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Halal poultry slaughter technology: A critical review of control points

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Abstract. Halal production holds substantial potential for further development, driven by the growing global demand for high-quality, safe, and ethically produced food products. In addition to meeting the needs of Muslim consumers, certified halal products are increasingly appealing to a broader audience that values compliance with high standards of hygiene, traceability, and quality. Modern trends highlight the importance of adhering to stringent requirements, enhancing the competitiveness of halal production in international markets. This literature review examined the technological process of poultry slaughter with a focus on compliance with halal standards and requirements. The study aimed to identify risks at each stage of production, assess their impact on product quality, and propose strategies to optimise production processes in accordance with Islamic standards. The analysis was based on a review of contemporary scientific literature, certification standards, and risk management practices in food production. Key risks are associated with pre-slaughter inspection, stunning, slaughter, bleeding, evisceration, chilling, and post-mortem inspection. It was found that violations at these stages may lead to mechanical damage to carcasses, insufficient bleeding, microbial contamination, or non-compliance with religious standards. Implementing risk management systems, such as HACCP, and adopting modern traceability technologies, including RFID tags and blockchain, can improve transparency, production efficiency, and compliance with international standards. The value of this study lies in identifying directions for improving process control systems, particularly through the integration of automated solutions for monitoring critical points and analysing product quality. The findings may prove useful for raising awareness about poultry slaughter quality requirements in halal-certified production. Future research prospects include the enhancement of slaughter technologies, the development of automated control systems, and the optimisation of quality assessment methods to improve production efficiency and ensure compliance with high hygienic and religious standards

Keywords: halal production; meat safety and quality; critical control points; risk management; traceability

Introduction

The halal products market is a significant sector of the modern food industry, catering not only to Muslim consumers but also to a broader audience interested in high standards of quality, safety, and ethical production. Products manufactured in compliance with Islamic norms include not only meat products but also a wide range of items, such as cosmetics, pharmaceuticals, and logistics services (Azam & Abdullah, 2020; Hidayat & Musari, 2022). According to M. Gul *et al*. (2023), the halal industry is experiencing significant growth and holds substantial potential for further development. This growth is driven by the increasing global demand for high-quality, safe, and ethically produced food products. Halal certification is increasingly seen as a mark of quality assurance. This positions halal products favourably in both local and international markets, indicating a promising future for the industry. The main idea of the study conducted by M. Asri Abdullah & E. Siddique (2021) is to define "halal entrepreneurship" as a distinct concept from conventional entrepreneurship, highlighting the specific features that characterise entrepreneurs operating within the halal industry, and to explore the diverse business opportunities in the global halal market.

Poultry meat occupies a central position in the halal sector due to its versatility, relatively

low production costs, and compliance with religious requirements. Poultry farming is one of the most dynamic sectors of the agri-food industry, demonstrating stable growth in production and consumption. This can be attributed to the high nutritional value of poultry meat, the absence of religious restrictions in most cultures, and the efficiency of industrial farming methods. The rapid development of this sector highlights the need for modern technologies at all stages of production – from transportation and slaughter to post-slaughter processing and traceability of the final product. This also presents significant opportunities for exporting halal meat from Ukraine, which has substantial potential for livestock development and the establishment of certified halal production facilities. The growing global demand for halal products can be met by leveraging Ukraine's competitive advantages, including high-quality meat and affordable pricing (Lupenko *et al*., 2022; Kryvenko, 2022).

The slaughter of poultry in compliance with halal requirements involves a series of technological operations, each subject to strict monitoring. Failure to meet any of these requirements may lead to the loss of halal status and reduce the product's quality and competitiveness. For instance, M. Ramli *et al*. (2024a) identified seven critical halal risk points (HRPs) in poultry slaughtering processes, covering transportation, hanging, stunning, slaughtering, bleeding, evisceration, and chilling. Each of these points requires careful monitoring to prevent violations of halal norms and ensure food safety standards. Particular attention is paid to electrical stunning, proper slaughtering techniques, effective bleeding, and sanitary conditions during evisceration and chilling. The growing global demand for halal products drives the expansion of production capacities and the adoption of advanced quality control methods. In this context, integrating traceability systems, automation, and modern technologies, such as RFID tags and blockchain, plays a crucial role in maintaining transparency and enhancing consumer confidence (Tieman & Williams, 2019; Ng *et al*., 2021). Thus, the increasing focus on halal standards necessitates strict adherence to technological and religious norms during poultry meat production. This requires a comprehensive approach that includes monitoring all stages of the technological process, implementing innovative technologies, and ensuring compliance with international standards for product quality and safety (Mylostyvyi, 2023).

The aim of this review was to critically analyse the control points of halal poultry slaughter, focusing on identifying problem areas, evaluating their impact on product quality and production efficiency, and examining modern approaches to optimising processes in accordance with Islamic standards. The review also addressed transparency and traceability within the production cycle. This review employed a systematic approach to analyse the technological processes involved in halal poultry slaughter. The methodology involved a comprehensive search and critical examination of relevant scientific literature, including peer-reviewed journal articles, conference proceedings, and industry reports. Additionally, international halal certification standards were consulted to understand the regulatory framework and compliance requirements. Risk management practices and quality control guidelines in food production were also reviewed. The analysis focused on identifying critical control points, assessing potential risks at each stage of poultry slaughter, and evaluating the impact of these risks on product quality and halal compliance. Modern technologies and traceability systems were also examined in the context of enhancing transparency and efficiency in halal poultry production. This multi-faceted approach allowed for a comprehensive understanding of the challenges and opportunities in halal poultry slaughter, leading to the development of informed recommendations for optimising

processes and ensuring compliance with both religious and technological standards.

Pre-slaughter factors and their role in determining poultry meat quality

Pre-slaughter factors, including catching, transportation, feed withdrawal, lighting, and handling, play a critical role in determining poultry meat quality. Stress or improper handling during these stages can lead to significant economic losses, either through carcass rejection or reduced quality (Petracci *et al*., 2010). These factors are generally classified into long-term and short-term influences. Long-term factors, such as feeding practices, genetic characteristics, housing conditions, and health status, affect poultry throughout their lifecycle. Short-term factors, including catching, transportation, shackling, stunning, and slaughter, exert the greatest impact within 24 hours prior to processing. These factors can significantly alter the physical and chemical properties of meat. The selection of poultry for slaughter requires careful management to ensure optimal muscle development, health, and growth at the time of processing. Genetic traits influence growth rates and carcass characteristics, making proper rearing practices essential. Feed withdrawal, typically lasting 8-12 hours, is necessary to empty the gastrointestinal tract and reduce the risk of faecal contamination during processing. However, an imbalance in withdrawal time can affect meat quality and yield. Short withdrawal periods may leave partially filled intestines, leading to contamination risks, while extended periods can cause excessive weight loss, metabolic changes, and increased pH levels in muscles, negatively impacting texture and shelf life.

According to A. Abdallah *et al*. (2021), halal processing standards impose strict requirements for pre-slaughter practices, including veterinary inspections and isolation from prohibited sources, such as pig farms or by-products. Some standards, like HAS 23103:2012 (2012) and MS 1500:2019 (2019), mandate facilities to be at least 5 km away from pig farms, which may pose challenges in areas lacking such infrastructure. Compliance also requires animals to be alive, healthy, and inspected by a veterinary officer prior to slaughter to meet halal criteria. Proper management during harvesting and transportation minimises stress and injuries, which preserves meat quality and prevents commercial losses. Feed withdrawal management is integral to maintaining hygiene and meat quality, as outlined by P. Kumar *et al*. (2022). Effective withdrawal facilitates gut evacuation, reducing contamination risks during processing. Poultry held off feed for excessive durations may experience glycogen depletion, resulting in elevated muscle pH and inferior meat texture. Extended fasting can also weaken the intestines, increasing the likelihood of rupture and contamination. Studies indicate that broilers lose 0.18-0.42% of their weight per hour after feed withdrawal, with males experiencing greater losses than females. After 16 hours, glycogen levels in breast and thigh muscles decrease by 0.27% and 0.22%, respectively, further compromising quality.

Environmental conditions, such as lighting and temperature, also influence feed withdrawal outcomes. Digestion slows in darkness, requiring at least four hours of light to stimulate gut activity. Adequate water availability mitigates dehydration, supports gut evacuation, and maintains carcass quality. In warm climates, shorter withdrawal periods are effective due to faster metabolic rates, while colder environments require longer periods to achieve similar results. Prolonged withdrawal may also lead to bile accumulation, increasing the risk of bile sac rupture and staining, which can affect flavour and visual appeal. M. Ramli *et al*. (2024b) emphasised the importance of integrating halal assurance systems (HAS, 2012) into production processes to manage risks related to feed contamination, medication use, biosecurity, and logistics. Implementing HACCP (1997) principles alongside halal compliance ensures

product safety and integrity. F. Mehak *et al*. (2024) highlighted the role of early biosecurity measures in preventing pathogen transmission, particularly among species that act as reservoirs for zoonotic diseases. Pre-slaughter preparation should include veterinary inspections and isolation protocols to mitigate infection risks. Managing feed withdrawal is a complex process that requires balancing gut evacuation efficiency with weight retention and meat quality. Short withdrawal periods increase contamination risks due to retained feed, while prolonged fasting weakens intestinal integrity, leading to ruptures. Extended periods also promote bile accumulation, risking staining and flavour alterations in carcasses. Optimal withdrawal strategies consider physiological and environmental factors to maintain product quality and halal compliance. Effective lighting, controlled temperature, and access to water further optimise gut evacuation and reduce processing issues, ensuring compliance with hygiene and safety standards.

Catching and loading: A critical pre-slaughter stage

The process of catching and loading poultry is a critical pre-slaughter stage that directly impacts meat quality and production efficiency. Improper handling, excessive stress, or injuries sustained during catching can lead to bruising, fractures, and dislocations, which reduce carcass quality and increase wastage (Saraiva *et al*., 2020). To minimise stress, catching is recommended during cooler periods, such as early morning or evening, when birds are calmer and less active. During manual catching, it is essential to follow established guidelines, including lifting poultry by both legs and avoiding carrying more than three poultry simultaneously. This approach reduces the risk of skeletal damage, muscle injuries, and dislocations. Additionally, dim lighting or low-intensity illumination can be used to calm poultry, facilitating handling and minimising stress-induced reactions. In larger poultry farms, mechanised systems, such as vacuum devices and conveyor belts, are increasingly employed to improve efficiency, reduce labour intensity, and enhance poultry welfare.

Mechanised methods provide several advantages, including reduced handling errors and lower injury rates. Vacuum systems, for example, enable rapid and uniform collection of poultry with minimal human intervention, while automated conveyors control movement and prevent overcrowding in transport containers. Modular transport systems, incorporating sliding drawers, further reduce injury risks and allow for the efficient loading of up to 6,000 poultry per hour with a team of three workers. Following the catching process, poultry are loaded into containers or modular systems equipped with sufficient ventilation and optimised stocking density to prevent overheating and overcrowding. Stocking density is adjusted based on environmental conditions; during hot weather, fewer poultry are placed in each container to facilitate airflow and cooling. Standard transport crates, which typically accommodate 12-14 poultry, are equipped with ventilation openings to maintain proper air circulation and prevent physical damage.

Transportation is another critical stage requiring meticulous planning to minimise stress and preserve meat quality. Transport time should be minimised, and temperature and ventilation within vehicles must be strictly controlled to prevent heat stress or chilling. Fluctuations in temperature, vibrations, sudden accelerations, and noise levels are additional stressors that can compromise poultry welfare and meat quality (Tkachuk *et al*., 2023). Forced ventilation systems and humidity control help maintain optimal conditions, reducing the risk of heat stress during warm weather or hypothermia in colder months. Studies by P. Govindaiah *et al*. (2023) emphasise that poor handling during catching and loading can cause measurable physiological stress

responses in poultry, such as elevated creatinine and total protein levels in the blood. These biochemical changes reflect physiological stress, which can negatively affect meat quality. Ensuring humane handling practices throughout catching, loading, and transport reduces stress indicators and helps maintain the quality of poultry products.

In halal production systems, additional requirements govern pre-slaughter handling. According to A. Abdallah *et al*. (2021), birds must undergo a health inspection before loading, and any weak or diseased individuals must be excluded to prevent compromising product quality. Furthermore, halal standards such as HAS 23103:2012 (2012) and MS 1500:2019 (2019) mandate strict controls to ensure animals are free from exposure to prohibited substances or contamination from non-halal sources. These guidelines also emphasise the importance of animal welfare at all stages, requiring that birds remain "alive or deemed alive" and are certified healthy by veterinary inspectors before slaughter. Effective management of catching, loading, and transport processes is essential to maintaining high product quality and ensuring compliance with halal standards. Mechanised systems and modular transport units play a crucial role in reducing injuries and stress while improving operational efficiency. Adherence to welfare protocols and pre-slaughter inspection requirements supports the production of high-quality halal poultry products, enhancing their competitiveness in global markets.

Unloading of poultry, ante-mortem inspection and preparation processes for poultry stunning

The unloading of birds at processing facilities represents a critical stage that requires meticulous handling to minimise stress and injury. Poultry are unloaded in designated areas near the primary processing unit, where containers are carefully removed from vehicles to reduce the risk of falls or impacts (Vieira *et al*., 2024). Holding units with poultry should be located indoors or under shelters to protect them from adverse weather conditions and to ensure adequate ventilation. It is essential to avoid abrupt or rough handling during unloading, as such practices can lead to increased stress, injuries, and reduced meat quality. Modern facilities often employ automated unloading systems, where modular containers are transferred via conveyor belts to the point of poultry extraction. These systems not only reduce the need for manual labour but also improve process efficiency and poultry welfare. The use of such systems ensures smoother and faster unloading, minimising stress and the likelihood of injuries. Moreover, ventilation and humidity levels within the unloading zone must be closely monitored to prevent excessive moisture accumulation, which could lead to respiratory complications or other health issues among birds. Workers are required to inspect the poultry during unloading, identifying any signs of injury or illness. Poultry that are unfit for processing due to injury or disease must be separated for further inspection, treatment, or humane disposal if necessary. Proper unloading practices, coupled with modern automation and continuous monitoring, play a key role in maintaining poultry welfare and optimising the efficiency of processing operations.

After poultry are removed from containers or modules, they must undergo thorough inspection to detect any injuries or damage sustained during transportation. Each batch is assessed to determine the physical condition of the poultry, including checks for head, leg, and wing injuries. This inspection is performed by a qualified veterinarian and must take place under adequate lighting to ensure effective visualisation. Following the ante-mortem inspection, poultry are prepared for slaughter by securing them in specialised fixtures designed to minimise stress and injury. Poultry typically calm down after an initial period of wing

flapping. Movement can be further reduced by gently restraining their legs or through brief physical contact with other parts of their bodies. The ante-mortem inspection procedure at the facility is strictly regulated to comply with international quality standards and religious requirements. The primary goal is to assess the overall health of the poultry, ensuring compliance with halal standards. The main aspects of this process are detailed in Table 1.

Table 1. *Ante-mortem inspection procedure*

Control points	Parameters
Comprehensive veterinary inspection	
Physical condition assessment	Detection of signs of diseases, injuries, abnormalities, or behavioural deviations. Poultry showing symptoms of infection or exhaustion are immediately culled.
External appearance evaluation	Particular attention is given to the skin, eyes, beak, and feathers to identify any pathological signs.
Sample testing	Selective testing for infectious agents or antibiotic residues, which is a mandatory requirement for exporting products to Muslim countries.
Compliance with halal requirements	
Selection of healthy poultry	According to Islamic standards, only healthy animals are eligible for slaughter. This is ensured through a comprehensive pre-selection process.
Supervision by a halal inspector	Each stage of the pre-slaughter inspection is carried out under the supervision of a certified representative of the Muslim community, ensuring compliance with Islamic rules.
Technological aspects of the process	
Infrastructure	Facilities certified for halal production must have designated areas for inspection to minimise contact between healthy and potentially diseased poultry.
Hygienic conditions	All operations are performed in sterile environments to prevent cross-contamination and maintain poultry welfare.

Source: developed by the authors

Ante-mortem inspection plays a crucial role in evaluating animal health and preventing the entry of contaminated carcasses into the food chain. According to P. Kumar *et al*. (2022), veterinary specialists assess the general condition of poultry to identify pathological conditions and exclude unfit animals. The inspection covers feather contamination, injuries, and signs of respiratory or gastrointestinal diseases, ensuring compliance with established standards. Once inspected, poultry are prepared for stunning, a process aimed at minimising suffering and ensuring effective exsanguination. Most facilities employ electrical water-bath stunning, although larger operations may use inert or mixed gas stunning systems. Maintaining optimal parameters for electric current or gas concentration is critical to achieving complete loss of consciousness without causing excessive trauma (Table 2).

Table 2. *Humane handling measures during ante-mortem inspection*

Control points	Parameters
Ethical handling	Poultry are kept in comfortable conditions that minimise stress and fear. Gentle handling is ensured.
Proper transportation	Poultry are delivered in containers preventing overcrowding and injuries, equipped with ventilation.
Access to water and feed	Water and feed are provided if waiting time exceeds regulated limits.
Waiting conditions	Poultry are kept in areas with controlled temperature and ventilation to prevent overheating or chilling.

Table 2. Continued

Control points	Parameters
Halal inspector supervision	Procedures are monitored by halal inspectors to ensure compliance with religious and welfare standards.
Ethical handling	Poultry are kept in comfortable conditions that minimise stress and fear. Gentle handling is ensured.

Source: developed by the authors

Humane handling during ante-mortem inspection forms an integral part of halal production standards. Emphasis is placed on reducing noise levels, using blue lighting, and maintaining comfortable climatic conditions to preserve product quality and meet international standards. These measures are essential for compliance with halal certification and improving animal welfare (Mehak *et al.*, 2024). Preparation for stunning must adhere to hygienic standards to prevent contamination with blood, which may contain residual pathogens, reducing the risk of zoonotic infections. As noted by P. Govindaiah *et al*. (2023), improper stunning methods may alter blood biochemistry, increasing creatinine, alanine aminotransferase, and triiodothyronine levels, which can negatively impact meat quality. Technological requirements for halal compliance are presented in Table 3.

Table 3. *Technological requirements for halal compliance*

Requirement	Characteristics
Dedicated slaughter zones	Separate areas are designated for halal processing to prevent cross-contamination with non-halal products.
Selection of healthy poultry	Only healthy birds, confirmed by inspection, are processed for slaughter.
Hygienic standards	All operations take place in sterile environments to prevent cross-contamination and meet halal standards.
Compliance with Islamic rituals	Religious requirements, including prayers and blessings, are observed throughout the process.

Source: developed by the authors

The transition from inspection to stunning must be swift to prevent poultry from regaining consciousness and to preserve welfare standards during slaughter (Table 4). Traditional halal slaughter without stunning is also practised, ensuring efficient blood drainage, reducing residual metabolites, and improving meat quality (Govindaiah *et al*., 2023).

Table 4. *Infrastructure and technological process control*

Control points	Parameters
Separate zones for slaughter and inspection	Facilities must have designated areas to maintain hygiene and meet halal requirements.
Sanitary conditions	All spaces and equipment must remain sterile to avoid contamination and comply with halal standards.
Handling practices	Systems must minimise stress and injuries. Ventilation, lighting, and temperature are optimised.
Modern equipment	Automated systems for slaughter and processing must meet halal standards and undergo regular inspections.
Process control	Documentation and monitoring systems ensure compliance with halal certification and production standards.

Source: developed by the authors

The integrated approach ensures compliance with halal requirements throughout the ante-mortem inspection and stunning preparation phases, securing animal welfare, product quality, and adherence to international trade standards.

Stunning of poultry: Techniques, parameters, and halal considerations

Stunning is a critical stage in poultry slaughter aimed at minimising stress and pain, improving bleeding efficiency, and facilitating subsequent processing operations. The most common method is electrical stunning in water baths, where current flows through the poultry body from the head to the legs. Achieving effective stunning requires precise calibration of voltage, current strength, and duration to ensure temporary loss of consciousness without violating halal production standards. According to international guidelines, stunning must be reversible and must not cause cardiac arrest or irreversible tissue damage. However, as noted by K. Al-Shammari (2021), inappropriate electrical stunning parameters may result in tissue damage, including muscle haemorrhages, bone fractures, and skin discolouration, which negatively impact carcass quality. These defects are often associated with high voltage or prolonged exposure to current, highlighting the importance of proper equipment calibration.

Different halal standards adopt varying approaches to stunning. In most cases, electrical stunning is permitted as long as it does not cause death before exsanguination. However, certain countries, such as Pakistan, prohibit any form of pre-slaughter stunning (Akbar *et al*., 2023). Meanwhile, I. Shahdan *et al*. (2016) proposed a system of six control points to ensure compliance with halal requirements, including monitoring stunning parameters to prevent violations of religious standards. Alternative methods, such as controlled atmosphere stunning using low-oxygen or inert gas mixtures (CO_2, nitrogen), are also gaining attention as means to reduce stress and physical damage. However, these methods require strict control of parameters and alignment with halal compliance regulations. Studies by M. Farouk *et al*. (2014) emphasise that the effectiveness of electrical stunning depends not only on technical parameters but also on the biological characteristics of the poultry, such as body mass, breed, and health status. Improper equipment settings can lead to insufficient or excessive stunning, impacting both animal welfare and meat quality.

I. Shahdan *et al*. (2017) highlight optimal stunning parameters, including a current of 105-150 mA and exposure durations of 4-6 seconds. These conditions enable effective immobilisation without causing severe tissue damage or compromising halal requirements. Nevertheless, K. Al-Shammari (2021) argues that traditional halal slaughter without stunning demonstrates advantages in reducing bacterial contamination and extending meat shelf life due to improved bleeding efficiency. At the same time, electrical stunning requires rigorous monitoring to ensure compliance with religious standards. Thus, adherence to the stunning parameters outlined in Table 5 is essential to integrate technological efficiency, humane treatment of poultry, and compliance with halal production requirements.

Table 5. *Electrical stunning parameters*

Control points	Parameters
Stunning process	Poultry are suspended upside down and passed through a water bath that conducts electric current. This process ensures rapid and effective immobilisation before slaughter.
Current intensity	The electric current must be strong enough (typically 105-150 mA) to induce loss of consciousness without excessive damage to the carcass (fractures, haemorrhages).

Table 5. Continued

Control points	Parameters
Hygiene conditions	The water in the bath must be clean, with added salt to improve conductivity, ensuring effective stunning.
Stress control	Poultry are hung in dimly lit areas or under blue lighting to minimise stress. Breast supports are used to reduce wing flapping.
Halal inspector supervision	A representative of the Muslim community ensures that stunning does not result in death prior to slaughter, maintaining halal compliance.

Source: developed by the authors

Continuous monitoring and calibration of stunning equipment are critical for maintaining quality standards and ensuring humane handling of poultry. Proper oversight at each stage helps prevent violations of halal principles while preserving the high quality of the final product.

Detailed examination of the poultry slaughter procedure

Following stunning, poultry are transported via a conveyor system to the slaughter machine, where the jugular veins and carotid arteries are severed using circular cutting blades. This procedure effectively drains blood from the poultry, which is essential for preserving meat quality. Precision in the incision is critical, as a deep cut may damage the nervous system, causing complications during feather removal, while a shallow incision may lead to insufficient bleeding and discolouration of the skin.

According to the comprehensive standard PBD24:2007 implemented in Brunei, the poultry slaughter procedure mandates strict adherence to Islamic principles, including the prohibition of mechanical slaughter (Deuraseh & Brunei Darussalam, 2020). Instead, slaughter must be performed manually with the mandatory invocation of Allah's name before each incision. The trachea, oesophagus, and major blood vessels must be severed to ensure complete blood drainage and a rapid death. The standard emphasises that the slaughter process must be conducted with the appropriate intention (niyyah) and must not involve actions likely to cause prolonged pain or suffering to the animal (Riaz *et al.*, 2021). Strict control over slaughter techniques is maintained in facilities employing automated systems (Table 6). Each stage is overseen by a certified halal inspector. Blades are checked for sharpness before each shift, and modern blood-draining technologies are implemented to minimise contamination of carcasses, thereby preserving product quality and safety.

Table 6. *Poultry slaughter control*

Control points	Parameters
Slaughter technique	Poultry undergo severing of the jugular veins and carotid arteries while leaving the trachea and oesophagus intact to ensure maximum blood drainage. Performed manually or automatically.
Bleeding time	A minimal time lapse (up to 15 seconds) is ensured between stunning and severing of blood vessels to prevent recovery of consciousness. Bleeding lasts 90-150 seconds for complete blood removal.
Halal inspector's role	A representative of the Muslim community must be present to ensure compliance with all halal slaughter norms, including reciting a prayer before each slaughter (audio recordings permitted).

Table 6. Continued

Control points	Parameters
Slaughter equipment	Blades must be sharp to ensure a clean cut without excessive tissue damage. Automated systems are adjusted to handle poultry of different sizes.
Hygienic conditions	Slaughter areas must maintain sterility to prevent microbial contamination of carcasses. Spraying systems are used to remove blood residues and tissue fragments.

Source: developed by the authors

The poultry slaughter process involves rapid severing of the primary blood vessels in the neck (carotid arteries and jugular veins) to ensure effective bleeding (Raj, 2004). It is critical that this step occurs immediately after stunning, as even a short delay can compromise meat quality and increase the risk of poultry regaining consciousness. In industrial settings, either mechanical methods (circular blades) or manual techniques (operator with a knife) are employed. Ritual slaughter, such as halal or kosher, often relies on manual cutting accompanied by prayers, although large-scale processing plants may incorporate automated systems to improve efficiency.

As highlighted by M. Farouk *et al*. (2015), debates regarding slaughter methods – with or without stunning – persist in many countries. While stunning is often viewed as a means to reduce animal suffering, ensuring that birds remain alive in accordance with Sharia principles until the incision is made is equally critical. Facilities that process high volumes of poultry typically employ electrical water-bath stunning, where attention to parameters such as frequency, voltage, and current strength is essential to prevent haemorrhages, broken bones, and deviations from religious standards. The slaughter process is a pivotal stage in halal meat production, requiring rigorous compliance with both religious and technological standards. The halal food industry continues to expand due to growing demands for quality, hygiene, and Sharia compliance. Quality management systems are implemented to address every stage of production – from slaughter to transportation. According to I. Vanany *et al*. (2019), particular focus is given to critical control points, including raw material preparation, equipment calibration, documentation, hygiene protocols, and personnel training.

Poultry scalding procedures and quality considerations

Scalding poultry is a crucial stage in the preparation of carcasses for feather removal, achieved through brief immersion in hot water. This process induces protein denaturation in feather follicles and loosens follicular structures, facilitating feather plucking (Kumar *et al*., 2022). The temperature and duration of scalding depend on the poultry species, age, and subsequent processing requirements. In "soft" scalding (50-53°C), the epidermis is preserved, whereas "hard" scalding (59-61°C) removes the waxy outer layer, potentially compromising the carcass's visual appeal. For young broilers, a "medium" scalding scheme (54-58°C for 60-120 seconds) is commonly applied to prevent damage to delicate skin and minimise microbiological risks.

The scalding temperature and duration significantly influence meat quality. High-temperature scalding (59-61°C) facilitates feather removal but may damage the skin, leading to dehydration, colour alterations, or reduced marketability of the carcasses. Conversely, lower-temperature scalding preserves skin structure but requires stricter parameter control to ensure effective feather removal. P. Govindaiah *et al*. (2023) emphasise that electrical stunning prior to scalding may alter the meat's water-holding capacity and muscle fibre structure. However, traditional halal slaughter methods

maintain pH stability and reduce myofibrillar protein fragmentation, improving the product's texture. Hygienic considerations during scalding are critical to preventing cross-contamination. Water in scalding tanks must be clean, with a counterflow renewal system, and may include permitted disinfectants to control microbial loads. Regular monitoring of water temperature and chemical composition is mandatory to ensure compliance with sanitary standards. For process optimisation, single- or multi-stage scalding systems are employed, allowing gradual temperature reductions that better prepare carcasses for further processing (Table 7).

Table 7. *Scalding process*

Control points	Parameters
Water temperature	Water temperature for scalding should range between 54-61°C, depending on the poultry species. Higher temperatures may damage the skin, while lower temperatures may fail to remove feathers effectively.
Immersion time	Poultry should be immersed in water for 45-90 seconds to ensure effective feather removal. Shorter times are suitable for young birds, while longer durations are needed for waterfowl.
Hygiene requirements	Scalding water must be free from contaminants to avoid cross-contamination. Filtration systems and regular water renewal are mandatory.
Water quality monitoring	Water temperature and composition must be continuously monitored. Chemical agents are used to reduce microbial contamination in the water.
Types of scalding systems	Single- and multi-stage scalding systems exist. Multi-stage systems gradually lower water temperature, optimising the process for various poultry species.

Source: developed by the authors

Feather plucking (defeathering) follows scalding and involves the mechanical removal of feathers. Automatic machines equipped with rotating rubber fingers are used to remove feathers without damaging the skin. Plucking intensity is adjusted based on the species and age of the poultry to prevent mechanical damage. P. Govindaiah *et al*. (2023) highlight that proper machine settings minimise stress and maintain tissue integrity. Automated feather removal systems ensure high efficiency but require regular maintenance and adherence to hygiene standards. Machines are equipped with adjustable speed and pressure systems, enabling adaptation to different poultry types (Table 8).

Table 8. *Feather plucking requirements*

Control points	Parameters
Type of equipment	Mechanical machines with rotating rubber fingers are used, adapted to the poultry species and age. These systems ensure gentle feather removal without skin damage.
Adjustment of plucking intensity	Intensity is adjusted according to poultry type. Lower speeds are used for young birds, while higher speeds suit mature birds.
Skin damage	The distance between the bird and rubber fingers must be monitored to prevent skin tears or bone fractures. Close proximity may cause mechanical damage.
Hygiene requirements	High hygiene standards must be maintained during plucking to prevent cross-contamination. Equipment is regularly cleaned of feathers and other contaminants.
Technology and maintenance	Plucking machines must be well-calibrated to optimise performance and minimise poultry damage. Regular maintenance ensures safety and process efficiency.

Source: developed by the authors

Feather distribution varies across different parts of the poultry body, with denser coverage in the lower sections requiring more effort for removal than the upper sections. Machines are equipped with additional rubber fingers in denser areas to improve efficiency. Proper feather removal is essential for preserving meat quality, as mechanical plucking prevents skin damage. Plucking machines operate using a cyclomatic design, where rotating rubber fingers contact the birds and extract feathers. Proper adjustment of the finger-to-bird distance is critical, as excessive proximity may cause skin tears and fractures, while too much distance may result in incomplete feather removal. Following plucking, flaming is applied to eliminate residual feather filaments and down through exposure to a blue flame for 5-10 seconds. This process improves carcass appearance and prevents surface defects. However, excessive heat must be avoided to prevent skin burns, stress, or additional damage, which could compromise meat quality.

Poultry evisceration and cooling procedures

Evisceration is a critical stage in poultry processing that involves the separation of edible and inedible internal organs from carcasses. This process is typically performed using mechanised systems to ensure efficiency and hygiene (Blevins *et al.*, 2018). Initially, an incision is made along the abdominal wall, from the keel to the cloaca, followed by the removal of internal organs such as intestines, heart, liver, and spleen using specialised equipment. After organ removal, veterinary inspection is carried out to examine carcasses and viscera for any potential pathologies or defects.

Edible offal, such as the liver and heart, is separated from other organs and thoroughly rinsed with water. To prevent microbiological contamination, water spraying systems with disinfectants are used. Waste materials that fail to meet quality or religious standards are removed and disposed of in accordance with sanitary regulations and halal production guidelines. Evisceration processes play a vital role in maintaining high sanitary standards and preserving meat quality. The evisceration process at the facility is conducted under strict regulations to ensure religious compliance, technological efficiency, and sanitary cleanliness (Table 9). Supervision by a certified halal inspector guarantees compliance with each stage of the process, from incision to the handling of edible offal. Automated systems help prevent mechanical damage and maintain hygienic conditions throughout carcass processing.

Table 9. *Requirements for poultry evisceration process*

Control points	Parameters
Compliance with halal requirements	Evisceration must be carried out by a certified operator in accordance with Sharia rules. The presence of a halal inspector is mandatory.
Equipment type	Automated or semi-automated systems are used to prevent damage to carcass integrity and internal organs.
Removal of internal organs	Organs that do not meet Sharia requirements (e.g., gall bladder) must be removed separately and disposed of in compliance with regulations.
Hygiene control	Work areas and equipment must be regularly cleaned and disinfected to prevent cross-contamination. Water used for cleaning must comply with sanitary standards.
Product integrity	Damage to skin or internal organs must be avoided, as this may affect product quality.
Waste disposal	Waste must be disposed of according to sanitary norms and halal production rules. Separate collection of organic and inorganic residues is mandatory.

Source: developed by the authors

Evisceration is a crucial stage in poultry processing that involves the removal of edible and inedible internal organs using mechanised systems to ensure efficiency, hygiene, and compliance with halal standards. The process includes precise incision, removal of organs, veterinary inspection, and separation of edible offal, such as the liver and heart, which are thoroughly cleaned. Strict hygiene measures, including regular disinfection and the use of water spraying systems with disinfectants, are implemented to minimise contamination risks. Waste materials are sorted and disposed of according to sanitary and halal requirements. Supervision by certified halal inspectors ensures adherence to religious standards, while automated systems help preserve carcass integrity and product quality throughout processing.

The cooling of poultry carcasses after slaughter is a critical stage for preventing microbial growth and ensuring the safety and quality of meat (Kumar *et al*., 2022). In modern processing facilities, poultry carcasses are typically cooled to approximately 4°C or below within 1-2 hours after evisceration. This is achieved through either water immersion or air chilling methods. Water immersion cooling, widely used in many countries, involves passing carcasses through a series of sequential tanks filled with cold water, often supplemented with approved disinfectants. This approach ensures rapid temperature reduction and the removal of residual blood or tissue fragments. Conversely, air chilling takes place at temperatures ranging from 2-7°C and requires 1-3 hours, during which carcasses are conveyed through a chilled chamber with air circulation. While water immersion cooling effectively reduces microbial contamination, it may result in slight water absorption by the carcasses. In contrast, air chilling may lead to minor weight loss due to surface dehydration. Therefore, the selection of the cooling method depends on processing requirements, quality expectations, and regional regulatory standards.

Effective post-mortem inspection techniques for poultry carcasses

Following the completion of the main stages of slaughter and carcass processing, a thorough post-mortem inspection is conducted to ensure the meat meets safety and quality standards (Kumar *et al*., 2022). This process focuses on identifying any signs of pathology, defects, or residual organ materials that could affect the product's suitability for consumption. Veterinary inspector or qualified personnel examine the external appearance of the carcasses and internal organs (if removed, these are inspected alongside the carcasses), paying attention to signs of inflammation, pathological changes, or residual digestive contents. If localised lesions or defects are detected, the affected areas are removed, and the carcass is re-inspected to determine its suitability for consumption. In cases of systemic pathology or infectious diseases, the carcass may be completely excluded from further processing. This approach ensures high food safety standards and maintains consumer confidence in poultry processing facilities (Table 10). Post-mortem inspection also involves evaluating meat quality to detect potential abnormalities. As noted by P. Govindaiah *et al*. (2023), assessing meat colour parameters, such as redness, helps identify residual haemorrhages often associated with electrical stunning. Conversely, traditional slaughter methods (without pre-stunning) demonstrate better blood drainage, reducing bacterial contamination risks and improving colour stability during storage.

Table 10. *Requirements for post-mortem inspection*

Control points	Parameters
Inspector oversight	Inspection of carcasses under the supervision of a certified halal inspector to ensure compliance with Islamic principles.
Carcass examination	Detection of physical defects, signs of disease, damage, or residual organs that do not comply with religious standards.
Meat quality	Evaluation of colour, texture, and odour to determine freshness and compliance with standards.
Hygiene standards	Use of sterile tools, disinfection of equipment, and cleaning of work areas to prevent contamination.
Removal of non-compliant carcasses	Immediate removal of carcasses that do not meet halal requirements or exhibit defects to maintain cleanliness in production.
Documentation	Maintaining records of inspection results to ensure transparency and compliance with standards.

Source: developed by the authors

During the post-mortem inspection, carcasses are cleaned of potential faecal contamination using chlorinated water or other approved disinfectants in specialised washing stations. After this, carcasses are thoroughly washed using spray nozzles to remove residual materials and then cooled to the required temperature during the chilling process. Carcasses that pass inspection and meet established standards are stamped and sent for further processing. Non-compliant carcasses or defective parts are discarded in accordance with sanitary regulations and halal production rules. This inspection stage plays a crucial role in maintaining high product quality, adhering to religious and hygiene requirements, and minimising risks for consumers.

Enhancing halal product traceability for consumer confidence

Traceability is a vital component of food safety systems, enabling monitoring of product movement from farm to consumer. It allows for the timely identification and resolution of potential food safety risks, enhancing consumer trust and transparency in production processes (Sucipto *et al.*, 2021). Halal product certification relies on international standards such as MS 1500:2009 (Malaysia) and GSO 993:2015 (2015), which regulate production, storage, packaging, and transportation processes (Table 11). Modern technologies, including RFID tags and blockchain systems, have been integrated to ensure continuous monitoring and recording of all production stages.

Table 11. *Halal product certification and inspection*

Control points	Parameters
Certification of facilities	Production facilities must be certified according to halal standards. Certification is issued by official bodies ensuring compliance with Islamic principles.
Continuous inspector presence	Certified halal inspectors must be present at every stage, from pre-slaughter inspection to final packaging, ensuring compliance with Islamic norms.
Equipment and facility inspection	Equipment, facilities, and processes are evaluated for compliance with halal standards. Contact with prohibited substances is strictly forbidden.
Documentation and traceability	All operations must be recorded and documented. A full record of production processes ensures transparency and compliance.
Staff training	All employees involved in production undergo specialised training on halal standards, including Islamic requirements and hygiene protocols.

Source: developed by the authors

Modern technologies, such as blockchain and RFID tags, provide automated monitoring of compliance with halal standards at all stages of production and logistics (Tieman & Williams, 2019). These technologies optimise traceability processes, reduce certification costs, and enable rapid responses to potential safety threats. However, even the most advanced systems cannot entirely replace inspector oversight, which ensures adherence to religious norms and evaluates production processes. Innovative methods for detecting hidden ingredients include molecular and spectroscopic techniques, integrated with artificial intelligence for analysing complex food matrices (Ng *et al*., 2021). Such tools enhance fraud detection accuracy, identifying prohibited components such as traces of pork or excessive alcohol levels. Despite their effectiveness, the widespread adoption of these methods faces challenges related to standardisation, equipment costs, and the need for global harmonisation of testing approaches.

Technologies such as the Internet of Things (IoT) and wireless sensor networks (WSN) support real-time monitoring of storage and transportation conditions (Ng *et al*., 2021). These systems help maintain appropriate temperature and humidity levels, minimising contamination risks. Special attention is given to integrating traceability standards to ensure compliance with halal requirements at all stages, including slaughter, processing, and packaging (Abdullah *et al*., 2019). Traceability systems preserve evidence of compliance and record product origin, which is critical for quality control and fraud prevention. As emphasised by S. Azam *et al*. (2021), the implementation of Halal Compliance Rating (HCR) systems, based on auditing key components such as hygiene, risk management, and knowledge of halal standards, enhances production transparency. These systems improve process monitoring, ensuring regulatory compliance and access to international markets.

Laboratory methods, including PCR and spectroscopy (FTIR, NMR), combined with chemometrics and artificial intelligence, allow for the analysis of complex food products and identification of prohibited ingredients (Ng *et al*., 2021). Despite their high accuracy, these approaches require substantial investment in equipment and method standardisation, posing challenges for large-scale implementation. Monitoring cross-contamination at all stages of production and logistics is essential for preserving the halal status of products (Supian, 2018). Combining blockchain technologies with audits and laboratory testing guarantees compliance with standards and increases consumer confidence (van der Spiegel *et al*., 2012). Thus, traceability systems play a key role in ensuring product quality, safety, and halal compliance, integrating modern technologies to enhance transparency and efficiency across production processes.

Animal welfare and meat quality

Animal welfare is a critical factor in ensuring high meat quality. Stress caused by poor handling or unfavourable conditions during transportation and slaughter can significantly degrade the flavour and texture of meat. Therefore, strict standards for animal handling are followed at processing facilities, including proper transportation, slaughter conditions, and pre-slaughter inspections. A key requirement is the use of stunning methods that minimise stress in poultry during slaughter. Animal welfare directly influences the quality of meat produced, as excessive stress during transportation and slaughter leads to deteriorations in physicochemical properties and an increased likelihood of defects (Kumar e*t al*., 2022; Sejian *et al*., 2024). Stress indicators such as respiratory rate, heart rate, and corticosteroid levels increase under poor handling or unsuitable housing conditions, contributing to quality issues – such as meat with excessive residual blood, bruises, or elevated microbial

contamination. Gentle handling, optimal stocking density in cages, and adequate resting periods before slaughter are essential factors for reducing stress levels and improving the commercial properties of poultry products.

Rising consumer awareness regarding halal standards has highlighted the importance of animal rearing methods, housing conditions, feeding practices, and slaughter techniques. Research by I. Aslan & H. Aslan (2016) emphasises the importance of certification and adherence to Islamic principles, which mandate humane treatment of animals during transportation and slaughter. Criteria such as the absence of contamination with haram ingredients and clear product labelling are crucial for maintaining trust among Muslim consumers. Ensuring animal welfare involves minimising stress and adopting humane slaughter practices, which, according to F. Mehak *et al*. (2024), also positively affect meat quality. Stress can trigger the release of toxic substances and the accumulation of metabolites in tissues, reducing product quality and increasing contamination risks. Halal slaughter methods promote more effective blood drainage, lowering the likelihood of residual pathogens and enhancing the organoleptic properties of meat (Govindaiah *et al.*, 2023). Most countries have enacted laws prohibiting animal cruelty and mandating humane slaughter methods, such as electrical stunning. Poor treatment of animals during slaughter affects not only their welfare but also the quality of the meat, including elevated levels of stress hormones, which impair texture and flavour characteristics.

Conclusions

The production of halal poultry meat requires strict adherence to both religious and technological standards. Effective control of the technological process, including ante-mortem inspection, stunning, bleeding, evisceration, chilling, and post-mortem inspection, is crucial for ensuring product quality and compliance with halal requirements. The identification of critical risk points enhances process control and prevents violations of standards. Studies highlight the need for implementing audit systems and risk analysis to optimise production processes and ensure food safety. This review has provided a comprehensive overview of the critical control points in halal poultry slaughter, highlighting the interconnectedness of technological processes, religious requirements, and animal welfare. By examining each stage, from pre-slaughter handling to post-mortem inspection and traceability, the study identifies potential risks and proposes strategies for optimising production processes. The practical value of this research lies in its potential to inform producers, processors, and regulatory bodies in their efforts to improve efficiency, ensure compliance with halal standards, and enhance consumer trust. The identified best practices and technological advancements can be implemented to minimise risks, improve product quality, and strengthen the competitiveness of halal poultry products in the global market. Furthermore, this review serves as a foundation for future research aimed at developing innovative solutions for halal poultry production, ultimately contributing to a more sustainable and ethical food industry.

Particular emphasis is placed on animal welfare, as stress during transportation and slaughter significantly affects the physicochemical properties of meat. Humane slaughter methods, such as electrical stunning, help reduce stress and improve organoleptic characteristics. The integration of modern technologies, including RFID tags, blockchain, and IoT systems, improves traceability and operational efficiency, ensuring compliance with halal standards and reinforcing consumer trust in the products. Further research should focus on improving slaughter control technologies, integrating automated quality assurance systems,

and optimising certification processes to meet the demands of international markets.

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Conflict of Interest

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Технологія халяльного забою птиці: критичний огляд контрольних точок

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Анотація. Халяльне виробництво має значний потенціал для подальшого розвитку, зумовлений зростаючим глобальним попитом на якісні, безпечні та етично виготовлені харчові продукти. Окрім задоволення потреб мусульманських споживачів, сертифіковані халяльні продукти стають дедалі привабливішими для ширшої аудиторії, яка цінує дотримання високих стандартів гігієни, простежуваності та якості. Сучасні тенденції підкреслюють важливість дотримання суворих вимог, що підвищує конкурентоспроможність халяльного виробництва на міжнародних ринках. У цьому літературному огляді розглядався технологічний процес забою птиці з акцентом на дотримання халяльних норм і вимог. Метою дослідження було виявлення ризиків на кожному етапі виробництва, оцінка їх впливу на якість продукції та визначення шляхів оптимізації виробничих процесів відповідно до ісламських стандартів. Аналіз базувався на огляді сучасної наукової літератури, стандартів сертифікації та практик управління ризиками в харчовому виробництві. Основні ризики пов'язані з такими етапами, як передзабійний огляд, оглушення, забій, знекровлення, потрошіння, охолодження та післязабійний контроль. Встановлено, що порушення на цих етапах може

призвести до механічних пошкоджень тушок, недостатнього знекровлення, мікробного забруднення або невідповідності релігійним вимогам. Впровадження систем управління ризиками, таких як HACCP, а також використання сучасних технологій простежуваності, включаючи RFID-мітки та блокчейн, може покращити прозорість, ефективність виробництва та відповідність міжнародним стандартам. Цінність дослідження полягає у визначенні напрямків удосконалення систем контролю технологічного процесу, зокрема шляхом інтеграції автоматизованих рішень для моніторингу критичних точок та аналізу якості продукції. Отримані результати можуть бути корисними для підвищення обізнаності щодо вимог до якості забою птиці в контексті сертифікації халяльного виробництва. Перспективи подальших досліджень включають вдосконалення технологій забою, розробку автоматизованих систем контролю та оптимізацію методів оцінки якості для підвищення ефективності виробництва та відповідності високим гігієнічним і релігійним нормам

Ключові слова: халяльне виробництво; безпечність і якість м'яса; критичні точки; управління ризиками; простежуваність