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DEVISING PREVENTIVE ACTIONS IN THE PRODUCTION OF BROILER CHICKENS USING ULTRAVIOLET RADIATION FOR LONG-TERM STORAGE BASED ON RISK ANALYSIS

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The development of local poultry farming and import substitution are the main solutions to ensuring the safety of products in any state. For the effective development of poultry farming, it is necessary to overcome one of the constraining factors – the insufficiency of a modern safety monitoring system throughout the food chain. Especially in the development of the system of deep processing of poultry meat – starting from pre-slaughter keeping, cutting, preparation of semi-finished products, etc. In this regard, the current study has considered the effect of treatment with ultraviolet radiation under a non-stationary mode at such a control-critical point as the process of pre-slaughter aging in the production of broiler chickens. Additionally, this study was conducted in order to reduce the risks of increasing microbiological hazards at the production stage. As a result of the study, intermediate production control was established, and it was proved that in order to increase the shelf life of chilled meat of broiler chickens, it is advisable to sterilize with UV radiation in doses of 200 mJ/cm to 254 mJ/cm. A reduction in the risks of reproduction of potentially pathogenic microflora in poultry meat has been achieved at a cooling temperature of the carcass from +2 °C to +25 °C for no more than 135 days of risk. Research into the microbiological indicators of slaughter products of broiler chickens makes it possible to conclude that it is possible to use a given treatment in order to improve the quality and safety of finished products. Additionally, studying the effect of ultraviolet radiation on the inactivation of a number of microorganisms is very important for reducing pathogenic microbiological indicators in intermediate production control. The data reported here make it possible to prolong the period of sale and storage of the resulting product

Keywords: production risks, poultry meat, ultraviolet treatment, shelf life, food safety, broiler chickens

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1. Introduction

Meat production is one of the most dynamically developing sectors of world agriculture while poultry meat is the most affordable and expanding source of protein for the population of all income strata. In connection with the latest world events, such as the coronavirus pandemic, and given its consequences, the issue of ensuring the safety of "affordable" food products, among which poultry meat takes its rightful place, is acute. For Kazakhstan, as for all countries, it is important to expand the range of food products that can significantly increase the immunity of the population to successfully overcome the consequences of the COVID 19 pandemic. To date, according to the analytical materials "Coronavirus in Kazakhstan" [1], the number of infected is 1,225,997 people or 6.4 % of the population.

The development of local poultry farming and import substitution are the main solutions for ensuring the safety of products in any state. For the effective development of poultry farming, it is necessary to overcome one of the constraining factors – the insufficiency of a modern safety monitoring system throughout the food chain. Especially in the development of a system of deep processing of poultry meat – starting from pre-slaughter keeping, cutting, preparation of semi-finished products, etc.

The "Hazard Analysis and Counter-Critical Points" system for poultry production, from maintaining, slaughtering, and butchering requires additional automation programs and processing methods to storage. Traceability systems in large poultry companies are interrelated with the system of comprehensive enterprise management, which are common in Kazakhstan; these are ISO, GMP systems. That provides for a system of management and certification of production, which must include all digital parameters for high-quality traceability [2–4]. The potential and practical use of radiation energy as a means of preserving meat and meat products have been studied for many years.

In the process of pre-slaughter keeping, poultry meat and semi-finished products from it can be contaminated by microorganisms that live on the skin, feathers, in the digestive tract, and in a polluted environment. During slaughter and processing of carcasses, some bacteria die but subsequent cross-microbial contamination is possible at any stage of the production process (feather removal, evisceration, washing before storage, cooling or freezing, etc.). Therefore, it is extremely important to apply adequate technologies for obtaining perishable meat products, extending their shelf life, as well as more reliable control methods. This is a relevant issue for the poultry processing industry [5, 6].

Ultraviolet light (UV) has significant prospects in the food industry as an alternative to traditional heat treatment. Its applications include pasteurization of liquid products, processing of meat after mortality, treatment of surfaces of contact with food, and prolongation of the shelf life of fresh products. Our paper will review research on the use of UV treatment of poultry meat as one of the main critical points and risks [7, 8].

Thus, studies on risk analysis and the development of preventive actions in the production of broiler chickens using ultraviolet radiation for long-term storage are relevant.

2. Literature review and problem statement

Paper [9] reports the results of studying the effect of ultraviolet radiation from amalgam lamps with high bactericidal power on the number of imago mites of the genus *Tyrophagus* in the litter when growing broiler chickens in the experiment. Thus, with a surface flux density of UV radiation equal to 7–11 mW/m^2, the number of mites in the litter decreased.

In [10], the authors show the results of a study into the application of the Bayer program when the floor and litter of the studied poultry houses were significantly contaminated with invasive elements. After disinfection with the drug "Baicox", a noticeable decrease in pathogenic microorganisms was established. However, that drug has its contraindications – it is forbidden to treat with insecticidal suspension feeders, drinkers, and surfaces that can come into contact with feed and cattle. Working suspension of the insecticide should not be applied to dirty, highly porous, as well as freshly whitewashed surfaces.

Achieving serious advances in the development of a new generation of low-pressure UV lamps is possible through amalgam lamps, in which amalgam is the source of mercury vapor. The bulk of mercury in the bulb is in a bound state (amalgam), and only 0.03 μg is in the free state. The lamps are made of durable doped quartz with a special coating that excludes the release of the ozone-generating spectrum of UV radiation. These lamps are significantly safer than even fluorescent lamps, which are used everywhere for lighting [11]. Study [12] identified a total of 6 Gram-negative bacterial species in the air of poultry houses, 31 Gram-positive, and 11 fungal species; the authors noted a predominance of the Gram-positive bacteria *Staphylococcuslentus, S. chromogenes, Bacillus cereus, B. licheniformis* and *E. Faecalis*. Fungi and Gram-negative bacteria include *Candida albicans* and *Sphingomonas paucimobilis*, respectively.

Many of these microorganisms have been reported as dangerous pathogens for birds and immunocompromised people.

Paper [13] shows that the effect of UV radiation on poultry helps improve its hematological status, enhance gas-energy, and protein-mineral metabolism, and increase natural resistance, safety, and productivity. However, when conducting experiments with the use of UV radiation in the presence of poultry, UV lamps were used that emit ozone and contain a large amount of "free" mercury. When working with such lamps, strict implementation of safety measures is required, excluding the impact on poultry and people of ozone, as well as mercury vapor in the event of damage to the lamp. There are more environmentally friendly and safer low-pressure ultraviolet ozone-free amalgam lamps in which mercury is in a "bound" state. Such lamps are used in medical institutions, pharmaceutical and food industries, and public transport [14].

Paper [15] reports that MP UV lamps effectively inactivate microorganisms and suppress repair in *E. coli*. The bactericidal effect of far-ultraviolet radiation (UV and UV-B: 220–320 mJ/cm^2) is mainly due to the formation of pyrimidine dimers in the genome DNA. Near-ultraviolet light (UV-A: 320–400 mJ/cm^2) is known to produce active substances that cause lethal and sublethal effects [15].

Those studies typically included an assessment of organoleptic spoilage (4, 5, 9 points) and listed the total count and "most common" organisms found in the product after irradiation and storage [16, 17]. The effects of irradiation and storage on the overall microflora found in the product have rarely been studied, and the effects of conventional processing methods, whether accidental or intentional, have rarely been taken into consideration.

Studies [18, 19] conduct a microbiological assessment of the effect of radiation treatment on poultry during keeping on the extension of shelf life. Radiation resistance of organisms that cause food poisoning is usually associated with poultry, so the choice of the recommended dose was determined and taken into consideration.

All this suggests that it is advisable to conduct a study into the development of preventive actions in the production of broiler chickens using ultraviolet radiation for long-term storage.

3. The aim and objectives of the study

The aim of this study is to devise preventive actions in the production of broiler chickens using ultraviolet radiation for long-term storage based on risk analysis. The results of the study would make it possible at the production stage to control the parameters of ultraviolet radiation treatment during pre-slaughter keeping of poultry to ensure the safety of the resulting product.

To accomplish the aim, the following tasks have been set:

– based on the would-be parameters of treatment with ultraviolet radiation, to investigate the decrease in mycobiological parameters;

– to develop a critical limit to the process of pre-slaughter keeping of broiler chickens by means of ultraviolet radiation treatment.

4. The study materials and methods

4. 1. The study object and hypothesis

The objects were broiler chickens aged from 2 to 3 weeks, which were born to a local poultry producer.

The hypothesis of our study assumed the following. By controlling the parameters of ultraviolet radiation treatment in the production of broiler chickens, as a preventive measure, it is possible to ensure the safety of the resulting product during its long-term storage.

Our study looked at one control-critical point in the production of broiler chickens, which, in turn, affects the microbiological performance of the finished product. The critical limit to be developed is a controlled production intermediate parameter. Through this parameter, the quality and safety of the finished product are adjusted.

4. 2. The study procedure

Broiler chickens were treated with UV radiation (lamps) by the UV irradiators OBN-150 from 200 mJ cm^2 to 254 mJ/cm^2. Further, after processing and slaughtering, the carcasses were packed directly individually in plastic bags (Dow polyethylene No. 309-T; thickness, 1.2 mil), which were sealed by wire twisting and then packed in crushed ice. Delivery was carried out in the company's isothermal refrigerated van; the carcasses were delivered to the laboratory about 5 hours after slaughter.

After delivery, the entire batch was stored at a cooling temperature (5 °C) until the following day. At that time, the carcasses were removed and cut into eight pieces: two legs, two wings, two parts of the back, and two parts of the breast. These pieces were then individually and freely packaged in new plastic bags. Initially, a piece from the entire batch without processing was used to determine the initial microbial parameters but later experiments analyzed a piece from each bird after treatment.

After the radiation, the radiation resistance of microorganisms on the carcass of the bird was determined.

Bacteria of the *E. coli* group were determined in poultry carcasses, offal and semi-finished products from poultry meat according to GOST R 54374-2011 "Poultry meat, offal and semi-finished products from poultry meat. Methods for identifying and determining the number of bacteria of the Escherichia coli group (coliform bacteria)". Detection of bacteria of the genus *Salmonella* was carried out in accordance with GOST 31468-2012 "Poultry meat, offal and semi-finished products from poultry meat. Method of detection of salmonella". Detection of *Listeria* monocytogenes in poultry meat and poultry products was carried out in accordance with GOST 32031-2012 "Food products. Methods for detecting the bacteria *Listeria monocytogenes*".

Studying the effect of ultraviolet radiation on the inactivation of a number of microorganisms is very important for reducing pathogenic microbiological parameters in intermediate production control. If necessary, the levels of ultraviolet radiation required to meet E. coli standards may be relatively more effective than chlorination in killing pathogens. UV treatment processes are well documented and were used in the slaughter of broiler chickens [20, 21].

Despite the effectiveness of ultraviolet radiation for disinfecting smooth surfaces, this technology is used relatively rarely in the food industry. The limited range of commercially available particulate disinfection equipment may contribute to its limited use. In addition, most of the kinetic data of microbial inactivation were obtained in suspension in an aqueous medium or in air. These data have limited applications for predicting the rate of disinfection of the surface. Since complex interactions can occur between microorganisms and surface materials, such as protective effects against incident ultraviolet radiation, the effectiveness of ultraviolet radiation depends on the structure or topography of the surface [22, 23].

4. 3. Procedure for calculating the process of treatment with ultraviolet radiation

With ultraviolet treatment with radiation during pre-slaughter keeping of broiler chickens, the temperature of the amalgam lamp is t_1=0, 10, 20, 30, and 40 °C. The degree of blackness ε_1=0.8; 0,65; 0,52; 0.35; 0.21; and 0.8 for black broiler chickens; C_0=5.67 is the degree of blackness of an absolutely black body. Source temperature t_1=50 °C. We set the temperature t_2=0; 10; 20; 30; and 40 °C.

For example: t_2=0 °C

$$q_l = 0.8*5.67\left[\left(\frac{273+50}{100}\right)^4-\left(\frac{273+0}{100}\right)^4\right]=242\ \text{W/m}^2.$$

For other values of temperatures t_2 and ε_1, the estimated data for determining the density of radiant flux q_1 were summarized in Table 1.

Table 1

Radiant flux density value q_1

ε_1	t_2, °C				
	0	10	20	30	40
0,8	242	202	160	111	58
0,65	196	160	130	90	47
0,52	157	131	104	72	38
0,35	106	89	70	49	26
0,21	63	53	42	29	15

The plot of the dependence of the density of the radiant flux on the temperature and degree of darkening of the chicken meat is shown in Fig. 1.

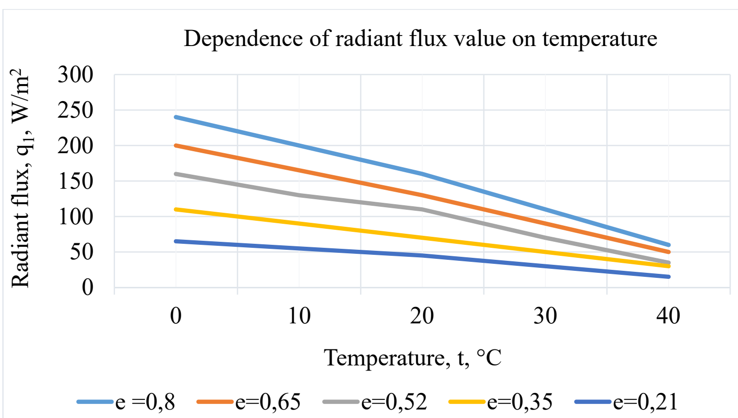

Fig. 1. Dependence of the radiant flux value on temperature

The radiation coefficient of the body under study, which has the form of a flat surface, is calculated as follows:

$$\left(q_{1,2}=c\left[\left(\frac{\tau_1}{100}\right)^4-\left(\frac{\tau_2}{100}\right)^4\right]=\kappa\varphi\right),$$

where c is the emissivity, W/(m^2*K^4),

t_1, t_2 is the heating temperature of the lamp.

To determine the expected value of the resulting radiation impact, the dependence of the resulting radiation is used [24, 25].

5. Results of studying the development of preventive actions in the production of broiler chickens using ultraviolet radiation

5. 1. Results of studying the reduction of mycobiological parameters based on the determined parameters of ultraviolet radiation treatment

Our experiments were conducted to determine whether irradiation affected the extension of the shelf life of fresh poultry and the reduction of microorganisms. Therefore, no attempt has been made to adjust or modify the processes in production.

Our studies revealed BGCP in samples, bacteria of the genus *Salmonella* and *Listeria monocytogenes*. In general, fresh carcasses shipped from production were contaminated with 1.864–2.71×10^5 CFU/g of skin material (Table 2).

Table 2

Microbiological indicators of poultry meat without UV radiation treatment

Sample No.	QMAFAnM, CFU/g	BGKP (coli-forms)	Bacteria of the genus *Salmonella*	*Listeria monoc ytogen es*
Technical guidelines	Not exceeding 1×10^5	Not exceeding 1.0 g	Not exceeding 25 g	Not exceeding 25 g
1	(2.71±0.22)×10^5	1.5±0.22	29±0.14	30±0.56
2	(4.18±1.25)×10^5	1.75±0.12	31±0.24	31±0.64
3	(1.37±0.12)×10^5	1.73±0.34	30±0.25	31±0.25
4	(2.47±0.52)×10^5	2.5±0.35	35±0.35	32±0.65
5	(1.54±0.31)×10^5	2.5±0.54	28±0.65	35±0.36
6	(1.864±0.233)×10^5	2.7±0.45	28±0.47	36±0.54

The results without treatment with UV radiation show the detection of the content of BGCP (coliform bacteria) in poultry meat stored for 5 days at a temperature of 0 to +2 °C. For example, at the beginning of our study, BGCP was detected in 13.3 % in 6 samples but, when stored for 5 days at the temperature of a household refrigerator, they were detected in 33.3 % of the samples (Fig. 2–4). Bacteria of the genus *Salmonella* were detected in 13.3 %, and the number in positive tests for salmonella and pathogenic staphylococci doubled.

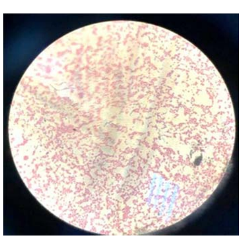

Fig. 2. Bacteria of the Escherichia coli group under a microscope coloration according to Gram ×1000

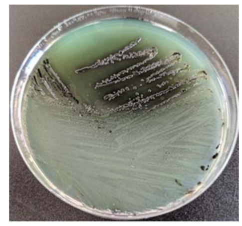

Fig. 3. Bacteria of the genus Salmonella on bismuth-sulfite agar

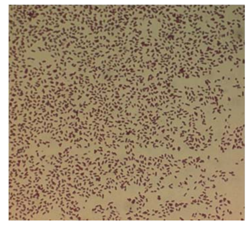

Fig. 4. Bacteria of the genus *Salmonella* under a microscope, coloration according to Gram ×1000

In smears-prints prepared from samples of poultry meat without treatment with UV radiation during pre-slaughter keeping, when stored in a chilled state for five days, more microorganisms were detected, compared with smears-imprints on the first day of our study (Table 3).

Table 3

Microscopy results of smears from poultry meat when stored for 5 days at temperatures from +2 °C to +25 °C

Sample No.	Number of cocci	Number of rods	MO total	Degree of freshness
1	11	6	17	Questionable freshness
2	12	14	26	With signs of first-degree damage
3	12	5	17	Questionable freshness
4	12	6	18	Questionable freshness
5	11	13	24	With signs of first-degree damage
6	12	6	18	Questionable freshness

After treatment with UV sources during pre-slaughter containment, the quality and duration of storage on different days and radiation doses were evaluated. The UV irradiators OBN-150 were used during pre-slaughter keeping. Our experimental data obtained after a 30-minute treatment of air with UV radiation from those irradiators are given in Table 4; it shows the number of spoiled poultry carcasses.

Processing for 30 minutes with the help of the OBN-150 device affected the quality of poultry meat (Table 4).

At a normal cooling temperature of +2 °C, fresh carcasses were found to be organoleptically acceptable for a period of 5 to 135 days (Table 4).

Over that time, bacterial counts as a whole increased compared to the original number. Irradiation at a temperature of +2 °C led to an immediate decrease in the number of bacteria. During storage, surviving organisms at 25 °C multiplied at 200–210 mJ/cm^2 than on the poultry irradiated at 240 mJ/cm^2. As a result, when processing 220 mJ/cm^2, the shelf life increased to about 14–45 days, the processing of 240 mJ/cm^2 – up to 90–135 days (Table 4). In some cases, individual carcasses were not spoiled after long-term storage even after 14 days although their microbial index approached 3 % of organisms per gram of skin material.

Table 4

Percentage of irradiated poultry carcasses organoleptically spoiled at different storage intervals at +2 °C and 25 °C

Exposure level, mJ/cm²	Storage time (days)	+2 °C			25 °C		
		Total number of analyzed birds, pieces	Spoiled as a percentage of total, %		Total number of analyzed birds, pieces	Spoiled as a percentage of e total, %	
			before processing	after processing		before processing	after processing
254	135	18	100	0	18	100	16
240	90	18	100	3	18	100	16
230	45	18	100	3	18	100	16
220	14	18	100	3	18	100	16
210	10	18	95	3	18	100	20
200	5	18	90	10	18	100	25

The radiation treatment of poultry was studied for microbiological indicators. The recommended dose of radiation is 220–254 mJ/cm², which increases the shelf life at a temperature of +2 °C by about 45 days. This treatment also led to a decrease in the number of viable species of various microorganisms, including salmonella by 10 and 11 CFU/units and strains of *Staphylococcus aureus*, respectively.

5. 2. Developing a critical limit to the process of pre-slaughter keeping of broiler chickens using ultraviolet radiation treatment

Table 5 gives a proposed plan for corrective actions in the process of pre-slaughter keeping of broiler chicken production, developed on the basis of data obtained on the reduction of mycobiological indicators.

This plan is designed to obtain high-quality indicators and high shelf life of products achieved by the use of ultraviolet radiation. The critical limit is to reduce the bacterial contamination of poultry meat to increase its shelf life.

Table 5

Practical plan of production intermediate control parameter for the process of pre-slaughter keeping of broiler chicken production

Plan		Do	Check			Act	
Production process	Danger factor	The critical limit	Monitoring procedure			Correction, corrective actions	Remarks
			Procedure (what will be measured, how, how often)	Frequency	Responsible		
Pre-slaughter content	Biological hazard – growth of microorganisms – QMAFAnM, BGKP, Bacteria of the genus *Salmonella*, *Listeria monocytogenes*	Sterilization by UV radiation in doses 200 mJ/cm to 254 mJ/cm	Compliance with technological regimes and control of UV radiation	After a certain set period	Operator	Identification of the causes of nonconformities and their elimination. Calibration and monitoring of equipment. Product control, if necessary, its rejection, isolation, and disposal. Additional staff training	Entries in the technological parameters control log. Records of verification of measuring instruments. Records of the results of internal and external audits. Records confirming the competence and responsibility of personnel

6. Discussion of results of studying the development of preventive actions in the production of broiler chickens

The most common organisms that cause spoilage to poultry carcasses, such as *Pseudomonas, Achromobacter, Flavobacterium*, etc., are usually not detected immediately after irradiation of 200 mJ/cm² or more [22, 26]. However, depending on the storage conditions after irradiation, these organisms can reproduce.

In addition, it is possible that in some localities, various radiation-resistant organisms may be local. As a result, depending on the radiation dose, time, and temperature of storage, different types of organisms can be represented in large quantities with or without noticeable organoleptic spoilage. Some of these organisms may also be pathogenic [27].

There is a confidence that these organisms do not pose an additional danger to public health. However, such ecological shifts in the microbial population of irradiated and stored poultry need to be analyzed in more detail. This should be done before eliminating any dangers to public health from potentially pathogenic organisms that are occasionally found during the keeping of poultry. In this respect, the radiation resistance of organisms belongs to the genera *L. monocytogenes*.

A clear advantage of preliminary irradiation is the elimination of common types of microorganisms without making the product undesirable for the consumer. It is estimated that the volume of salmonella in carcasses is approximately 2 per 10 billion grams of meat. At the proposed dose of 200 mJ/cm², microorganisms can be reduced in the numbers indicated in Table 2. Thus, this treatment eliminated resistant organisms.

The devised parameter can be used in quantitative intermediate assessments of production processes. The values of these parameters can be correlated with the results of the microbiological and organoleptic evaluation of the resulting product.

It should be borne in mind that the correlation of the values of individual physical parameters with organoleptic data is often not so linear since the overall organoleptic quality is due to a combination of many changing factors.

7. Conclusions

1. Based on studying the effect of ultraviolet radiation treatment un-

der a non-stationary mode for 30 minutes, the effectiveness of disinfection in keeping and pre-slaughter aging of poultry led to a decrease in the number of viable species of various microorganisms, including salmonella, by 10 and 11 CFU/unit and strains of *Staphylococcus aureus*, respectively.

2. An intermediate production control has been developed by sterilization with UV radiation in doses of 200 mJ/cm to 254 mJ/cm. And a decrease in the reproduction of potentially pathogenic microflora in poultry meat at a cooling temperature of the carcass from +2 °C to +25 °C for 135 days has been achieved.

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