Short Communication

# Commercial laying hen farms' general characteristics, environmental management, and biosecurity practices in the sub-arid area of Algeria

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## Abstract

The success of commercial laying hen farms depends on the possibility of managing environmental conditions properly and performing strict biosecurity measures, which would increase productivity, enhance the performance of the flock, and save money, especially in regions characterized by challenging climatic conditions, such as the sub-arid and arid areas. There is, however, very little literature exploring these issues in the Algerian context. The objective of the study was to assess environmental management and biosecurity practices, and the relationship between these and farm size in the Algerian sub-arid area (northeast Algeria). The face-to-face interviews were conducted between January 2024 and April 2025 among 144 laying hen farmers, who were interviewed using a structured questionnaire. Most of the farms had a population of 12,000-40,000 hens (68.06%), with the largest population, at 33.33%, being that of ISA Brown. Findings revealed that numerous critical practices such as light intensity control ($\chi^2$ = 24.984; $P$ < 0.001), hygrometry regulation ($\chi^2$ = 45.958; $P$ < 0.001), frequency of manure removal ($\chi^2$ = 23.386; $P$ < 0.001), environmental management systems ($\chi^2$ = 45.958; $P$ < 0.001), wheel dips ($\chi^2$ = 61.714; $P$ < 0.001), maintenance of footbath ($\chi^2$ = 71.324; $P$ < 0.001), shoe changing protocols ($\chi^2$ = 45.958; $P$ < 0.001), compliance for fallow period ($\chi^2$ = 26.128; $P$ < 0.001), wild bird and rodent control ($\chi^2$ = 32.863; $P$ < 0.001), and disposal of carcass ($\chi^2$ = 82.505; $P$ < 0.001) were poorly applied, especially in small-sized farms (<12,000 hens and 12,000–40,000 hens). In comparison, larger farms (>40,000 hens in size) had comparatively high compliance, likely due to their financial capacity and resource availability. Comprehensively, the results show that environmental management and biosecurity activities in the study area are deficient. Specific measures, such as farmer training and raising awareness levels, are the most urgent methods to encourage the adoption of these necessary practices and protect the health of poultry and farm productivity.

**Keywords:** biosecurity, environmental, laying hen, management, sub-arid

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## Introduction

Harsh climatic conditions have long been identified as a detrimental factor affecting productivity in both laying hens and broilers, as highlighted by numerous reports (Liu *et al*., 2019; Chauhan *et al*., 2021). Thus, adequate management of the environmental conditions, such as high temperatures, is a crucial element in poultry production in these areas. The production of eggs has become one of the most rapidly developing fields in global animal farming, providing a cost-effective source of high-quality protein at an affordable price (Higham *et al*., 2024). To meet the increasing demand, the size of flocks has increased significantly on average, placing an ever-growing strain on farm management practices to protect the health, productivity, and welfare of animals (van Veen *et al*., 2023). Recent research has emphasized the interconnection between the welfare and performance of laying hens and environmental control in poultry houses. Successful regulation of microclimatic conditions not only enhances animal performance but also boosts egg production (Jeon *et al*., 2025).

Humidity and temperature are examples of environmental factors that have an objective impact on flock performance (Li *et al*., 2024). The light parameters, including duration, wavelength, and intensity, have also been shown to have a considerable impact on the productivity (Erensoy *et al*., 2021; de Souza Granja Barros *et al*., 2024; Clark *et al*., 2025). Biosecurity is another very important aspect of poultry management, alongside environmental control. Biosecurity is defined as a collection of preventive and control practices that restrict the introduction and transmission of infectious agents, thereby maintaining flock health and the economic viability of poultry production systems (Delpont *et al*., 2023). The accumulating evidence confirms that the strong application of biosecurity will not only decrease the occurrence and intensity of infectious disease outbreaks but also reduce the losses that can be incurred in monetary terms due to morbidity and lowered productivity (Hosseini *et al*., 2025; Wei *et al*., 2025).

On this background, it is urgent to consider the practices of environmental management and biosecurity on Algerian laying hen farms. Batna province, a sub-arid area and the largest egg-producing area of the country, is a particularly topical case study. The Algerian poultry industry, a region of extreme importance, is still marked by low-quality production and comparatively low productivity (Alloui and Bennoune, 2013; Kaci, 2022). There is a dearth of scientific work on the topic of biosecurity in Algerian laying hen farms, where only two studies have documented findings on a total of 16 farms (Alloui and Ayachi, 2012; Alloui *et al*., 2021). In addition, there are practically no studies that have explored poultry house environmental management practices in Algerian poultry houses, especially in arid and sub-arid regions. The gap in knowledge is severe based on the fact that commercial laying hen farms are increasing rapidly, and their findings may enlighten specific interventions that would enhance the efficiency of the management and the farm results.

The current paper aims to address this gap by outlining the overall features of laying hen farms in a leading area in terms of poultry production and determining the level of environmental management and biosecurity practice. This study offers sizeable impacts on the existing practices of poultry-farming by concentrating on a highly populated area of the poultry farms in the sub-arid area of northeast Algeria and identifying areas that are in need of development to improve the flock welfare and the productivity of the farm. Precisely, our study was designed to investigate the relationship between the farm size of commercial laying hens and the adoption of various environmental management and biosecurity practices.

## Materials and Methods

***Study site*:** This research was executed in a sub-arid area (the Batna district), which is in northeastern Algeria and is about 405 km away from the capital, Algiers (35°32′60″ N; 6°10′0.001″ E). The climate is semi-arid, overcast in winter and hot in summer; the average temperatures in the months are 0.9 °C in January and 35.4 °C in July. Mean precipitation amounts to about 386.84 mm/annum. Cedar forests (*Cedrus atlantica*) with sprinkles of holm oak (*Quercus ilex*) dominate the vegetation. Study area is a leading center of the Algerian poultry sector, and the leading provider of national table eggs, having been at the top of the table for 12 consecutive years (2000-2012) (DSA, 2015, as cited in Alloui *et al*., 2021). The Scientific Council of the Institute of Veterinary Sciences and Agricultural Sciences, University of Batna 1 in Algeria, granted ethical approval for this research.

***Questionnaire survey and participants*:** The questionnaire was undertaken in the period between January 2024 and April 2025. In the initial case, 225 respondents were approached at random, and 144 were finally included in the study data. The inclusion criteria of the farmers in the survey depended on their willingness to participate in the study and to provide access to the poultry sheds. The sample size was determined according to the formula provided by Yamane (1967):

$$\mathrm{n} = \frac{N}{1 + N\,(e)^2}$$

Where $n$ represents the sample size, $N$ symbolizes the population size, and $e$ denotes the margin of error. In this study, $N = 225$ and $e = 0.05$ (5%). Table 1 depicts the summary of the participants' socio-demographic profiles. Farmers in 19 municipalities (Bitam, Merouana, Oulated Assafir, Ain Djasser, Oued El Ma, Talkhemt, Ouled Aouf, Hidoussa, Ouled Fadel, Zana El Beida, El Hassi, Lazrou, Ain Touta, and Serina) were interviewed face-to-face. These municipalities in total produced nearly 95% of the total eggs in the study area in the 2023 agricultural year. The study questionnaire was developed after conducting a thorough literature review (Scott *et al*., 2018; Aguidissou *et al*., 2020; Tsegaye *et al*., 2023). Firstly, a preliminary questionnaire has been performed in coordination with the technical, professional, and administrative poles of the poultry sector. The content validity of the questionnaire was pretested in a pilot study that was conducted by distributing the prepared version of the questionnaire to 30 farmers to ensure the effectiveness of the questionnaire, and no reformulations were required. The questionnaire, comprising open-ended and closed-ended questions, was structured in such a way that it gathers data on the overall nature of commercial laying hen farms, and environmental management and biosecurity practices. Complex issues that need to be explained were done in open-ended questions, whereby the respondents could explain the answer in detail using their own words. Dichotomous (e.g., "yes/no"), categorical (e.g., "acquired/transmitted"), and polytomous choices (e.g., "primary school," "secondary school," "university education") were used as closed-ended items. The questionnaire was determined in four sections: Respondent profile - age, education, years of service in farming, training in egg production and source of knowledge; Farm specifications - farm size, sheds and breeding hens raised; Practices of environmental management - the nature of lighting used, management of light level, regulation of temperature and humidity, the type of ventilation, the frequency at which manure is removed and whether the establishment has an environmental management system; and Biosecurity practices – presence of perimeter fencing, wheel dips, footbath functionality, disinfection of vehicles and equipment, shoe-changing protocols, availability of clothing for visitors, fallow period compliance, wild bird and rodent control, and carcass disposal methods. The participants' attitude towards environmental management practices was evaluated based on the answers of participants in the attitude items. For the type of lighting, the scale varied from 1 for "fluorescent lighting", 2 for "LED lighting", and 3 for "incandescent" in the attitude item "What lighting type do you use in your sheds?". The farmers' attitudes towards light intensity, temperature, and hygrometry control were assessed using the question: "Do you control this parameter or not?". Where the score of one was attributed to the farmers who adopt this practice, and the score of 0 was attributed to those who did not adopt the control practice. The practice of manure removal frequency was investigated with an answer scale ranging from "one" to "three" times per week. The environmental management systems were classified into two categories: "automatic" and "non-automatic". The biosecurity practices investigated were mainly assessed with questions with two scales: "Yes" for the framer who adopted the practice, and "No" for the framer who did not adopt the practice. Whereas the farmers were classified into two categories according to the adopted fallow period: "less than 15 days" and "more than 15 days". In order to make the questionnaire clear and easily accessible, it was written in French and Arabic. Involvement was voluntary, with all respondents having their informed consent taken verbally. The questionnaires were carried out anonymously, and the confidence levels of all data were highly maintained. There were three classes of farms according to the size of flock, which included fewer than 12,000 hens, 12,000-40,000 hens, and over 40,000 hens. The cage density was determined as the number of laying hens per cage divided by the floor area of the cage.

***Statistical analysis:*** Analysis of the data was conducted in SPSS 25.0. Socio-demographic and professional characteristics of respondents (frequencies and percentages) and generic farm characteristics were described with the use of descriptive statistics (frequencies and percentages). The Chi-square or Fisher's exact test was used in the case when more than 20% of the cells have expected frequencies < 5 to compare the differences in environmental management and biosecurity practices between the categories of farm size. Further tests on associations between farm size and management practices were conducted with Cramer's V coefficients. The strength of associations was denoted as follows: negligible (0.00 to ≤ 0.10), weak (> 0.10 to ≤ 0.20), moderate (> 0.20 to ≤ 0.40), relatively strong (> 0.40 to ≤ 0.60), strong (> 0.60 to ≤ 0.80), and very strong (> 0.80 to ≤ 1.00). All analyses were statistically significant at a $P$-value of less than 0.05.

## *Result and Discussion*

***Socio-economic characteristics of surveyed farmers*:** The socio-economic features of the farmers were tabulated in Table 1. Most of them (79.86%) fell between the ages of 45 and 59, meaning that the production of eggs in the area is mainly controlled by middle-aged people. In terms of education, 58.33% of the farmers were reported to have completed secondary school, and only 4.86% of them had a university degree, implying that there is limited access to higher education by the respondents. Regarding professional experience, 44.44% of the respondents had worked in egg production between 6 and 10 years, which indicated an average degree of experience in the industry. Interestingly, almost all farmers (97.92%) indicated that they have not been trained formally on poultry production, a gap in the study area that is very crucial when it comes to the capacity-building and extension services provided to farmers.

***General characteristics of laying hen farms*:** Table 2 gives an overview of the overall nature of the surveyed laying hen farms, such as flock sizes, number of sheds, and the breeds reared. The median size of farms was 12,000 to 40,000 hens (68.06%), significantly higher than the reported ranges of earlier studies of Algerian poultry farms, which had flock sizes of 4,705 to 10,000 hens (Alloui, 2011; Mahmoudi *et al*., 2015). The technical and economic efficiency of medium-sized farms over the recent years could be considered a potential cause of their predominance in the given study, as they are more likely to be sustainable than smaller ones. As far as housing is concerned, most farms (75.69%) had only one shed. This is because the few sheds per farm could be attributed to the fact that they face financial constraints, which limit them from investing in infrastructure. The Algerian poultry industry has structural problems such as poor regulatory and legislative systems, access to credit and finance, and the fluctuation of the poultry markets, which deter the expansion of facilities among farmers (Kaci and Cheriet, 2013). The most common strains reported were in regard to breeds with ISA Brown (33.33%) and Hy-Line Brown (32.64%). The high production performance of ISA Brown and its larger egg size, which has a great demand in the market, could be the reason behind its wide usage. The benefits are confirmed by comparative studies: Hasan *et al*. (2021) have identified the least adaptable and most profitable strain of ISA Brown in 30 commercial layer farms in Bangladesh, whereas Hinsemu *et al*. (2018) have focused on the amount of its eggs (around 300 eggs per hen per cycle) and its shell quality. On the same note, Islam and Kabir (2021) have observed that consumers favor ISA Brown eggs because of their desirable size and color. Abd-El Hamed and Abo-Gamil (2022) also recognized the most profitable breed, ISA Brown, under the Egyptian production conditions. In a slightly more recent experimental study, Ayinde *et al*. (2023) discovered that ISA Brown has better feed conversion efficiency and productivity when compared to Harco Black and Shika Brown strains in Nigeria. The other commercial hybrid, Hy-Line Brown, also showed excellent productive results. Palacio Holguin *et al*. (2019) stated that both Hy-Line Brown and ISA Brown offer similar advantages in regard to adaptability, productivity, and profitability, which is why the two are dominant in the farms surveyed.

**Table 1** Socio-economic and professional characteristics of farmers in the study area.

| Characteristics | Frequency (n) | Percentage (%) |
|---|---|---|
| **Age** | | |
| 26-44 | 16 | 11.11 |
| 45-59 | 115 | 79.86 |
| Over 60 | 13 | 9.03 |
| **Educational level** | | |
| Primary school | 9 | 6.25 |
| Middle education | 44 | 30.56 |
| Secondary education | 84 | 58.33 |
| University education | 7 | 4.86 |
| **Egg Production Experience** | | |
| 1-5 | 1 | 0.7 |
| 6-10 | 64 | 44.44 |
| 11-15 | 54 | 37.5 |
| Over 15 | 25 | 17.36 |
| **Training in poultry production** | | |
| Yes | 3 | 2.08 |
| No | 141 | 97.92 |
| **Source of the know-how** | | |
| Acquired | 66 | 45.83 |
| Transmitted | 78 | 54.17 |

**Table 2** Overview of laying hen farms in the study area.

| Variables | Frequency (n) | Percentage (%) |
|---|---|---|
| **Laying hens/farm** | | |
| Less than 12000 | 37 | 25.68 |
| 12000 – 40.000 | 98 | 68.06 |
| More than 40.000 | 9 | 6.25 |
| **Shed/farm** | | |
| 1 | 109 | 75.69 |
| 2 | 27 | 18.75 |
| 3 | 6 | 4.17 |
| 4 | 2 | 1.39 |
| **Breed** | | |
| Hy-line Brown | 47 | 32.64 |
| H&N | 42 | 29.17 |
| ISA Brown | 48 | 33.33 |
| ISA White | 70 | 4.86 |

***Environmental management:*** The environmental control practices that commercial laying hen farms operating in the study area have implemented are shown in Table 3. All examined factors showed significantly ($P < 0.001$) high effects, with the exception of lighting type. Of these, hygrometry ($\chi^2 = 45.958$; $P < 0.001$) and the existence of an environmental management system ($\chi^2 = 45.957$; $P < 0.001$) remained as the most significant predictors of environmental control, succeeded by light intensity ($\chi^2 = 24.984$; $P < 0.001$) and manure removal frequency ($\chi^2 = 23.386$; $P < 0.001$). These findings underscore the critical role of microclimate regulation and waste management in maintaining optimal production conditions. Regarding lighting practices, the 40-watt incandescent lamp (52.78%) was the most frequently used, followed by light-emitting diode (LED) lights (47.22%) (Table 3). Interestingly, adoption of LED was higher in large farms (>40,000 hens) where 77.78% farmers said they used LEDs as opposed to the 22.22% who used incandescent bulbs. Such a choice can probably be justified by the technical and economic benefits of the LEDs: they offer consistent and selective spectral outputs (Steranka *et al*., 2002) and can be easily dimmed to control the intensity of light (Benson *et al*., 2013). The higher rate of use of LEDs in larger farms can be attributed to their financial ability to invest in more advanced and cost-effective technologies that improve their productivity as well as the well-being of their flocks. No usage of fluorescent lighting was mentioned in the 144 surveyed farms. This observation agrees with previous research that has shown no significant differences in the feed consumption, egg production, mortality, and egg weight in fluorescent and LED lighting systems (Long *et al*., 2016). In the same vein, Liu *et al*. (2018) found that poultry-specific LED systems provided a similar egg quality and production performance to the conventional fluorescent lighting in W-36 laying hens, an additional reason why there was no fluorescent lighting in the surveyed farms. The light intensity control was also very different among the categories of farm size ($P$ < 0.001). Farm size-all farms containing more than 40,000 hens reported controlling the intensity of light actively as compared to most smaller farms (<12,000 hens and 12,000–40,000 hens) at 16.22% and 27.55%, respectively. It is probably these distinctions that are due to a higher level of professionalization of bigger farms and the possibility of investing in monitoring devices (Mahmoudi *et al*., 2015). In most farms (70.83%), there was no control of the light intensity. It was not measured precisely but was simply evaluated visually in 22.92% (n = 33), and only in 6.25% (n = 9) was a luxmeter employed to monitor. These findings reveal that there is a general deficiency in serious light management, which points to the fact that not all farmers understand that light intensity is an important factor that predetermines laying productivity and livestock health. The management of light must be well controlled in terms of its intensity and duration. Unmated light levels may potentially cause nervousness and feather-pecking among laying hens, whereas the duration of the lighting has a direct effect on feed consumption and subsequently on the weight and quality of the eggs (Kouba *et al*., 2010). Moreover, the wavelength of light is a very important factor in the performance of reproduction and various studies have shown that the wavelength of light can be used to increase egg production and enhance the laying persistence of the older hens (Gongruttananun, 2011; Reddy *et al*., 2012; Min *et al*., 2012; Baxter *et al*., 2014; England and Ruhnke, 2020). One hundred percent of all surveyed farmers (100) indicated that they monitored temperature with thermometers. Nonetheless, manual control of house temperature during hot weather was the norm, though it necessitated direct farmer intervention in the process of switching cooling pads and exhaust fans. This reliance on manual cooling has proven to be extremely problematic, considering that the study region has hot and dry summers (Alloui *et al*., 2015). Heat stress has been well reported to decrease egg production and egg quality and to suppress immune functions of laying hens (Biswal *et al*., 2022). Likewise, Wasti *et al*. (2020) reported that extended heat stress causes varying physiological imbalances, which eventually cause reduced productivity, poor egg quality, and financial losses to poultry farmers. Control of hygrometry differed tremendously among sizes of farms ($P$ < 0.001). Humidity measurement was not executed in either of the farms having less than 12,000 laying hens (100%) or having 12,000-40,000 hens (100%). Conversely, hygrometry was controlled by one-third of the farms that had over 40,000 hens (33.33%). In general, most of the farms (97.92%, n=141) did not control the humidity, which is mostly explained by the semi-arid climate of the study area that inherently predetermines the low humidity, which in turn makes people feel less inclined to regulate it (Bendib *et al*., 2022). However, the percentage of farms using hygrometry control was only a small number (2.08%, n=3), and they were aware of high humidity as a contributor to the negative impact of high temperatures on the production and quality of eggs (Balnave and Brake, 2005). Ventilation of all the surveyed farms was dynamic and controlled by exhaust fans and air inlets, which is relatively uniform in environmental management. The frequency of manure removal also varied considerably when the farm size was considered ($P$ < 0.001). Most of the large-scale farms (n = 77.78) with a population of over 40,000 laying hens removed manure three times a week, in contrast to only 18.92% of small farms (population below 12,000 hens) and 13.27% of medium-sized farms (12,000-40,000 hens). Such a difference is probably indicative of variations in manure management systems. Automatic manure belts are common on larger farms and make it easier to maintain personal hygiene (due to more frequent manure removal) and are also associated with better hygiene (due to faster removal) (Van Staaveren *et al*., 2018). In most of the surveyed farms, most of the manure was most often removed twice a week (71.53%, n = 144). Only 2.08% of the sampled farms had optimal management of lighting, temperature, and humidity. The conditions within the sheds were managed in such situations with the help of automated control systems. In comparison, 97.92% of the farms exhibited poor monitoring of environmental factors, and this inadequacy was strongly related to smaller farm sizes-100% of the farms containing less than 12,000 hens and those containing 12,000-40,000 hens, compared with 66.67% of those farms with more than 40,000 hens. Such a gap demonstrates a poor investment in the developed production facilities of smaller and medium-scale farms. As implied in the earlier research, automated technologies in the monitoring and control of environmental parameters can be deployed to help farmers improve shed environments and flock health, which will increase productivity, competitiveness, and profitability and minimize losses (Neto *et al*., 2020; Olejnik *et al*., 2022). Poor operation of ventilation and cooling systems, especially in small and medium farms, can lead to uncontrolled high levels of internal heat and humidity. This situation undermines the well-being and performance of birds, causing adverse effects such as a decrease in the feed-to-energy ratio, an increase in energy use, and a subsequent mortality rate. These results validate the need for introducing new technologies, equipment, and innovative control tools to enhance environmental control and facilitate the sustainable evolution of the poultry production system (Linker *et al*., 2011; Al-Nasser *et al*., 2020).

**Table 3** Environmental control practices of commercial laying hen farms in the study area.

| Factors | Farm size: Less than 12.000 n (%) | 12.000-40.000 n (%) | More than 40.000 n (%) | Total n (%) | $\chi^2$ | *P* value | Cramer's Values |
|---|---|---|---|---|---|---|---|
| **Type of lighting** | | | | | | | |
| Fluorescent | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | | | |
| Led | 13(35.14) | 48(48.98) | 7(77.78) | 68(47.22) | 5.661 | 0.059 | 0.198 |
| Incandescent | 24(64.86) | 50(51.02) | 2(22.22) | 76(52.78) | | | |
| **Light intensity** | | | | | | | |
| Controlled | 6(16.22) | 27(27.55) | 9(100.00) | 42(29.17) | 24.984 | <0.001 | 0.417 |
| Not controlled | 31(86.78) | 71(72.45) | 0(0.00) | 102(70.83) | | | |
| **Temperature** | | | | | | | |
| Controlled | 37(100.00) | 98(100.00) | 9(100.00) | 144(100.00) | / | / | / |
| Not controlled | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | | | |
| **Hygrometry** | | | | | | | |
| Controlled | 0(0.00) | 0(0.00) | 3(33.33) | 3(2.08) | 45.958 | <0.001 | 0.565 |
| Not controlled | 37(100.00) | 98(100.00) | 6(66.67) | 141(97.92) | | | |
| **Ventilation type** | | | | | | | |
| Dynamic | 37(100.00) | 98(100.00) | 9(100.00) | 144(100.00) | / | / | / |
| Natural | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | | | |
| **Manure removal-Frequency** | | | | | | | |
| One | 5(13.51) | 9(9.18) | 0(0.00) | 14(9.72) | | | |
| Two | 25(67.57) | 76(77.55) | 2(22.22) | 103(71.53) | 23.386 | <0.001 | 0.403 |
| Three | 7(18.92) | 13(13.27) | 7(77.78) | 27(18.75) | | | |
| **Environmental management system** | | | | | | | |
| Automatic | 0(0.00) | 0(0.00) | 3(33.33) | 3(2.08) | 45.958 | <0.001 | 0.565 |
| Non automatic | 37(100.00) | 98(100.00) | 6(66.67) | 141(97.92) | | | |

**Table 4** Biosecurity practices in laying hen farms in the study area.

| Factors | Farm size: Less than 12.000 n (%) | 12.000-40.000 n (%) | More than 40.000 n (%) | Total n (%) | $\chi^2$ | *P* value | Cramer's Values |
|---|---|---|---|---|---|---|---|
| **Fence around the farm** | | | | | | | |
| Yes | 37(100.00) | 98(100.00) | 9(100.00) | 144(100.00) | / | / | / |
| No | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | | | |
| **Wheel dips** | | | | | | | |
| Yes | 0(0.00) | 0(0.00) | 4(44.44) | 4(2.78) | 61.714 | <0.001 | 0.655 |
| No | 37(100.00) | 98(100.00) | 5(55.56) | 140(97.22) | | | |
| **Footbaths states** | | | | | | | |
| Changed regularly | 0(0.00) | 0(0.00) | 2(22.22) | 2(1.39) | | | |
| Dirty | 4(10.81) | 7(7.14) | 7(77.78) | 18(12.5) | 71.324 | <0.001 | 0.498 |
| Not functional | 33(89.19) | 91(92.86) | 0(0.00) | 124(86.11) | | | |
| **Disinfection of vehicles and equipment** | | | | | | | |
| Yes | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | / | / | / |
| No | 37(100.00) | 98(100.00) | 9(100.00) | 144(100.00) | | | |
| **Change of shoes** | | | | | | | |
| Yes | 0(0.00) | 0(0.00) | 3(33.33) | 3(2.08) | 45.958 | <0.001 | 0.565 |
| No | 37(100.00) | 98(100.00) | 6(66.67) | 141(97.92) | | | |
| **Clothes for visitors** | | | | | | | |
| Yes | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | / | / | / |
| No | 37(100.00) | 98(100.00) | 9(100.00) | 144(100.00) | | | |
| **Fallow period** | | | | | | | |
| Less than 15 days | 30(81.08) | 75(76.53) | 0(0.00) | 105(72.92) | 26.128 | <0.001 | 0.246 |
| More than 15 days | 7(18.92) | 23(23.47) | 9(100.00) | 39(27.08) | | | |
| **Wild bird and rodent control** | | | | | | | |
| Yes | 3(8.11) | 10(10.20) | 7(77.78) | 20(13.89) | 32.863 | <0.001 | 0.478 |
| No | 34(91.89) | 88(89.90) | 2(22.22) | 124(86.11) | | | |
| **Dispose of dead birds** | | | | | | | |
| Burial | 3(8.11) | 7(7.14) | 0(0.00) | 10(6.94) | | | |
| Incineration | 3(8.11) | 10(10.20) | 5(55.56) | 18(12.50) | 82.505 | <0.001 | 0.535 |
| Incineration + burial | 0(0.00) | 0(0.00) | 4(44.44) | 4(2.78) | | | |
| Throwing | 31(83.78) | 81(82.65) | 0(0.00) | 112(77.78) | | | |

***Biosecurity management*:** Table 4 summarizes the biosecurity measures that have been adopted in laying hen farms. The findings show that the majority of practices had a very significant impact ($P < 0.001$) on the overall biosecurity management. It is interesting to note that the strongest determinants of effective biosecurity management in the surveyed farms included the disposal of dead birds ($\chi^2 = 82.505$; $P < 0.001$), the presence and maintenance of footbaths ($\chi^2 = 71.324$; $P < 0.001$), and the use of wheel dips ($\chi^2 = 61.714$; $P < 0.001$). Wheel dips and farm size shared a notably strong association (Cramer's V = 0.655; $P < 0.001$). Likewise, shoe-changing habits (Cramer's V = 0.565; $P < 0.001$), disposal of dead birds (Cramer's V = 0.535; $P < 0.001$), footbath maintenance (Cramer's V = 0.498; $P < 0.001$), wild bird and rodent control management (Cramer's V = 0.478; $P < 0.001$), and fallow durations among flocks (Cramer's V = 0.246; $P < 0.001$) also exhibited relatively strong association with farm size. One hundred percent of all surveyed farms were fenced to avoid unauthorized entry. Nonetheless, wheel dips to disinfect cars were installed on only 2.78% of farms. Wheel dips were especially absent among small-scale farms (less than 12,000 hens) and medium-scale farms (12,000 to 40,000 hens), where none of them had adopted this measure (100%). Footbaths in all surveyed farms were in poor condition but with great variation: only 1.39% were clean and regularly used, 12.50% dirty, and up to 86.11% out of commission, especially in smaller farms. Farms that had 12,000-40000 hens (92.86%) and farms with fewer than 12-000 hens (89.19%) had the most prevalence of non-functional footbaths. Barriers, including the lack of willingness to embrace biosecurity measures by the farmers (Richens *et al*., 2018), financial limitations, and insufficient training (Rousset *et al*., 2020; Laconi *et al*., 2023; Souillard *et al*., 2024), may explain the poor condition of the wheel dips and footbaths in those smaller and medium-sized farms. No transport vehicles and equipment were disinfected on either of the investigated farms. The deficiency of prioritizing critical measures of disinfection, such as wheel dips and footbaths, is contrasted with practices in the United Kingdom, where farmers give special importance to disinfection mats, wheel dips, footbaths, and deep cleaning and disinfection of all the vehicles entering the premises (Hosseini *et al*., 2025). Perimeter/external biosecurity is also crucial in poultry production systems, and disinfection points at farm entrances and vehicle wheel washing are considered critical in carrying out the prevention of the introduction of pathogens outside the farm (Biocheck, 2024). All the farmers investigated in our study stated that they did not offer special work clothes for visitors, as well as for staff workwear. 97.92% did not acquire a pair of boots for each shed but rather had one pair of boots to work in all sheds on the farm. The latter was universal (100%) in the two minor sizes of farms, and less common (66.67%) in the bigger farms. Besides, all surveyed farms (0%) did not apply more stringent biosecurity practices, which include showering before entering sheds, putting on disposable clothing, and assigning special clothing and footwear to visitors. Such results reveal the insufficiency of biosecurity standards that regulate the entry and exit of workers and visitors, specifically the wearing of specially designed clothing and footwear, which constitute major risk factors in the introduction and transmission of pathogens in poultry flocks (Silva *et al*., 2014; Hertogs *et al*., 2021). Concerning fallow periods, 72.92% of farms were disinfecting sheds and leaving them unoccupied for less than 15 days prior to restocking with a new flock, whereas only 27.08% followed fallow periods of more than 15 days. It is interesting to note that most of the small farms of less than 12,000 hens (81.08%) and medium farms of 12,000-40,000 hens (76.53%) employed less than 15 days fallow. In such instances, the fallow time was below the suggested biosecurity and sanitary management precautions (Silva *et al*., 2014). This insufficient implementation is probably associated with the unwillingness of the farmers to implement biosecurity, with underestimation of its utility, and with a lack of training (Richens *et al*., 2018; Laconi *et al*., 2023; Amalraj *et al*., 2024). In the current study, the fallow period was not applied using the normal arrangements in most of the surveyed farms. Fallowing is described as a preventative practice in epidemiology that is aimed at decreasing the microbial burden of pathogenic organisms in poultry houses (Andreatti Filho and Patrício, 2004). It covers the period between cleaning and disinfection of the poultry house with the following flock (Jaenisch *et al*., 2004), and it is expected to take 15 to 20 days (Lopes *et al*., 2015). Rodent control was hardly practiced, with only 13.89% of farms reporting practicing it, with large and small farms reporting significant practice (77.78%). Conversely, the wild bird control was not taken care of in 86.11% of farms, especially in small-sized operations (91.89% and 89.8%, respectively). Lack of rodent and wild bird management poses a significant biosecurity threat because the vectors have the potential of causing and spreading infectious disease outbreaks among poultry herds (Scott *et al*., 2009; FAO, 2013; Wade *et al*., 2023). Regarding carcass disposal, indiscriminate disposal (or throwing) was the most common mode among farmers (77.78%), where small farms were the most common (83.78% and 82.65%, respectively). Incineration was used on 12.50% of the farms, which were mainly in bigger operations (55.56%), and burial was mentioned in 6.94%. Critically, a lack of a dedicated quarantine zone to isolate sick or visibly infected birds was detected in all the surveyed farms, which is an essential deficiency in biosecurity management. The results of this study show that most farmers had not acquired the best methods of managing the carcass, and most of them disposed of the dead birds by merely dumping them. On the contrary, burial or incineration has been noted as a hygienic option for carcass disposal (Abouelenien *et al*., 2020). The same observation aligns with those of Abouelenien *et al*. (2020), who found that 87.5% of Egyptian farmers disposed of dead birds in domestic waste. It is, however, in contrast to the results of Aguidissou *et al*. (2020), who indicated that in Benin, 80.0% of the farmers used burial as the main method of carcass disposal. The general findings point toward a significant lack of the introduction of biosecurity practices in all examined laying hen farms. Such results are consistent with Alloui and Ayachi (2012) and Alloui *et al*. (2021), who proved that Algerian poultry farms have lower biosecurity practices than international ones. The compliance level with some biosecurity practices is low, which can be explained by a lack of awareness of the advantages of these practices among farmers. As recent evidence indicates, the targeted coaching interventions could have a strong positive effect on adherence to the biosecurity measures in poultry farms, which were reported in Belgium and Italy (Amalraj *et al*., 2024; Tilli *et al*., 2024). The results obtained in our study indicate that biosecurity protocols must apply to several sections, including: personnel and visitor requirements, respecting the fallow period, proper shed sanitization, equipment and vehicle disinfection, and adequate and sanitary management of dead birds. These biosecurity practices may be used efficiently to reduce the potential introduction of infectious diseases into poultry farms. If an infectious disease is introduced, the previous protocols might limit the spread of the disease within and across farms. Adequate application of biosecurity protocols ensures good health and welfare of poultry on farms and reduces economic losses by minimizing the magnitude and frequency of infectious disease outbreaks.

In conclusion, this study clearly shows that environmental and biosecurity management practices are still of great concern to commercial laying hen breeders in the study area. The practices were especially weak in smaller farms and tended to be quite strong in large farms. The findings indicate that the current situation makes increased education and awareness among the breeders a priority, since the inability to apply the biosecurity measures strictly endangers the performance of production, the profitability of farms, and, ultimately, the sustainable nature of commercial egg production. In order to counter such challenges, more funds and technical resources must be channeled to small-scale farmers, where many lack the means and knowledge to adopt useful biosecurity measures. The enhancement of these plans is vital not only in enhancing the health and productivity but also in protecting the resilience and sustainability of the Algerian poultry industry.

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