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# Overcoming cold stress challenges in indigenous laying hens through diet supplementation with garlic, hot chili, and onion

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**Abstract** In this study, the ability of dietary supplementation (2%) with fresh garlic (*Allium sativum*), onion (*Allium cepa*), and hot chili pepper (*Capsicum annuum*) to reduce cold stress and improve the productivity response of indigenous laying hens (*Gallus gallus domesticus*) was investigated. These dietary additives were administered over a two-month period, from November to December. Hens (36 weeks old; n = 180) were assigned to four groups (n = 45/group) and housed in a Mediterranean temperate climate, where temperatures can drop as low as 3°C. Two percent supplements or cornmeal-based diets without supplements (control) were administered to the groups. Assessments were made on egg production, feed conversion ratio (FCR), egg quality, cholesterol levels, and plasma hormones, including follicle-stimulating hormone (FSH), luteinizing hormone (LH), and corticosterone. The results showed no significant differences in body weight ($P>0.05$) across the groups. However, throughout the experiment, egg production, feed conversion ratio, and egg mass were significantly higher ($P<0.05$) in all supplemented groups. Egg protein content improved ($P<0.05$) with garlic and chili, and garlic supplementation reduced cholesterol levels ($P<0.05$). Yolk color was enhanced by the chili additive ($P<0.05$). Garlic and chili also elevated FSH and LH levels ($P<0.05$) and reduced corticosterone concentrations ($P<0.05$), while onion showed milder effects. These findings suggested that *Allium sativum* and *Capsicum annuum* enhance cold stress resilience, productivity, and egg quality in laying hens, supporting their use as natural feed additives to improve welfare and performance under cold stress conditions.

**Keywords:** cold stress, egg production, herbal supplements, nutritional impact, poultry farming

## Introduction

Various factors influence egg quality and production in poultry farming, such as nutrition, environmental conditions, and health care management. Chicken rearing plays a vital role in the rural economies of developing countries such as Morocco and contributes significantly to food security. Nonetheless, farmers face seasonal limitations that negatively affect production (Benabdeljelil and Arfaoui, 2001; Smaiti, 2023).

One of the major challenges is the decline in both egg quality and production during the winter months (Benabdeljelil and Arfaoui, 2001; Boujenane, 2023), a phenomenon observed in many regions with temperate climates. Exposure to cold temperatures affects egg production and quality in poultry, with significant economic implications (Li et al., 2020). Beyond these performance losses, extreme temperatures alter blood parameters and impair immune function (Alves et al., 2012). Environmental stress also reduces antioxidant levels, further compromising health and productivity in chickens (Oke et al., 2024).

To mitigate such seasonal variations (Ncho et al., 2025), natural and cost-effective strategies to enhance egg production and preserve egg quality are gaining popularity (Salem and Abd El-Dayem, 2025). Herbal nutritional supplements such as garlic (*Allium sativum*) (Navidshad et al., 2018), hot chili peppers (*Capsicum annuum*) (Abd El-Hack et al., 2022), and onion (*Allium cepa*) (Dosoky et al., 2021) have emerged as promising alternatives due to their bioactive properties. These plants are rich in compounds such as allicin, capsaicinoids, and quercetin that may counteract the effects of cold stress through various mechanisms (Damaziak et al., 2017). Garlic's sulfur-containing antioxidants (e.g., allicin) (Grela and Klebaniuk, 2007) scavenge free radicals and reduce oxidative stress (Gong-chen et al., 2014), while capsaicinoids in chili promote thermogenesis and energy metabolism (Zhang et al., 2025). Onion flavonoids (e.g., quercetin) exhibit anti-inflammatory and immune-modulating properties (Omar et al., 2020).

We hypothesized that dietary supplementation with garlic, chili, and onion will mitigate cold stress in laying hens by (1) reducing oxidative damage via antioxidant activity, (2) enhancing metabolic heat production through thermogenic pathways, and (3) stabilizing reproductive hormones (FSH, LH) and suppressing stress markers. These effects are expected to improve cold resilience, thereby enhancing egg production, quality, and hen welfare during winter. To our knowledge, this is the first study to systematically evaluate these mechanisms in a traditional Moroccan poultry system. Consequently, this study aims to evaluate the potential of these herbal supplements to mitigate the adverse effects of cold weather on egg production, quality, and hormonal profile in traditionally farmed hens in Morocco.

## Material and methods

### *Ethical Standards*

The study was approved by the Polydisciplinary Faculty of Larache. The authors confirm that they have followed EU standards for the protection of animals used for scientific purposes, as outlined in Directive 2010/63/EU.

### *Experimental design and preparation of feeds*

A total of 180 indigenous (Beldi) laying hens (*Gallus gallus domesticus*), aged 36 weeks with a mean initial body weight of 1,828 ± 25.09 g (mean ± SD), were randomly allocated to four treatment groups (n=45 hens/group). Hens were distributed based on initial body weight and health status to ensure uniformity across groups. The experiment was conducted over two months (November and December 2023), on a private farm located in the Sefrou region with a Mediterranean temperate climate, with maximum temperatures reaching 13°C and minimum temperatures dropping to 3°C (during the experiment). The coordinates of the location are 33° 49′ north latitude and 4° 25′ west longitude, with an altitude of 1,250 meters above sea level. Hens were subjected exclusively to natural daylight, with photoperiod decreasing from 10.5 hours (early November) to 9.5 hours (late December) as per the latitude and season. No artificial lighting was applied, replicating traditional smallholder management practices.

The diet base consisted of cornmeal, and each group received a specific supplement:

- Group 1 (Control): Cornmeal-based diet without any dietary additive supplements.
- Garlic group: Cornmeal-based diet supplemented with 2% fresh garlic (*Allium sativum*).
- Onion group: Cornmeal-based diet supplemented with 2% fresh onion (*Allium cepa*).
- Chili peppers group: Cornmeal-based diet supplemented with 2% hot Chili peppers (*Capsicum annuum*).

This 2% dose reflects local breeder recommendations for safe winter management, with supplements costing ≤$1.00/ kg feed, ensuring affordability and bioactive efficacy.

The basal diet consisted solely of cornmeal to simulate typical smallholder practices; supplements (2% fresh garlic, onion, or chili peppers) were added directly to this base diet.

The supplements were purchased from the local market, analyzed for moisture content and active compounds, and cut into small slices. They were then incorporated daily into the cornmeal-based diet for the laying hens throughout the experiment. Each group of hens was housed in cages (3m x 7m x 1.5m) with a natural light/dark regimen, allowing them to roam freely. Feed and water were provided *ad libitum*. The housing conditions included proper ventilation, temperature control, and clean bedding to ensure animal welfare.

### *Analytical procedures for feed composition analysis*

The following parameters were analyzed to determine the nutritional composition of the samples (Table 1):

*Crude protein (CP, %)*

The crude protein content was determined using the Kjeldahl method, which involves digesting the sample with concentrated sulfuric acid in the presence of a catalyst, followed by distillation and titration to measure the nitrogen content (Silva et al., 2016). The crude protein content was calculated as follows:

$$CP\ (\%) = N \times 6.25$$

Where, N is the nitrogen content (%) obtained from the Kjeldahl method.

*Neutral detergent fiber (NDF, %)*

The NDF content was analyzed using the Van Soest method. Samples were boiled in a neutral detergent solution to remove non-fiber components such as proteins, lipids, and starch. The remaining fiber fraction (hemicellulose, cellulose, and lignin) was dried and weighed (Van Soest et al., 1991).

NDF (%) = (Sample weight (g)/Weight of NDF residue (g)) ×100

**Table 1.** Chemical analysis of the different diets (Dry matter basis)

| | Control group | Garlic group | Onion group | Chili pepper group |
|---|---|---|---|---|
| Crude protein (%) | 8.43 | 9.13 | 8.96 | 8.81 |
| Neutral detergent fiber (NDF, %) | 45.00 | 42.80 | 43.50 | 44.20 |
| Acid detergent fiber (ADF, %) | 27.50 | 25.90 | 26.30 | 27.00 |
| Ether extract (%) | 2.80 | 3.10 | 3.00 | 2.90 |
| Ash (%) | 5.20 | 5.50 | 5.40 | 5.30 |
| Metabolizable energy (kcal/kg) | 2110.47 | 2175.96 | 2147.59 | 2128.55 |

Control group: Cornmeal-based diet without supplements; Garlic group: Cornmeal-based diet supplemented with 2% fresh garlic (*Allium sativum*); Onion group: Cornmeal-based diet supplemented with 2% fresh onion (*Allium cepa*). Chili pepper group: Cornmeal-based diet supplemented with 2% hot chili pepper (*Capsicum annuum*).

*Acid detergent fiber (ADF, %)*

The ADF content was determined by boiling the sample in an acid detergent solution, which removes hemicellulose, leaving behind cellulose and lignin. The residue was then dried and weighed to calculate the ADF percentage (Van Soest, 1963).

ADF (%) = (Sample weight (g) / Weight of ADF residue (g)) ×100

*Ether extract (EE, %)*

The ether extract, representing crude fat content, was determined using Soxhlet extraction. The samples were extracted with petroleum ether, and the solvent was evaporated to measure the weight of the extracted fat (Blasi et al., 2017).

EE (%) = (Sample weight (g) / Weight of extracted fat (g)) ×100

*Ash (%)*

The ash content was measured by incinerating the samples in a muffle furnace at 550°C for 6 hours to remove all organic matter. The residue was weighed and expressed as a percentage of the original sample weight (Ismail, 2017).

Ash (%) = (Sample weight (g)/Weight of ash (g))×100

*Metabolizable energy (kcal/kg)*

The gross energy (GE) content of the feed samples was determined using a bomb calorimeter, following the procedure described by Cherney (2000). Approximately 1 gram of dried and finely ground sample was combusted in a high-pressure, oxygen-rich environment inside the calorimetric chamber. The heat released during complete combustion was recorded in kilojoules (kJ) by the calorimeter.

The GE was calculated using the following equation:

GE (MJ/kg) = [Heat released (kJ) /Simple weight (kg)] ÷ 1000

To express the energy in kilocalories per kilogram (kcal/kg), the GE values were converted as follows:

GE (kcal/kg) = GE (MJ/kg) × 239

Finally, the metabolizable energy (ME) was estimated using a metabolizability coefficient (*k*) of 0.82:

ME (kcal/kg) =GE (MJ/kg) × 239×0.82

This coefficient reflects the average proportion of gross energy that is metabolizable in poultry diets.

## Blood sampling and laboratory analyses

Upon completion of the experimental procedure, 6 hens from each group were used for blood sample (5 mL) collection using anticoagulated tubes with sodium heparin via the wing vein. Then, blood samples were centrifuged at 3500 × g for 10 min at 4 °C to obtain the plasma and stored at −20 °C for analysis of the reproductive hormones and corticosterone.

The plasma levels of follicle-stimulating hormone (FSH) and luteinizing hormone (LH), were determined using enzyme-linked immunosorbent assays (ELISA) kits (Jiangsu Industrial Co. Ltd., Yancheng, China) according to the manufacturer's protocols (Li et al., 2023). Corticosterone concentration in plasma was determined using ELISA according to the instructions of the Invitrogen™ Kit (Stowell et al., 2019).

The malondialdehyde (MDA) level was determined with 2-thiobarbituric acid, monitoring the change of absorbance at 532 nm with a spectrophotometer (Jensen et al., 1997).

## Egg collection and production performance

Hens were weighed individually once a week during the experiment. Daily egg collection was conducted. Eggs numbers and weight were recorded daily. Egg production was expressed on a hen-day basis to accurately represent the productivity of laying hens. Furthermore, the biweekly feed intake was measured as per day per hen, and the feed conversion ratio (FCR), was calculated as kilograms of feed intake per kilogram of egg produced.

*Egg quality analysis*

To comprehensively assess the external and internal egg quality characteristics, a total of 40 eggs was randomly selected during the last week of the study, with 10 eggs chosen from each group between 09:00 and 12:00 h. The following parameters were meticulously examined to provide a thorough understanding of the egg quality. Each egg was weighed and the shape index was measured. The egg content was broken onto a glass-topped table. Then the height and diameter of the yolk were measured using a digital caliper. By using these values, the yolk index [(yolk height/yolk diameter) x 100] was calculated. The yolk color was estimated using the DMS-firmenich Yolk Fan™. Then yolk, albumen, and shell weight (%) were measured using precise balance (Jiang et al., 2022).

*Egg proteins content*

The egg total protein content was measured using the Kjeldahl method, which determines the nitrogen content and converts it to protein using a factor of 6.25. The process involved digesting 1 g of homogenized egg (including both albumen and yolk) with 15 mL of concentrated $H_2SO_4$ and 5 g of a potassium sulfate-copper sulfate catalyst at 420°C for 2 hours. The resulting solution, containing ammonium ions, was distilled with 50 mL of 40% NaOH to release ammonia gas, which was absorbed in 4% boric acid. Ammonia was quantified via titration with 0.1 M HCl until a color change was observed. A blank test was performed for correction, and protein content was calculated using a standard formula (English, 2021). The protein content was calculated using the formula:

Protein (%) = $((V_{sample} - V_{blank}) \times M_{HCl} \times 14.01 \times 6.25 /\text{sample weight (g)}) \times 100$

*Egg cholesterol*

Cholesterol content was analyzed using two methods: HPLC with UV detection at 210 nm (utilizing a C18 reverse-phase column, e.g., Agilent Zorbax 250 mm × 4.6 mm, 5 µm) and a colorimetric assay based on the Liebermann-Burchard reaction. For the latter, lipids were extracted from 2 g of homogenized egg sample using chloroform: methanol (2:1 v/v), followed by centrifugation, filtration, and evaporation under nitrogen. The lipid extract was dissolved in chloroform, reacted with Liebermann-Burchard reagent, and incubated for 30 minutes, forming a greenish-blue chromophore. Absorbance at 625 nm was measured, and cholesterol content was quantified using a standard curve (0-2.0 mg/mL) (Bragagnolo and Rodriguez-Amaya, 2003). Cholesterol content (mg/g egg) was calculated using the equation:

Cholesterol content (mg/g egg) = Concentration from standard curve (mg/mL) × 10mL/ sample weight (g).

### *Statistical analysis*

Statistical analyses were performed using the JMP SAS 11.0.0 (SAS Institute Inc., Cory, NC, USA) program. The impact of feeding supplements underwent analysis using a single-factor analysis of variance (ANOVA). Upon detecting a significant effect through ANOVA, differences between treatments were further analyzed by the Dunnett's test at P < 0.05 to compare each treatment to the control. The Tukey's post hoc test was used to compare the means of the three supplemented groups (P<0.05).

## Results

### *Blood analysis*

The effects of dietary treatments on hormonal levels in laying hens are presented in Table 2. Compared to the control group, the garlic, chili pepper, and onion groups all showed significantly higher FSH levels (P<0.05), with the onion group exhibiting a more moderate increase. Similarly, LH levels were significantly elevated in the garlic and chili pepper groups, while the onion group displayed a modest increase (P<0.05). Corticosterone levels were significantly reduced in the garlic and chili pepper groups compared to the control, whereas the onion group showed no significant difference (P>0.05).

**Table 2**. Effect of diets treatments on blood FSH, LH, corticosterone and MDA in laying hens (mean± SEM)

| Parameter | Control group | Garlic group | Onion group | Chili pepper group |
|---|---|---|---|---|
| FSH (mIU/mL) | 17.16±0.05 | 19.06±0.03$^{*a}$ | 18.22±0.05$^{*b}$ | 19.10±0.07$^{*a}$ |
| LH (mIU/mL) | 16.24±0.03 | 16.81±0.03$^{*a}$ | 16.53±0.04$^{*b}$ | 17.02±0.03$^{*a}$ |
| Corticosterone (ng/mL) | 20.18±0.09 | 18.41 ±0.18$^{*b}$ | 19.74 ±0.15$^{a}$ | 17.39 ±0.07$^{*c}$ |
| Malondialdehyde (µmol/L) | 4.47±0.09 | 3.67±0.13$^{*c}$ | 4.18±0.11$^{*a}$ | 3.87±0.08$^{*b}$ |

[*] Indicates the significant difference between supplemented and control groups (P<0.05).

[a, b] Indicates significant differences amongst the means of supplemented groups (P<0.05).

Control group: Cornmeal-based diet without supplements; Garlic group: Cornmeal-based diet supplemented with 2% fresh garlic (*Allium sativum*); Onion group: Cornmeal-based diet supplemented with 2% fresh onion (*Allium cepa*). Chili pepper group: Cornmeal-based diet supplemented with 2% hot chili pepper (*Capsicum annuum*).

Blood levels of malondialdehyde (MDA) varied significantly among groups. The control group had the highest MDA concentration. The garlic group exhibited the greatest reduction in MDA levels, followed by the chili pepper group, which also showed a significant decrease, though to a lesser extent. The onion group demonstrated a moderate but significant reduction in MDA levels compared to the control, though the decrease was smaller than in the garlic and chili pepper groups.

### *Production performance*

None of the dietary supplements had a significant effect on the final body weight of the hens (Table 3). However, significant improvements were observed in several performance parameters, including the number of eggs per hen, overall egg production, feed consumption, egg mass, and feed conversion ratio for all three supplements tested. No significant differences were found among the supplements in the magnitude of these improvements.

**Table 3.** Effect of diets on laying hen performance (mean±SEM)

| | Control group | Garlic group | Onion group | Chili pepper group |
|---|---|---|---|---|
| Body weight (g) | 1801,94±24,78 | 1837,62±23,52 | 1817,91±22,86 | 1824,23±25,42 |
| Number of eggs per hens in 56 days | 38,4±0,91 | 50,92±0,97* | 50,8±1,02* | 51,84±1,04* |
| Egg production (%) | 64,02±4,22 | 84,85±6,45* | 84,65±6,28* | 86,38±4,94* |
| Feed consumption (g/day/bird) | 98.91±5,71 | 119.90±5,06* | 117.59±5,26* | 120.21±4,42* |
| Egg mass/hens (g) | 504,21±19,86 | 674,06±23,08* | 681,57±21,60* | 682,50±22,31* |
| Feed conversion (kg feed/kg egg) | 2,98±0,05 | 2,57±0,12* | 2,53±0,15* | 2,48±0,16* |

* Significantly different from the control group (P<0.05).

Control group: Cornmeal-based diet without supplements; Garlic group: Cornmeal-based diet supplemented with 2% fresh garlic (*Allium sativum*); Onion group: Cornmeal-based diet supplemented with 2% fresh onion (*Allium cepa*). Chili pepper group: Cornmeal-based diet supplemented with 2% hot chili pepper (*Capsicum annuum*).

### *Quality characteristics of chicken eggs*

Egg weight, yolk index, albumin percentage, yolk percentage, and shell percentage remained unaffected by the dietary supplements (Table 4). Notably, yolk color showed a significant increase in the hot chili pepper group compared to the other supplement groups (P<0.05).

Protein content in eggs was significantly higher in the garlic and hot chili groups compared to the control. The onion group showed a modest increase, though this difference was not statistically significant (Table 4).

Cholesterol levels in eggs were significantly reduced in the garlic group compared to the control. The hot chili and onion groups also showed lower cholesterol levels, but the reductions were less pronounced than those observed in the garlic group (Table 4).

**Table 4.** Effect of diets on egg quality in laying hens (mean±SEM)

| | Control group | Garlic group | Onion group | Chili pepper group |
|---|---|---|---|---|
| Egg weight (g) | 53.89±1.45 | 54.21±0.71 | 53.94±1.32 | 54.07±1.06 |
| Yolk index | 43.61±1,22 | 43.83±0,99 | 43.74±1,18 | 43.91±1,42 |
| Yolk color | 12.07±0.09 | 11.91±0.21[b] | 12.33±0.18[b] | 14.50±0.09*[a] |
| Albumin (%) | 60.52±2.18 | 60.41±1.93 | 60.71±2.13 | 60.20±1.58 |
| Yolk (%) | 27.08±1,04 | 27.00±0,09 | 26.91±1,15 | 27.14±1,03 |
| Shell (%) | 12.4±1.13 | 12.59±1.04 | 12.38±1.14 | 12.66±1.32 |
| Protein (g/100g) | 12.41 ± 0.14 | 13.22 ± 0.26*[a] | 12.44 ± 0.31[b] | 13.18 ± 0.43*[a] |
| Cholesterol (mg/100g) | 1885.39 ± 57.1 | 1761.44±45.22*[b] | 1873,42±47.53*[a] | 1869.18±39.81*[a] |

* Indicates the significant difference between supplemented and control groups (P<0.05).

[a, b] Indicates significant differences amongst the means of supplemented groups (P<0.05).

Control group: Cornmeal-based diet without supplements; Garlic group: Cornmeal-based diet supplemented with 2% fresh garlic (*Allium sativum*); Onion group: Cornmeal-based diet supplemented with 2% fresh onion (*Allium cepa*). Chili pepper group: Cornmeal-based diet supplemented with 2% hot chili pepper (*Capsicum annuum*).

## Discussion

The objective of this study was to assess the impact of dietary supplementation with fresh garlic (*Allium sativum*), onion (*Allium cepa*), and hot chili peppers (*Capsicum annuum*) on cold stress and productive performance in Beldi laying hens. While body weight remained unaffected, supplementation with garlic and chili significantly mitigated the negative effects of cold stress by enhancing egg production, feed conversion ratio (FCR), egg weight, and protein content, as well as by reducing cholesterol levels (garlic), improving yolk color (chili), and modulating hormone profiles (increased FSH and LH, decreased corticosterone). Onion showed milder effects. These findings demonstrated the potential of garlic and chili as natural supplements for improving productivity, egg quality, and animal welfare under cold stress conditions.

The observed improvements in egg production parameters during the cold season, a period typically associated with physiological stress and reduced laying performance in hens (Li et al., 2020), warrant mechanistic exploration. Cold exposure has been shown to reduce egg quality and quantity, especially shell integrity and albumen content (Alves et al., 2012). These changes are linked to hormonal disruptions, notably involving triiodothyronine, which regulates ovarian and metabolic functions, and elevates stress markers such as the heterophil-to-lymphocyte ratio (Klandorf et al., 1981; Hangalapura et al., 2004). Cold stress also compromises immune responses (Hu and Cheng, 2021) and induces oxidative stress by increasing malondialdehyde (MDA) levels and suppressing key antioxidant enzymes, including superoxide dismutase, glutathione peroxidase, and catalase (Kucuk et al., 2003), ultimately impairing health and reproductive performance.

The significant increases in FSH and LH observed in garlic- and chili-supplemented groups suggest that bioactive compounds in these plants, such as phytoestrogens (Mukherjee et al., 2007; Risikat et al., 2022) and capsaicin (Mondal et al., 2024), may stimulate gonadotropin release, enhancing reproductive function (Tamaya, 2005; Saleh et al., 2019; Liu et al., 2021). The marked reduction in corticosterone levels further indicates that garlic and chili reduced physiological stress. These effects may occur through bioactive mechanisms: allicin in garlic exerts antioxidant and anti-inflammatory actions that modulate the hypothalamic–pituitary–adrenal (HPA) axis, while capsaicin in chili activates TRPV1 channels involved in neuroendocrine regulation. Reduced stress improves metabolic efficiency and egg production (Shini et al., 2009; Hayat et al., 2018), consistent with previous findings that phytogenic feed additives enhance laying performance (Abou-Elkhair et al., 2018).

Additionally, these supplements may optimize nutrient metabolism, modulate gut microbiota, improve nutrient digestibility, and enhance ovarian function (Navidshad et al., 2018). Improved egg production during cold exposure likely results from these systemic benefits. For example, garlic's antimicrobial properties (Gheisari and Ranjbar, 2012; Hernández-Montesinos et al., 2023) may reduce cold-related infections. Moreover, garlic contains numerous biologically active compounds including allicin, ajoene, diallyl trisulfide, allylpropyldisulfide, and S-allyl cysteine, as well as enzymes (e.g., alliinase, peroxidase), amino acids (e.g., arginine), vitamins (A, C, D, E, and B-complex), and minerals (e.g., selenium, magnesium, phosphorus, calcium), all of which support chicken health, growth, and productivity (Grela and Klebaniuk, 2007; Mahmoud et al., 2010; Navidshad et al., 2018).

Our findings support the support the previous studies by Yalçın et al. (2006) and Omer et al. (2019) who found that dietary garlic powder (5–10 g/kg) significantly increased hen-day egg production and egg weight. Khan et al. (2007) reported higher egg production in hens fed with 2–8% dried garlic. Adibmoadi et al. (2006) observed that garlic improved intestinal morphology, such as increased villus height and crypt depth, suggesting enhanced digestive capacity.

As for chili peppers, their capsaicinoids exhibit thermogenic properties that help maintain metabolic rates under cold conditions (Szallasi, 2022; Zhang et al., 2025). Chili also contains essential vitamins, minerals, carotenoids, and phenolics such as luteolin and quercetin. Capsaicin, a key bioactive component, has demonstrated antioxidant, anti-inflammatory, and lipid-modulating effects, along with benefits for gut health and pain modulation (Prakash and Srinivasan, 2010). These attributes explain its positive impact on egg quality and production (Abhilasha et al., 2022).

Onions are thought to reduce oxidative stress under cold conditions, thereby supporting reproductive functions (Prakash and Srinivasan, 2010). Onion is rich in organic sulfur compounds (e.g., S-propenyl-cysteine sulfoxide, cycloalliin), flavonoids, phenolic acids, sterols (e.g., β-sitosterol), saponins, and trace volatile oils (Stoica et al., 2023). These compounds possess broad biological activities; antibacterial, antiviral, antifungal, antihypertensive, hypoglycemic, anti-inflammatory, and antioxidant (Mahmood et al., 2021; Biswas et al., 2024). Dietary onion was associated with improved egg production, as previously reported by Omer et al. (2019), who noted increased egg weight and feed efficiency, and decreased egg cholesterol levels.

In this study, MDA levels were significantly reduced in all three supplemented groups, with the greatest reduction observed in the garlic group, followed by chili and onion. This reduction in lipid peroxidation likely resulted from both direct antioxidant activity-via organosulfur compounds (allicin, diallyl disulfide) and flavonoids (quercetin) (Grela and Klebaniuk, 2007; Biswas et al., 2024), and the upregulation of endogenous antioxidant enzymes (superoxide dismutase, glutathione peroxidase, catalase) (Abubakar et al., 2023). By preserving mitochondrial function in ovarian cells, these antioxidants support cholesterol use in steroid hormone synthesis, leading to increased FSH and LH levels and suppression of stress-induced corticosterone (Agarwal et al., 2008). This hormonal stabilization promotes vitellogenin synthesis and yolk formation, improving egg production, weight, and feed efficiency (Burden, 2020).

Furthermore, garlic and chili supplementation significantly increased egg protein content, while garlic also lowered egg cholesterol levels. This is likely due to improved nutrient absorption and amino acid utilization by allicin and capsaicin (Lokaewmanee et al., 2013; Zhang et al., 2025). Garlic’s cholesterol-lowering effect is mediated by inhibition of HMG-CoA reductase and increased bile acid excretion (Chowdhury et al., 2002). As a result, eggs from garlic- and chili-fed hens were both richer in protein and lower in cholesterol, confirming their utility as functional feed additives to improve egg nutritional quality.

Overall, supplementing corn-based diets with garlic, onion, or chili peppers significantly enhanced the performance of indigenous Beldi hens during the cold season. These results validate traditional Moroccan practices that rely on such supplements in winter and offer the first empirical evidence of their efficacy in resource-limited poultry systems (Pedreira et al., 2023).

## Conclusion

This study demonstrated that dietary supplementation with garlic and chili pepper (2%) effectively enhanced cold-stress tolerance in indigenous laying hens. Significant improvements were observed in egg production efficiency, feed conversion ratio, egg quality parameters, and hormonal homeostasis, alongside reduced yolk cholesterol (garlic) and intensified yolk pigmentation (chili pepper). Onion supplementation yielded more modest improvements. These outcomes may be attributed to phytochemical constituents mitigating cold-induced oxidative insult, immune dysregulation, and metabolic burden, aligning with established mechanisms of phytogenic feed additives. Crucially, garlic and chili pepper represent economically viable, natural strategies for sustaining hen productivity and welfare during winter, offering practical advantages to small-scale poultry operations without compromising egg quality.

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## Conflict of interests

The authors state that there are no conflicts of interest.

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