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STUDY OF MEIQX AND PHIP ACCUMULATION IN PORK PATTIES DURING THEIR SEQUENTIAL HEAT TREATMENT

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Abstract
Heterocyclic aromatic amines, such as MeIQx and PhIP, are carcinogenic and mutagenic compounds formed in meat products during high-temperature cooking. Despite their proven harmful effects, they are not regulated in food products, as home-cooked products are at the highest risk of HAA formation. Therefore, research on effective ways to reduce their formation during home cooking is urgently needed. One promising approach is the use of vegetable oils, due to their high content of vitamin E, known for its antioxidant properties. However, the maintenance of these oils' inhibitory properties against HAA formation during repeated use is poorly understood. The aim of this study was to determine whether the inhibition of HAA formation by vegetable oils may be maintained during the sequential frying of multiple meat products. Three types of vegetable oils were used in the study: olive oil, high-oleic sunflower oil, and medium-oleic sunflower oil. Four pork patties were sequentially fried for each oil at a temperature of 160 °C until the center of the patty reached 72 °C. HAA content was determined using HPLC–MS/MS, and the fatty acid composition and vitamin E content of the oils were also examined. The data obtained showed no statistically significant accumulation of HAA from the first to the fourth patty fried in the same oil. This indicates that the antioxidant activity of the oils is maintained even after repeated use. However, significant differences were found between the different types of oils. The lowest content of both MeIQx (0.54 ng/g) and PhIP (1.75 ng/g) was recorded in patties fried in medium oleic sunflower oil, and the highest content was recorded in olive oil (0.89 ng/g and 2.37 ng/g, respectively). A clear negative correlation was established between the vitamin E content in the oils and the level of HAA formation. A negative correlation with the total proportion of unsaturated fatty acids was also noted. The results of the study demonstrate that vegetable oils, particularly medium-oleic sunflower oil with a high vitamin E content, effectively inhibit HAA formation during the heat treatment of meat products and maintain this ability during sequential frying of up to four products. This confirms the key role of antioxidants in inhibiting the Maillard reaction leading to HAA formation.

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Introduction

Almost any animal product requires heat treatment before consumption. Heat treatment imparts a more pleasant flavor and aroma, makes its nutrients more bioavailable, and makes the product safer from a microbiological standpoint. However, heat treatment also produces compounds that are potentially harmful to the human body. These compounds include heterocyclic aromatic amines (HAA), which are formed primarily in animal-based foods during heat treatment, especially high-temperature processes such as frying, baking, etc. [1,2]. In general, the formation of HAA is influenced by many factors. These include the extent of heat treatment, its duration, the type of raw materials used, and non-meat ingredients included in the product [3].

Despite the fact that HAA have proven carcinogenic and mutagenic effects [4], they are currently not standardized or controlled in food products in any country. This is partly due to the fact that homemade foods are more at risk of their formation, and it is impossible to control such products. Nevertheless, the global scientific community is actively working to find ways to reduce the amount of HAA formed in food products during heat treatment [5].

The main areas of research to find ways to reduce the amount of HAA formed include temperature modifications and the addition of plant-based ingredients containing components with high antioxidant activity (e. g., vitamin E) to meat product recipes, immediately before heat treatment, or prior to heat treatment (e. g., marinating).

The effect of ingredients containing components with high antioxidant activity on the formation of HAA was demonstrated in [6]. It was found that the addition of blueberry, cherry, acerola, and grape seed extracts to fish resulted in a reduction in HAA, such as norharman and PhIP, by 94.85 and 71.15 % relative to the control sample, respectively, while the amounts of IQ, 8-MeIQx, and 4,8-DiMeIQx decreased to concentrations below the detection limit of the method. Components included in garlic, namely diallyl disulfide, also significantly reduce the amount of HAA in the product. The addition of a nanoemulsion of diallyl disulfide with soy protein resulted in a reduction in the amounts of MeIQx, PhIP, and harman in fried pork by 52 %, 77 %, and 49 %, respectively [7].

The results of a study [8] investigating the effect of rosemary extract and pure vitamin E on the formation of IQ, MeIQ, MeIQx, DiMeIQx, and PhIP in minced beef products showed that the addition of vitamin E to the product formulation reduced the amount of formed HAA by 70–80 %, while rosemary extract reduced the amount of HAA by 12–87 %.

The effect of vegetable oils on the formation of HAA was most clearly demonstrated in a study [9], in which lard (control sample) and a mixture of lard with sunflower oil, olive oil, or pomegranate oil (test samples) were added to lean pork. The results of the study showed that partial replacement of animal fat with vegetable oil may lead to a reduction in the amount of HAA in the product by 83–100 %. The greatest effect was observed with pomegranate oil.

Some plant proteins exhibit an effect similar to that of vegetable oils in HAA formation. For example, adding soy protein isolate to pork resulted in a 69 %, 79 %, and 100 % reduction in MeIQx, 4,8-MeIQx, and IQx, respectively [10]. Carbohydrates also influence HAA formation. For example, study [11] examined the effect of adding corn, potato, and cassava starch to beef patties. The results showed that adding corn or cassava starch to the product before heat treatment reduced the amount of HAA formed in the product, while potato starch, conversely, increased their amount. Corn starch demonstrated the greatest inhibitory effect on HAA formation, with reductions observed in this study reaching 55 %.

Study [12] demonstrated the effect of adding carrot, tomato, and lettuce extracts to beef patties. Carrot extract demonstrated the greatest inhibitory effect, reducing the total HAA content in the product by almost 33 %. It also reduced each of the 12 analytes determined. Tomato extract demonstrated lower inhibitory properties, reducing the total HAA content in the product relative to the control sample by approximately 20 %. Furthermore, tomato extract did not reduce every analyte, slightly increasing some. The lowest HAA reduction was observed with lettuce extract, reducing the total HAA content relative to the control sample by approximately 8 %. As with tomato extract, lettuce extract did not reduce every analyte determined, but more importantly, adding lettuce extract to beef patties significantly increased the content of some HAA. Similarly, Zhang et al. [13] studied the effect of celery, carrot, and sweet potato extracts on HAA formation in mackerel cooked at different temperatures (180, 210, and 240 °C). In this case, the greatest effectiveness was observed with the addition of celery extract. The total HAA content in the product containing it was more than 12 times lower than in the control sample. Sweet potato reduced the total HAA content by almost 10 times, and carrots reduced it by almost 5 times.

Considering the “harmfulness” of meat, which has been actively discussed in the media in developed countries in recent years, the idea that plant-based products are safer than meat is being actively promoted. The authors of [14] studied the carcinogen content in beef patties and patties made from plant-based ingredients (soy, corn, and rice). They found that overall, plant-based patties produced lower levels of HAA than beef patties, although the levels of PhIP in beef and soy patties were almost the same. However, plant-based products produced significantly higher levels of PAHs than meat products.

The antioxidant activity of compounds in non-meat ingredients directly influences the amount of HAA formed during heat treatment. However, Zhang et al. [15] used a completely new approach to heat treatment of food products to increase their antioxidant capacity. The authors treated meat raw materials with plasma-activated water. This treatment of meat raw materials resulted in a reduction of the total amount of HAA in fried patties by up to 11 %.

Returning to the use of plant components to reduce the amount of HAA formed, it is worth noting the significant reduction achieved by the authors of the study [16]. In this study, an aqueous suspension of mandarin peels of varying concentrations was added to the frying of rabbit meat. According to the results obtained, the addition of mandarin peels during frying reduced the amount of HAA formed by 54–95 %.

It is important that, despite their good performance in inhibiting HAA formation in meat products, the addition of non-meat ingredients may negatively impact the development of flavor and aroma during heat treatment. For example, the authors [17] investigated the inhibitory properties of capers, oregano, wine, and green tea. Having established that the selected ingredients significantly impacted HAA formation in the product to varying degrees, they decided to evaluate the extent to which these ingredients might affect sensory perception. According to the presented results, capers and oregano had a little effect on the flavor and aroma of the products, while samples containing green tea and wine differed significantly from the “standard samples” and were the least appealing [18].

The study [19] examined the effect of the type of oil used for frying on the amount of HAA formed. Eight types of oils (seven vegetable oils and butter) were examined. According to the data presented, all vegetable oils used reduced the amount of HAA formed. The greatest reduction was observed in samples containing avocado oil, while butter, conversely, led to an increase in the amount of HAA formed. For all seven vegetable oils, the degree of HAA reduction correlated negatively with their vitamin E content; i. e., the more vitamin E in the oil, the less HAA formed when frying meat products in it.

The authors of the study [20] demonstrated that the antioxidant capacity of oils can be increased by adding antioxidants of various origins. Adinandra leaf extract, mixed with tea polyphenols, sesamol, or rosemary extract, was added to soybean oil before frying chicken breast. According to research results, adding only adinandra leaf extract to the oil resulted in a 12–38 % reduction in the total HAA content in the product. Meanwhile, a mixture of adinandra with tea polyphenols, sesamol, and rosemary extract resulted in a 34–61 %, 16–45 %, and 25–48 % reduction in HAA content, respectively.

Not all substances may exhibit the same inhibitory or catalytic effect under different conditions. This is well demonstrated in [21], which presents the effect of treating squid surimi with gallic acid before heat treatment on the MeIQx content. Squid meat treated with gallic acid was fried at temperatures of 100, 120, 140, 160, 180, 200, and 220 °C. According to the results, a significant reduction in MeIQx due to gallic acid was observed with heat treatment from 120 to 180 °C. At temperatures of 100 and 220 °C, the amount of MeIQx in the test sample was slightly lower than in the control, while at 200 °C, more MeIQx was formed in the test sample.

This review demonstrates that there are numerous ways to reduce the amount of HAA in fried products, ranging from adding non-meat ingredients to treating meat with plasma-activated water. However, information regarding the likelihood of HAA formation during repeated frying of minced meat products in the same oil is very limited. Therefore, research aimed at studying the accumulation of HAA during sequential frying of products made from minced meat products is highly relevant. The aim of this study was to determine whether the inhibitory properties of vegetable oils on HAA formation are maintained during sequential frying of several minced meat products.

Objects and methods

To make the patties, we used pork (*M. longissimus dorsi*), C1 grade chicken eggs, and pasteurized reconstituted cow's milk with a fat content of 3.2 %. The pork was chopped, removing visible fat and connective tissue, and then minced in a household meat grinder with a mesh diameter of 3–5 mm. Eggs were cracked into a 500 ml cup and then mixed with a whisk for 3 minutes until smooth. The ingredients were mixed at a meat: milk: egg ratio of 7:2:1, then mixed by hand until smooth. The resulting minced meat was formed into round patties, each weighing 50.0 ± 2.0 g and measuring approximately 6 cm in diameter and approximately 3 cm in height.

High-oleic sunflower oil, medium-oleic sunflower oil, and olive oil were used for cooking. These oils were chosen as the most commonly used for home cooking.

The heat treatment was carried out in a 15.5 cm diameter nonstick frying pan placed on RCT basic laboratory heater with an attached immersion thermometer (IKA, Germany). 50 ml of oil was added to the pan and heated to a constant temperature of 160 °C. Once the temperature was reached, a patty was placed in the pan and fried until the center of the patty reached a constant temperature of 72 °C. The patties were flipped every 2 minutes. Once the temperature reached, the patty was fried for an additional 2 minutes, then removed from the pan and placed in a plastic container with a lid, where it cooled to room temperature. After the first sample, three more were fried in the same oil and heat treated under the same conditions. Considering that after frying the fourth patty, there was almost no vegetable oil left in the pan, it was decided to fry four patties in each of the selected oils.

After cooling to room temperature, the patties were ground using Buchi B-400 laboratory homogenizer (Buchi, Switzerland) and then stored in plastic containers in a freezer at a temperature no higher than −18 °C until analyzed for HAA content (MeIQx and PhIP). HAA was quantified according to [22].

Vegetable oils were analyzed for fatty acid composition according to GOST 31663-2021[1] using Agilent 7890A gas chromatograph with a flame ionization detector (Agilent, USA), and vitamin E content was determined according to GOST 32307-2013[2] using Dionex Ultimate 3000 liquid chromatograph with a UV detector (Thermo Fisher Scientific, USA).

STATISTICA 10 software was used to calculate HAA content in the samples. Results were presented as mean ± SD. Statistical significance was calculated using analysis of variance (ANOVA) with Tukey's test. A probability of 0.05 was chosen as the significance level.

Results and discussion

Table 1 shows the results of determining the vitamin E content in oils.

Table 1. Vitamin E content in oils, mg/100 g

Oil type	Vitamin E content
Olive oil	13.8
High-oleic sunflower oil	42.4
Medium-oleic sunflower oil	46.1

Table 2 shows the results of the FA content in vegetable oils.

Table 3 and Table 4 show the results of the HAA content analysis in the samples.

The letters a, b show the significant difference between the obtained results of the average content of MeIQx in the batch.

The letters a, b show the significant difference between the obtained results of the average content of PhIP in the batch.

[1]GOST 31663-2021 “Vegetable oils and animal fats. Determination of methyl esters of fatty acids by gaz chromatography method”. Retrieved from https://internet-law.ru/gosts/gost/56502/ Accessed August 18, 2025

[2]GOST 32307-2013 “Meat and meat products. Determination of fat-soluble vitamins by high performance liquid chromatography”. Retrieved from https://docs.cntd.ru/document/1200107182 Accessed August 18, 2025

Table 2. Fatty acid composition of vegetable oils, %

Fatty acid	Olive oil	High-oleic sunflower oil	Medium-oleic sunflower oil
Myristic C14:0	less than 0.1	less than 0.1	less than 0.1
Palmitic C16:0	10.8	2.9	5.0
Palmitoleic C16:1	0.6	less than 0.1	less than 0.1
Margaric C17:0	less than 0.1	less than 0.1	less than 0.1
Heptadecenoic C17:1	less than 0.1	less than 0.1	less than 0.1
Stearic C18:0	3.6	3.2	4.0
Oleic C18:1	56.2	82.4	57.9
Linoleic C18:2	28.0	10.1	32.0
Linolenic C18:3	0.3	0.2	less than 0.1
Arachidic C20:0	0.4	0.3	0.2
Gondoic C20:1ω9	less than 0.1	0.2	0.1
Behenic C22:0	less than 0.1	0.8	0.8
Lignoceric C24:0	less than 0.1	less than 0.1	less than 0.1
∑ unsaturated fatty acids	84.5	92.9	90.0

Table 3. MeIQx content in the samples, ng/g

Vegetable oil used	Sample				Average content in a batch
	1	2	3	4	
Olive oil	**0.88 ± 0.09**	**0.85 ± 0.10**	**0.96 ± 0.06**	**0.85 ± 0.11**	**0.89**
High-oleic sunflower oil	**0.56 ± 0.06**	**0.61 ± 0.07**	**0.61 ± 0.04**	**0.60 ± 0.08**	**0.60a**
Medium-oleic sunflower oil	**0.55 ± 0.04**	**0.49 ± 0.04**	**0.53 ± 0.06**	**0.58 ± 0.05**	**0.54ab**

Note: Results are presented as the mean of three parallel measurements ± standard deviation. The standard deviation indicates the precision of the method.

Table 4. PhIP content in the samples, ng/g

Vegetable oil used	Sample				Average content in a batch
	1	2	3	4	
Olive oil	**2.35 ± 0.22**	**2.38 ± 0.18**	**2.42 ± 0.18**	**2.31 ± 0.24**	**2.37**
High-oleic sunflower oil	**1.84 ± 0.31**	**1.79 ± 0.15**	**1.75 ± 0.13**	**1.78 ± 0.20**	**1.79a**
Medium-oleic sunflower oil	**1.72 ± 0.07**	**1.76 ± 0.12**	**1.75 ± 0.09**	**1.75 ± 0.15**	**1.75ab**

Note: Results are presented as the mean of three parallel measurements ± standard deviation. The standard deviation indicates the precision of the method.

The results showed that HAAs do not accumulate in the products during sequential frying in the same oil. A slight difference in the obtained MeIQx and PhIP concentrations is observed, but it is statistically insignificant and is most likely due to an error in the determination method. Moreover, no difference was observed even between the first samples, which were fried in the original volume of oil, and the fourth samples, which were fried in a pan with significantly less oil. Thus, this circumstance may indicate that the oils do not lose their antioxidant activity during heat treatment when frying up to four samples of minced pork products in them sequentially.

However, statistically significant differences in the average MeIQx and PhIP content were observed in all three batches. This difference was most pronounced between the patties fried in olive oil and those fried in two types of sunflower oil. The amount of MeIQx in patties fried in olive oil was approximately 1.5 and 1.6 times higher than in patties fried in high-oleic sunflower oil and medium-oleic sunflower oil, respectively. A similar pattern was observed for the amount of PhIP: in patties fried in olive oil, its content was approximately 1.3 and 1.4 times higher than in patties fried in high-oleic and medium-oleic sunflower oils, respectively. The difference in the average MeIQx and PhIP content in patties fried in different sunflower oils was also statistically significant. Among the three selected types of vegetable oils, the lowest amount of HAA was formed in patties fried in medium-oleic sunflower oil.

Overall, the difference in HAA content negatively correlates with the vitamin E content of the oils used. Olive oil has the lowest vitamin E content, while the samples fried in it produced the highest amounts of HAA. Medium-oleic sunflower oil contains slightly more vitamin E than high-oleic sunflower oil, and the formation of HAA in patties fried in medium-oleic sunflower oil was correspondingly slightly lower than in patties fried in high-oleic sunflower oil. The strong negative correlation found between the vitamin E content in the oil and the level of HAA formed in the patties is fully consistent with the generally accepted mechanism of antioxidant action. Vitamin E, by inhibiting radical lipid oxidation reactions and suppressing peroxidation, indirectly prevents the formation of active intermediates (such as aldehydes), which are key participants in the Maillard reaction and subsequent stages of HAA formation. Thus, the higher vitamin E content in sunflower oils provides more effective protection against oxidation during frying, which leads to a decrease in the formation of MeIQx and PhIP. However, the obtained results do not agree with the results obtained in [19], in which the amount of HAA in steaks fried in sunflower and olive oils was at approximately the same level, and in steaks fried in high-oleic sunflower oil, less HAA was formed than in steaks fried in medium-oleic sunflower oil. The significant difference in HAA content between olive and sunflower oils may probably be explained by the fact that in [19], piece products were subjected to heat treatment, while in the present study, the raw material was ground, and in products made from ground meat, HAA are formed more intensively than in products made from whole pieces. This is due to the larger surface area in contact with atmospheric oxygen and the heating surface, a higher yield of reactive precursors (creatinine, free amino acids, sugars) from destroyed muscle cells, and also, possibly, the presence of additional catalytic components released during grinding. Nadeem et al. [23] conducted a large review of works devoted to methods for reducing HAA in meat products. A large number of works have shown that the addition of plant components to meat products allows for a decrease in the amount of formed HAA, however, the authors of the work [24] cited in this review emphasize that when marinating meat raw materials with plant ingredients, they also extract from the meat raw materials both precursors and inhibitors of the reaction of HAA formation. Work [24] may indirectly confirm the differences in the results of the present work with [19], since when grinding the raw materials, as was already noted earlier, a greater number of HAA precursors are released. That raw material grinding plays a positive role in the formation of HAA can be seen by comparing the obtained results with those of [25], where the authors added a source of omega-3 acids, flaxseed oil, to ground products. This resulted in a significant reduction in HAA relative to control samples. The present study did not aim to test the pre-added oil. However, based on the fact that the HAA content did not increase from sample to sample during sequential frying of products in the same oil, it can be concluded that grinding the raw material allows the vegetable oil to better penetrate the products and, accordingly, better exhibit its inhibitory properties.

The fatty acid composition of the oils (Table 2) also shows significant differences. Olive oil has the lowest total unsaturated fatty acid content (84.5 %) compared to sunflower oils (92.9 % and 90.0 %). Oleic acid (C18:1, 56.2 %) accounts for the majority of the unsaturated fatty acid content in olive oil, while for high-oleic and medium-oleic sunflower oils, these are oleic acid (82.4 % and 57.9 %) and linoleic acid (C18:2, 10.1% and 32.0 %), respectively. The HAA content in the studied samples also negatively correlates with the amount of unsaturated fatty acids in the oils. Olive oil has the lowest amount, while sunflower oils contain approximately the same amount, as does vitamin E. However, there is no reliable information on the effect of unsaturated FAs on the HAA formation. On the one hand, some studies argue that unsaturated FAs are more prone to oxidation upon heating, and their oxidation products (e. g., reactive aldehydes) may act as precursors or catalysts in the formation of HAA. When discussing the catalytic properties of unsaturated FAs, it is important to emphasize that it is their oxidation products that lead to an increase in the amount of HAA. A study [26] demonstrated a direct proportional relationship between the amount of PhIP formed and the content of propanal, hexanal, and other aldehydes formed as a result of fatty acid oxidation in the samples. It was demonstrated in [27] that aldehydes and other fatty acid oxidation products lead to an increase in HAA. According to the results, the higher the degree of fat oxidation and, accordingly, the more oxidation products are formed, the greater the amounts of PhIP formed in model systems of phenylalanine and creatine/creatinine, the main precursors of PhIP in meat. This is also confirmed by the research of Zhao et al. [28], which showed that when *Flos sophorae immaturus* extract is added to the product, due to its antioxidant properties, fewer oxidation products, essentially aldehydes, and, accordingly, fewer HAA are observed in the samples by reaction with thiobarbituric acid. A large review article [29] is devoted to the instability and strong oxidizability of unsaturated fatty acids (especially omega-3). Moreover, their oxidation actively occurs not only at elevated temperatures, but also under normal storage conditions of products containing them. Thus, the use of sources of unsaturated fatty acids in order to reduce the amounts of HAA during the preparation of meat products may not be a very good idea, since they will already contain some amounts of FA oxidation products. However, earlier Aslanova et al. [25] showed that the addition of flaxseed oil as a source of omega-3 FA resulted in a significant decrease in the HAA content in the samples, much greater in percentage terms than the use of flaxseed oil for frying [19], despite its relatively high vitamin E content, which may be due to the fact that the smoke point of flaxseed oil is quite low. In general, the influence of fat oxidation products on the reaction of HAA formation was discussed in detail in a review paper [30]. Aldehydes are the main products in the lipid oxidation reaction, and as a result of their oligomerization and cyclization, a large number of heterocyclic structures are formed in food products, which subsequently participate in the formation of carcinogenic and mutagenic HAA. Thus, sources of unsaturated fatty acids, since such acids are most prone to oxidation, should, in theory, lead to an increase in the amounts of HAA formed.

On the other hand, as shown in some studies, in addition to the antioxidant activity of unsaturated fatty acids themselves, their oxidation products may participate in competing reactions leading to the formation of compounds with antioxidant activity, or physically block highly reactive intermediates or functional groups in the reaction of HAA formation. The review paper [31] states that polyunsaturated fatty acids, due to their antioxidant activity, prevent the formation of HAA. This is confirmed by the work [32], the results of which show a significant decrease in HAA in the product due to the use of olive oil.

The inhibitory properties of unsaturated fatty acids in the reaction of HAA formation have also been proven in [33], where the authors marinated raw meat in propolis extract, a source of acids such as oleic, linoleic and linolenic. As a result of using propolis extract, it was possible to achieve a reduction of some HAA by up to 100 %. The inhibitory properties of polyunsaturated fatty acids are shown in [34]. Unlike most studies, the experiment was not conducted with raw meat. Instead, the authors experimentally reproduced the reactions occurring in meat products during heat treatment, which demonstrated the inhibitory properties of unsaturated fatty acids in isolation.

Therefore, it is difficult to assess the influence of unsaturated fatty acids on the amount of HAA formed in the samples studied in this study. However, the presence of unsaturated fatty acids in the product is important, as at high concentrations, unsaturated fatty acids may reduce the ability of HAA to form DNA adducts, which, accordingly, reduces the likelihood of tumors in the body from consuming products containing carcinogens [35]. In the oils used in this study, oleic acid accounted for the largest proportion of their composition. According to [27], the amount of oleic acid positively correlates with the amount of MeIQx and DiMeIQx formed in the product. However, based on the data obtained during this study, a relationship between oleic acid content and the amount of HAA cannot be established.

In this study, a negative correlation was observed between the total unsaturated FA content and HAA level, which is similar to the vitamin E content. Therefore, it is not possible to clearly separate the contributions of unsaturated FAs and vitamin E to the inhibition of HAA formation. The high unsaturated FA content of sunflower oils is likely an additional factor contributing to their antioxidant capacity, but vitamin E plays a key regulatory role in inhibiting adverse reactions.

This study demonstrates that the choice of vegetable oil for frying is a significant factor influencing HAA formation in meat products. Sunflower oils, especially medium-oleic oils, exhibit more pronounced inhibitory properties compared to olive oil due to their higher vitamin E content and fatty acid composition. A key finding is the stability of these inhibitory properties even when using the same volume of oil sequentially for frying up to four products.

Conclusion

The data obtained in this study showed that vegetable oils, most likely due to their high vitamin E content, maintain their inhibitory properties against HAA formation in meat products during heat treatment. The results showed that up to four patties can be fried in a single oil without increasing the HAA content. This study provides further confirmation that vitamin E, due to its antioxidant properties, plays a significant role in reducing the HAA content in meat products during heat treatment. HAA content also negatively correlates with the unsaturated fatty acid content of the oils used. However, it is impossible to say with certainty whether they inhibit HAA formation, as numerous studies currently exist demonstrating both the inhibitory properties of unsaturated fatty acids and, conversely, their catalytic properties. This study also once again demonstrates the risk of HAA formation in meat products during home heat treatment, and that this risk can be managed.

The practical significance of this study lies in confirming the feasibility of using vegetable oils to reduce HAA formation during heat treatment of meat products at home. The results of the study can be used to develop recommendations for the safe preparation of meat products. The data obtained expand our understanding of the mechanisms of HAA formation during heat treatment of meat products and confirm the important role of the antioxidant properties of vegetable oils in reducing the formation of potentially harmful compounds.

Although oils maintain their effectiveness in reducing HAA formation, further research is needed in related areas. First, it is necessary to study the maintenance of antioxidant properties in a larger number of oils, both those commonly used in heat treatment of meat products at home and those rarely used, such as canola, corn, avocado, and pomegranate oils. Second, it is important to study the accumulation of not only HAA but also other compounds potentially or proven to be harmful to the human body, such as acrylamide, acrolein, and PAHs. Third, it is of interest to study the effect of the degree of purification (refining) of oil on its antioxidant capacity and ability to inhibit HAA formation. Finally, sensory analysis of products prepared using oils after repeated heating is necessary to provide a comprehensive consumer assessment.

REFERENCES

1. Sugimura, T., Wakabayashi, K., Nakagama, H., Nagao, M. (2004). Heterocyclic amines: Mutagens/carcinogens produced during cooking of meat and fish. *Cancer Science*, 95(4), 290–299. https://doi.org/10.1111/j.1349-7006.2004.tb03205.x
2. Oz, E., Aoudeh, E., Murkovic, M., Toldra, F., Gomez-Zavaglia, A., Brennan, C. et al. (2023). Heterocyclic aromatic amines in meat: Formation mechanisms, toxicological implications, occurrence, risk evaluation, and analytical methods. *Meat Science*, 205, Article 109312. https://doi.org/10.1016/j.meatsci.2023.109312
3. Dundar, A., Saricoban, C., Yilmaz, M. T. (2012). Response surface optimization of effects of some processing variables on carcinogenic/mutagenic heterocyclic aromatic amine (HAA) content in cooked patties. *Meat Science*, 91(3), 325–333. https://doi.org/10.1016/j.meatsci.2012.02.011
4. Barzegar, F., Kamankesh, M., Mohammadi, A. (2019). Heterocyclic aromatic amines in cooked food: A review on formation, health risk-toxicology and their analytical techniques. *Food Chemistry*, 280, 240–254. https://doi.org/10.1016/j.foodchem.2018.12.058

5. Wang, H., Chu, X., Du, P., He, H., He, F., Liu, Y. et al. (2023). Unveiling heterocyclic aromatic amines (HAAs) in thermally processed meat products: Formation, toxicity, and strategies for reduction — A comprehensive review. *Food Chemistry: X*, 19, Article 100833. https://doi.org/10.1016/j.fochx.2023.100833
6. Li, M., Lin, S., Wang, R., Gao, D., Bao, Z., Chen, D. et al. (2022). Inhibitory effect and mechanism of various fruit extracts on the formation of heterocyclic aromatic amines and flavor changes in roast large yellow croaker (*Pseudosciaena crocea*). *Food Control*, 131, Article 108410. https://doi.org/10.1016/j.foodcont.2021.108410
7. Wan, Xi., Li, D., Lu, J., Yan, Y., He, Zh., Chen, J. et al. (2023). The construction of garlic diallyl disulfide nano-emulsions and their effect on the physicochemical properties and heterocyclic aromatic amines formation in roasted pork. *Food Chemistry*, 408, Article 135159. https://doi.org/10.1016/j.foodchem.2022.135159
8. Balogh, Z., Gray, J.I., Goma, E.A., Booren, A.M. (2000). Formation and inhibition of heterocyclic aromatic amines in fried ground beef patties. *Food and Chemical Toxicology*, 38(5), 395–401. https://doi.org/10.1016/s0278-6915(00)00010-7
9. Gunter, F., Kuhle, K., Chen, Q. (2017). Vegetable oil as fat replacer inhibits formation of heterocyclic amines and polycyclic aromatic hydrocarbons in reduced fat pork patties. *Food Control,* 81, 113–125. https://doi.org/10.1016/j.foodcont.2017.05.043
10. Li, W., Wan, X., Chen., C., Guo, Y., Jiao, Y., He, Z. et al. (2023). Effects of soy protein and its hydrolysates on the formation of heterocyclic aromatic amines in roasted pork. *Meat Science*, 204, Article 109236. https://doi.org/10.1016/j.meatsci.2023.109236
11. Li, G., Zheng, Xi., Wen, R., Zhao, Xi., Hu, Yi., Zhang, L. (2025). Inhibition of starch on the formation of free and protein-bound heterocyclic aromatic amines in roasted beef patties and the underlying mechanism. *Carbohydrate Polymers*, 366, Article 123936. https://doi.org/10.1016/j.carbpol.2025.123936
12. Li, Q., Zheng, X., Wen, R, Qi, J., Shao, L., Hu, Y. et al. (2025). Effects of vegetable extracts on the formation of heterocyclic aromatic amines and advanced glycation end products during roasting and *in vitro* digestion of roasted beef patties. *Meat Science*, 229, Article 109925. https://doi.org/10.1016/j.meatsci.2025.109925
13. Zhang, S., Wang, R., Chu, J., Sun, C., Lin, S. (2023). Vegetable extracts: Effective inhibitors of heterocyclic aromatic amines and advanced glycation end products in roasted Mackerel. *Food Chemistry*, 412, Article 135559. https://doi.org/10.1016/j.foodchem.2023.135559
14. Thamsorn, S., Phucharoenrak, P., Winuprasith, Th., Trachootham, D. (2024). Grilled plant (Soy, Rice, Corn)-Based patties contain lower amounts of heterocyclic aromatic amines but not polycyclic aromatic hydrocarbons than grilled beef patties. *Food Control*, 161, Article 110398. https://doi.org/10.1016/j.foodcont.2024.110398
15. Zhang, C.-X., Wang, X.-H., Xue, C.-Y., Chen, Y., Zhang, Z.-N., Ma, Y.-X. et al. (2024). Simultaneous mitigation of heterocyclic aromatic amines and advanced glycation end products in roasted beef patties by plasma-activated water: Effects and mechanisms. *Food Chemistry*, 456, Article 140003. https://doi.org/10.1016/j.foodchem.2024.140003
16. Ping, C., Zhao, X., He, C., Zheng, Y., Zhang, H. (2024). Comparing effects of tangerine-peel (*Citrus reticulata Blanco*) age and concentration on deep-fried rabbit meat: Impact on heterocyclic aromatic amines, amino acids, and flavor compound formation. *Food Chemistry: X,* 24, Article 101902. https://doi.org/10.1016/j.fochx.2024.101902
17. Meurillon, M., Engel, E. (2016). Mitigation strategies to reduce the impact of heterocyclic aromatic amines in proteinaceous foods. *Trends in Food Science and Technology*, 50, 70–84. https://doi.org/10.1016/j.tifs.2016.01.007
18. Meurillon, M., Anderson, Ch., Angenieus, M., Mercier, F., Kondjoyan, N., Engel, E. (2023). Sensory acceptability of antioxidant-based formulations dedicated to mitigate heterocyclic aromatic amines in cooked meat, *Meat Science,* 198, Article 109088. https://doi.org/10.1016/j.meatsci.2022.109088
19. Utyanov, D. A., Kulikovskii, A. V., Knyazeva, A. S., Kurzova A. A. (December 21–22, 2023). *Study of HAA and PAH accumulation in meat products during its heat treatment using different types of oils*. International Conference on Ensuring Sustainable Development: Ecology, Energy, Earth Science and Agriculture (AEES2023), Moscow, Russia, 2024. https://doi.org/10.1051/e3sconf/202449404003
20. Zhao, T., Zhang, C., M., Yu., Wang, X. (2023). Effect of simultaneous application of antioxidants in oil and in chicken on heterocyclic aromatic amine formation in deep-fat fried chicken breast. *LWT,* 187, Article 115287. https://doi.org/10.1016/j.lwt.2023.115287
21. Pan, C., Lv, M., Jiang, G., Yin, T., Ya, Sh., Luo, X. et al. (2025). Effects of gallic acid on squid surimi protein and heterocyclic amine during the frying process. *International Journal of Biological Macromolecules*, 312, Article 144245. https://doi.org/10.1016/j.ijbiomac.2025.144245
22. Utyanov, D.A., Kulikovskii, A.V., Knyazeva, A. S., Kurzova, A. A., Ivankin, A. N. (2021). Methodical approach for determination of the heterocyclic aromatic amines in meat products using HPLC–MS/MS. *Theory and Practice of Meat Processing*, 6(2), 118–127. https://doi.org/10.21323/2414-438X-2021-6-2-118-127
23. Nadeem, H. R., Akhtar, S., Ismail, T., Sestili, P., Lorenzo, J. M., Ranjha, M. M. A. N. et al. (2021). Heterocyclic aromatic amines in meat: Formation, isolation, risk assessment, and inhibitory effect of plant extracts. *Foods*, 10(7), Article 1466. https://doi.org/10.3390/foods10071466
24. Sepahpour, S., Selamat, J., Khatib, A., Manap, M.Y.A., Razis, A.F.A, Hajeb, P. (2018). Inhibitory effect of mixture herbs/spices on formation of heterocyclic amines and mutagenic activity of grilled beef. *Food Additives and Contaminants. Part A,* 35(10), 1911–1927. https://doi.org/10.1080/19440049.2018.1488085
25. Aslanova, M. A., Derevitskaya, O. K., Dydykin, A. S., Bero, A. L., Soldatova, N. E. (2023). The influence of heat treatment type on the fat component and heterocyclic aromatic amines formation in minced poultry meat products. *Theory and Practice of Meat Processing*, 8(2), 74–84. https://doi.org/10.21323/2414-438X-2023-8-2-74-84
26. Zhao, M., Liu, Zh., Zha, M., Sun, Yi., Shi, H., Zhang, X. et al. (2025). Investigation of the dose and structure effects of lipid oxidation products aldehydes on the generation of heterocyclic amines: A case study of 2-amino-1-methyl-6-phenylimidazo [4,5-b] pyridine (PhIP). *Food Chemistry: X*, 25, Article 102244. https://doi.org/10.1016/j.fochx.2025.102244
27. Zamora, R., Alcon, E., Hidalgo, F.J. (2012). Effect of lipid oxidation products on the formation of 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP) in model systems. *Food Chemistry*, 135(4), 2569–2574. https://doi.org/10.1016/j.foodchem.2012.06.062
28. Zhao, T.-P., Wang, S.-K., Yu, H., Gao, J.-Y., Zhang, A.-H., Zhang, C.-X. et al. (2024). Effect of Flos Sophorae Immaturus extract on the formation of heterocyclic amines and quality characteristics of fried chicken patties. *LWT*, 214, Article 117137. https://doi.org/10.1016/j.lwt.2024.117137
29. Wang, W., Yang, H., Johnson, D., Gensler, C., Decker, E., Zhang, G. (2017). Chemistry and biology of ω-3 PUFA peroxidation-derived compounds. *Prostaglandins and Other Lipid Mediators*, 132, 84–91. https://doi.org/10.1016/j.prostaglandins.2016.12.004
30. Zamora, R., Hidalgo, F.J. (2020). Formation of heterocyclic aromatic amines with the structure of aminoimidazoaza-

renes in food products. *Food Chemistry*, 313, Article 126128. https://doi.org/10.1016/j.foodchem.2019.126128

31. Teng, H., Deng, H., Zhang, C., Cao, H., Huang, Q., Chen, L. (2023). The role of flavonoids in mitigating food originated heterocyclic aromatic amines that concerns human wellness. *Food Science and Human Wellness*, 12(4), 975–985. https://doi.org/10.1016/j.fshw.2022.10.019
32. Ekiz, E., Oz, F. (2019). The effects of different frying oils on the formation of heterocyclic aromatic amines in meatballs and the changes in fatty acid compositions of meatballs and frying oils. *Journal of the Science of Food and Agriculture,* 99(4), 1509–1518. https://doi.org/10.1002/jsfa.9325
33. Gumus, D., Kizil, M. (2022). Comparison of the reducing effects of blueberry and propolis extracts on heterocyclic aromatic amines formation in pan fried beef. *Meat Science*, 186, Article 108746. https://doi.org/10.1016/j.meatsci.2022.108746
34. Wu, K.-Y., Kuo, Y.-H., Chao, P.-C., Luo, Y.-S., Lin, W.-Yu., Chiang, S.-Y. (2025). A generalized chemical kinetics explains heterocyclic amine formation in high-temperature processed meats. *Food Chemistry*, 490, Article 145128. https://doi.org/10.1016/j.foodchem.2025.145128
35. Moonen, H. J. J., Dommels, Y. E. M., van Zwam, M., van Herwijnen, M. H. M., Kleinjans, J. C. S., Alink, G. M. et al. (2004). Effects of polyunsaturated fatty acids on prostaglandin synthesis and cyclooxygenase-mediated DNA adduct formation by heterocyclic aromatic amines in human adenocarcinoma colon cells. *Molecular Carcinogenesis*, 40(3), 180–188. https://doi.org/10.1002/mc.20032

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