes* in the lahmacun samples cooked at other cooking times and temperatures decreased by approximately 5 logs (< 1.0 log10), making them edible (Table 1). This can be explained by the fact that the thermal degradation of pathogens is significantly affected by many factors such as pH, aw, fat and salt content, changes in bacterial strains, humidity, temperature, cooking time, etc. (Charimba et al., 2010; Ilhak et al., 2013).

Table 1. *E. coli O157:H7, S.* Typhimurium and *L. monocytogenes* counts in cooked lahmacuns (log10 CFU/g)

Cooking temperature (°C)	Cooking time (min)	*Escherichia coli* O157:H7	*Salmonella* Typhimurium	*Listeria monocytogenes*
Control		5.69 ±0.08*	5.40 ±0.29*	5.15 ±0.15*
180	**3**	3.50 ±0.10^{a}	3.81 ±0.03^{a}	3.23 ±0.23^{a}
180	**5**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
180	**8**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
190	**3**	3.40 ±0.09^{a}	2.43 ±0.06^{b}	3.08 ±0.48^{a}
190	**5**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
190	**8**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
200	**3**	2.45 ±0.15^{b}	2.40 ±0.10^{b}	2.95 ±0.18^{a}
200	**5**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
200	**8**	< 1.0 ^{c}	< 1.0 ^{c}	< 1.0 ^{b}
Statistics	**H**	$P \leq 0.01$	$P \leq 0.01$	$P \geq 0.05$
	T	$P \leq 0.001$	$P \leq 0.001$	$P < 0.001$
	HxT	$P \leq 0.001$	$P \leq 0.001$	$P \geq 0.05$

$^{a-c}$: Different superscripts indicate the statistical significance among the groups ($P < 0.05$). ***H:*** Lahmacun cooking temperature; ***T:*** Cooking time; ***H×T:*** Interaction between temperature and time. *Post-inoculation count

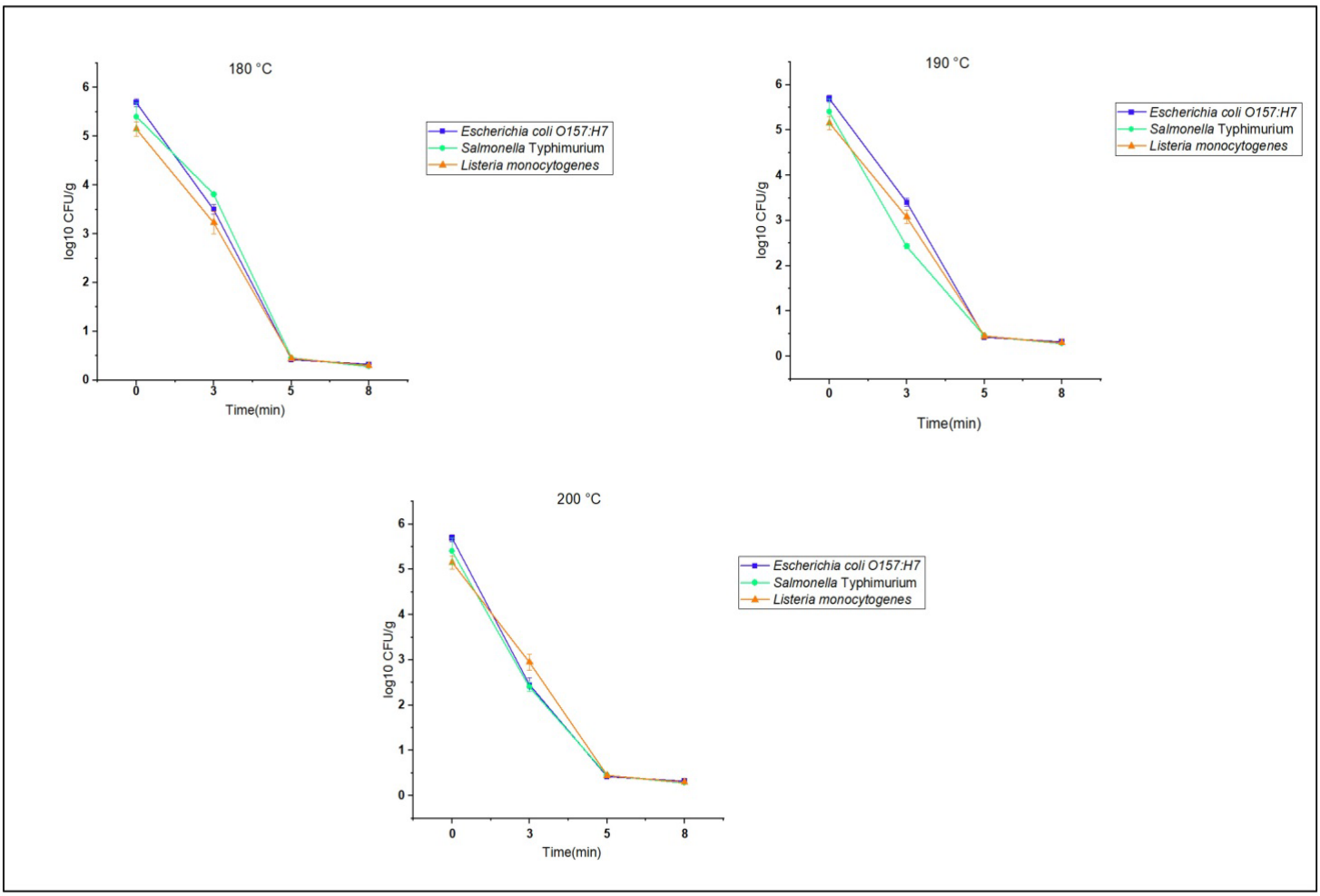

Figure 1. *Escherichia coli O157:H7*, *Salmonella* Typhimurium and *Listeria monocytogenes* counts in 180, 190 and 200°C cooked lahmacun (log10 CFU/g)

The fact that the number of *L. monocytogenes* did not decrease as much as that of *E. coli O157:H7* and *S.* Typhimurium at 3 min of cooking at all temperatures can be explained by the fact that gram-positive bacteria show more heat resistance than most non-spore-forming gram-negative pathogens (Lahou, 2015). In support of the results of the present study, Huang et al. (2019) reported that *E. coli O157:H7* was potentially the least heat resistant, while *L. monocytogenes* was the most heat resistant in their global analysis of the effect of temperature and fat on the thermal resistance of *L. monocytogenes*, *E. coli O157:H7* and *S.* Typhimurium in meat.

While the number of bacteria decreased by 5 logs at other cooking times, this decrease was not observed at 3 minutes. The most important reason is that the lahmacuns' internal temperature remained below 70°C during this period. The internal temperature of the lahmacuns was measured at a maximum of 68.4°C at 3 minutes of cooking time and above 75°C at other cooking times at all temperatures. Even at 180°C for 5 minutes, it was not surprising that the product's internal temperature was over 75°C. This is because the fryer is designed for extremely high heat transfer rates. The excellent insulation of the fryer prevents heat loss and ensures a rapid rise in the product's internal temperature. Therefore, high product temperatures can be expected quickly during the cooking process in an air fryer (Teruel et al., 2015).

Table 2. D-values of *E. coli O157:H7*, *S.* Typhimurium and *L. monocytogenes* in lahmacun at 180, 190 and 200°C

	Temperature (°C)	D-values (min)	R^2
E. coli O157:H7	180	1.29±0.05[a]	0.862±0.024
	190	1.30±0.10[a]	0.864±0.030
	200	1.34±0.08[a]	0.856±0.032
***S.* Typhimurium**	180	1.33±0.09[a]	0.845±0.035
	190	1.41±0.07[a]	0.860±0.040
	200	1.41±0.11[a]	0.859±0.027
L. monocytogenes	180	1.42±0.13[a]	0.861±0.026
	190	1.44±0.10[a]	0.866±0.020
	200	1.43±0.06[a]	0.864±0.032

[a-c]: Different superscripts indicate the statistical significance among the groups ($P < 0.05$), **R^2:** Regression of determination, **D-values:** Time required to reduce the microbial population by 90%

When the literature is examined, the number of studies investigating the viability of pathogenic bacteria in cooking foods with an air fryer is limited to our knowledge. In a study, the effect of cooking chicken wings in an air fryer at different temperatures (176, 190 or 204°C) and times (2, 5, 10, 15, 20, 22 and 25 minutes) on the viability of Salmonella was investigated. It was reported that the internal cooking temperature of chicken wings (73.8°C) was reached after an interval of 7.5 to 8.5 minutes. Salmonella counts decreased by 6.5 log 10 CFU/wing when this temperature was reached. It also reported that chicken wings reached an internal temperature rise earlier and faster in the fryer than in the conventional oven (Cano et al., 2022). However, in the present study, the internal temperature of the lahmacun exceeded this value after 5 min. This difference between the two studies, albeit at low rates, is thought to be due to the difference in the air fryer device used and that lahmacun is thinner than chicken wings.

The thermal resistance (D-values in minutes) of *E. coli O157:H7*, *S.* Typhimurium and *L. monocytogenes* obtained by linear regression in lahmacun samples cooked at 180 and 200°C are presented in Table 2. D-value for *E. coli O157:H7* decreased with increasing temperature. There was no significant difference between the temperatures for *S.* Typhimurium and *L. monocytogenes*.

The thermal resistance of microorganisms is usually determined by calculating D-values to study their survival when exposed to heat treatment. No studies investigate thermal resistance parameters (D-values) for lahmacun served in many restaurants in Turkey and the EU countries. In the study, the D-values of *E. coli O157:H7, S.* Typhimurium and *L. monocytogenes* when the lahmacun samples were cooked at different temperatures and times are given in Table 2. Thermal inactivation of *E. coli O157:H7*, *S.* Typhimurium and *L. monocytogenes* in different meat and meat products has been determined by other researchers (Murphy et al., 2002; Murphy et al., 2004a; Murphy et al., 2004b; Murphy et al., 2004c; Osaili et al., 2007; Osaili et al., 2007; Karyotis et al, 2017; Osaili et al., 2020), but the thermal resistance parameters (D-values) reported in the literature were found to vary from one study to another, including the findings of our study. This can be explained by the fact that many factors affect the thermal resistance of bacteria, including heating time and temperature, cooking method (grill, pan, etc.), bacterial species and strains, fat content, moisture, pH, salt content, and the presence of antimicrobials (Osaili et al., 2007; Karyotis et al., 2017; Osaili et al., 2020).

Conclusion

It was found that *E. coli O157:H7, L. monocytogenes* and *S.* Typhimurium bacterial counts were reduced (approximately 5 log) and became edible when lahmacun was cooked in an air fryer at 180, 190 and 200°C (5 and 8 min). However, it was found that cooking at these temperatures (3 min) did not reduce *E. coli O157:H7, L. monocytogenes* and *S.* Typhimurium counts by < 1.0 log10, although the lahmacun became sensory edible. The results of the study show that if the specified temperatures and times are followed, it can be said that cooking lahmacun in an air fryer does not pose a risk in terms of pathogenic bacteria. However, it should be noted that even low numbers of pathogens can pose significant public health risks if undercooked or consumed by people from a high-risk population. In conclusion, besides the fact that lahmacun is a popular food, the results of this study indicate that uncontrolled heat treatment during cooking with an air fryer increases the risk of pathogenic bacteria in lahmacun. The data obtained from this study may help to design appropriate processing times and temperature/cooking regimes to ensure food safety when cooking lahmacun in an air fryer.

Compliance with Ethical Standards

Conflict of interest: The author(s) declares that they have no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: The authors declare that this study does not include experiments with human or animal subjects, so ethics committee approval is not required.

Data availability: Data will be made available at the request of the author(s).

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Disclosure: -

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