

Ecological desalination of anchovy bones using lime and activated carbon made from argan shells: sustainable use of waste for poultry feed in Morocco

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Abstract

This study aims to develop an environmentally friendly process for desalinating salted anchovy bones (*Engraulis encrasicolus*) through the combined use of activated carbon from argan tree shells (*Argania spinosa*) and quicklime (CaO), with a view to sustainable recovery for poultry feed. The bones, which are rich in protein and minerals but highly salty, were successively treated with water, activated carbon (0.25–0.5 g/5 g of bones), and then quicklime (0.5–1.5 g/5 g of bones). Physicochemical analyses revealed a significant reduction in salt content, from 15.4% to less than 0.6%, accompanied by a marked increase in calcium (up to 10.74%) and magnesium (1.32%), while maintaining stable levels of crude protein (≈29%) and fat (≈5.7%). The fish bone meal obtained in this way was incorporated at a rate of 3% into feed formulations for broiler chickens (*Gallus gallus*) during the starter and grower phases, using ALLIX[®] software. Zootechnical trials showed no negative effects on live weight, feed intake, or feed conversion ratio compared to the control group, confirming the equivalent nutritional value of the experimental diets. This integrated approach simultaneously valorizes fishery and agricultural co-products, contributing to the implementation of a circular economy model and the achievement of Sustainable Development Goals (SDGs 12 and 14).

Keywords: bio-based adsorbent, broiler performance, circular economy, mineral enrichment, poultry feed, salted anchovy bones (*Engraulis encrasicolus*)

Introduction

At a time when the sustainability of food systems is becoming a global priority, two major issues are particularly pressing: the overexploitation of fishery resources and the poor management of agri-food waste. Every year, these industries generate considerable quantities of by-products, which remain largely or entirely unutilized. This is particularly the case for fish bones from seafood processing, which, due to their high salt content, are too often discarded despite their high nutritional potential (Rustad et al., 2011; Caruso, 2015).

In Morocco, anchovy bones (*Engraulis encrasicolus*) are a particularly abundant by-product. Rich in protein, they can be valorized by enzymatic hydrolysis to produce peptides of nutritional interest (Ghaly et al., 2013; Boumendil et al., 2023), and their high calcium content (nearly 30%) makes them a promising source of minerals (Shen et al., 2019). These characteristics

open up prospects for use in human or animal food. For example, (Uthai, 2021) showed that salmon bone meal could advantageously replace part of the wheat flour in noodles, enriching the final product with protein. However, the excessive salinity of these bones remains an obstacle to their integration, particularly in animal feed. With this in mind, the present study aims to develop a combined treatment process to sanitize these bones while preserving their nutritional qualities. The innovation here lies in the use of activated charcoal from the shells of the argan tree (*Argania spinosa*), an emblematic tree of southern Morocco, followed by treatment with quicklime, known for its ability to reduce salinity (Min et al., 2016).

The choice of activated carbon is based on previous studies that have shown that argan cake can effectively contribute to reducing the salinity of anchovy bones (Boumendil et al., 2024). Following on from this work, this research explores the use of another argan tree

by-product, the carbon-rich "shells," which are well suited to the manufacture of activated carbon (Tesse et al., 2024). Charcoal is studied here not only for its potential effectiveness as a desalinating agent, but also as an absorbent of volatile organic compounds, odors, toxins, and micropollutants, thus contributing to the overall purification of the co-product. Lime treatment then follows to complete the reduction of salt content and improve product stability

The main objective of this work is therefore to integrate these two types of waste, "fishery and agricultural," into a cross valorization and sustainable approach, with a view to producing a functional feed for broiler chickens (*Gallus gallus*). This new feed is formulated from anchovy bones pretreated with activated carbon and then desalted with lime, and its effectiveness is assessed through analysis of the nutritional and zootechnical performance of the poultry.

Beyond simple recovery, this approach aims to demonstrate the technical and economic feasibility of an integrated system capable of transforming underutilized waste into strategic resources for animal feed. It is fully in line with international strategies to combat waste, promote sustainable management of natural resources, and promote local use of co-products, as recommended by the (FAO, 2019) and the Sustainable Development Goals (SDGs 12 and 14).

Material and methods

Raw Materials

Collection and preparation of raw materials

The bones of salted anchovies, belonging to the species *Engraulis encrasicolus*, were collected from an industrial unit specializing in fish processing. These residues come mainly from the filleting process, during which the bones are separated from the fillets and generally considered to be by-products. Due to their high sodium chloride (NaCl) content, prior desalination is essential in order to enable their recovery. After collection, the bones are stored at a temperature of 4°C until processing.

At the same time, argan shells were obtained from argan fruits collected in the Chtouka Aït Baha region, located in southwestern Morocco, in the province of Agadir. After extracting the kernels for oil production, the remaining shells are recovered for recovery.

Production of activated carbon from argan shells

The activated carbon used in this study was prepared from argan shells (*Argania spinosa*) using a two-step method inspired by (Tesse et al., 2024): chemical activation followed by thermal carbonization. The shells,

washed with distilled water and then dried at 110°C for 24 hours, are crushed and sieved to obtain a fine particle size. Activation is carried out by impregnation with concentrated phosphoric acid (H_3PO_4) at 120°C for 3 to 5 hours.

After storage in an airtight container, carbonization is carried out at between 300 and 800°C for 5 hours in a preheated electric oven. The carbonized material is then washed with a 0.1 M HCl solution and rinsed with distilled water until the pH is neutral. Finally, the charcoal is dried at 105°C for 8 hours and stored in a hermetically sealed bottle.

Desalination techniques

Desalination with drinking water H_2O

Before the experimental treatments, a simple pretreatment step was applied to the anchovy bones in order to reduce their free salt content on the surface. The bones were rinsed once with drinking water (1g/10ml), without adding any chemical agents, in order to carry out gentle desalination. After rinsing, the bones were drained and then dried at 60°C for 24 hours in a ventilated oven. Once dry, they were finely ground using a blade mill to obtain a homogeneous flour. This flour was then used to perform physicochemical analyses to determine the salt, dry matter, ash, calcium, phosphorus, magnesium, potassium, crude protein, and fat content (**Table 1**). According to the work of (Boumendil et al., 2022), the flour obtained can be stored for up to six months without significant alteration of its nutritional and functional qualities

Desalination treatment using activated carbon and quicklime (CaO)

The desalination protocol applied to anchovy bones is based on a sequential method aimed at removing both organic contaminants and salt ions. First, the bones are rinsed thoroughly with drinking water to remove excess free salt from the surface. This step aims to reduce surface salinity before applying specific treatments.

The bones are then immersed in distilled water at a bone-to-water mass ratio of 1:10. The treatment continues with the addition of activated carbon, applied in proportions of 0.25g and 0.5g. This pre-treatment with carbon allows the absorption of volatile organic compounds, odorous substances, toxins, and residual micropollutants.

After this organic purification step, the fish bones undergo chemical treatment with quicklime (CaO), added at a rate of 0.5 g and 1 g per 5 g of material.

Table 1. Methods for analysing physicochemical parameters.

Parameter analyzed	Analysis method
Salt (NaCl)	Titrimetry (Mohr method) / Refractometer
Dry matter (DM)	Drying at 105°C until constant mass
Total ash (TA)	Incineration at 550°C for 12 hours
Calcium (Ca)	Atomic absorption spectrophotometry / ICP-OES
Total phosphorus (P)	Atomic absorption spectrophotometry / ICP-OES
Magnesium (Mg)	Atomic absorption spectrophotometry / ICP-OES
Potassium (K)	Atomic absorption spectrophotometry / ICP-OES
Crude protein (MAT)	Nitrogen determination by Kjeldahl method
Fat (MG)	Soxhlet extraction with organic solvent at 100°C

This treatment precipitates sodium (Na⁺) and chloride (Cl⁻) ions through an ion exchange mechanism, thereby improving desalination efficiency. The entire mixture is kept under constant agitation at 150 revolutions per minute, at room temperature (25°C), for a period of 6 to 12 hours to ensure optimal contact between the reagents and the substrate.

Once the treatment is complete, the solid residues are separated by filtration, then the bones are transferred to a ventilated oven and dried at 60°C for 24 hours. The dry product is then finely ground using a blade mill until a homogeneous flour is obtained.

Finally, the flour obtained is subjected to a series of physicochemical analyses. These analyses include the determination of the residual salt content, dry matter, total ash, and the quantification of calcium, phosphorus, magnesium, potassium, crude protein, and fat, according to standardized and validated analytical methods (**Figure 1**).

Starter and grower feed formulation for broiler chickens (*Gallus gallus*)

Formulation protocol: Starter phase (0-21 days)

The starter compound feed formulation for broiler chickens (*Gallus Gallus*) was developed using

ALLIX3 software, incorporating desalted anchovy bone meal (FAD) as a natural source of protein, calcium, and phosphorus. FAD was characterized by an average content of 34% crude protein, 7% calcium, 4% total phosphorus, and 25% ash. The objective was to partially replace conventional mineral sources (calcium carbonate and dicalcium phosphate) while meeting the specific nutritional requirements for this phase (Bouvarel et al. 2014). The formulation was automatically adjusted while keeping the other raw materials constant, and the results were analyzed for nutritional coverage and economic feasibility (**Table 2**).

Formulation protocol - Growth phase (22-35 days)

Following on from the start-up protocol, a growth compound feed formulation was also carried out using ALLIX³ software with gradual integration of FAD to maintain a balanced nutritional intake with formulation objectives adapted to growth (Morinière, 2015; Bouvarel et al., 2014). Each formulation was generated and adjusted using ALLIX³ software to assess the impact of FAD on the final composition.

This protocol validated the use of FAD as a functional and economical ingredient in growth formulations for broiler chickens (*Gallus gallus*) (**Table 3**).



Figure 1. a Anchovy bones, b Anchovy bone meal, c Argan shells, d Activated carbon, e Allix compound feed formulation software3

Table 2. Formulation for the starter phase (0-21 days)

Ingredients	Standard formulation (%) (FAO 2004)	With FAD (%)
Corn	53.82	50.0
Soybean meal	23.47	29.00
Wheat bran	10.00	9
Hulled sunflower meal	9	7
Anchovy bone meal (FAD)	-	3.0
Calcium carbonate	1.51	0.8
Dicalcium phosphate	0.99	0.40
Salt	0.26	0.24
Soybean oil	0.05	0.1
Premix, additives, amino acids	0.90	0.46
Total	100.00	100.00

Table 3. Formulation for the growth phase (22-35 days)

Ingredients	Standard formulation (%) (FAO 2004)	With FAD (%)
Corn	55.0	48
Soybean meal	21.00	33
Wheat bran	10	8
Hulled sunflower meal	8	6
Anchovy bone meal (PAD)	-	3.0
Calcium carbonate	1.2	0.6
Dicalcium phosphate	0.9	0.30
Salt	0.25	0.23
Vegetable oil	0.10	0.15
Premix, amino acids, additives	0.55	0.72
Total	100.00	100.00

Application of formulations for broiler chicken (*Gallus gallus*) farming

As part of this study, two batches of chicks were fed experimental feed formulations based on anchovy bones that had been previously desalinated using activated charcoal and quicklime, while a third control batch was fed standard commercial feed available on the market. The rearing period was divided into two phases: a starter phase (from day 1 to day 21) and a growth phase (from 22 to day 35). Live weight and feed intake were monitored daily. These measurements were used to determine the average daily gain (ADG) and feed conversion ratio (FCR) for each batch in order to assess the impact of incorporating desalted anchovy bones on the zootechnical performance of the chicks during the two rearing phases.

Data analysis

Statistica® 10 software (StatSoft, Inc. www.statsoft.com) was used to perform statistical analysis of the data, and as part of a one-factor ANOVA with repeated measures (3 replicates), several comparisons were made, followed by Tukey's HSD test to detect significant differences between groups. A significance threshold was set at ($p < 0.05$).

Results and Discussion

As part of this research, a study was conducted to examine the effect of different technological methods of desalination on the nutritional and mineral value of anchovy bones. A detailed analysis of the results obtained for each of these samples is presented below:

Desalting with drinking water

Desalting with water is an essential step in the processing of salted anchovy bones. The aim is to reduce the salt content while preserving the nutritional properties. (Table 4) illustrates the impact of this procedure on the nutritional and mineral profile, which allows us to assess the relevance of this technique for the future use of the bones.

A comparative study of the three types of samples: FAB (fresh bones), SAB (salted bones), and DABW (salted bones desalted with water) reveals significant variations ($p < 0.05$) in their nutritional and mineral compositions. SAB has the highest concentrations of crude protein (34.13%), fat (7.13%), total minerals (ash: 16.10%), and salt (15.40%), indicating a highly concentrated and processed product. This profile indicates the use of preservation methods such as salting, which reduces moisture, concentrates nutrients, and extends the product's shelf life (FAO, 2020).

Table 4. Effect of desalting with water on the nutritional and mineral composition of salted anchovy bones

Parameter	FAB	SAB	DABW
Salt (%)	0.53 ± 0.06c	15.40 ± 0.20a	4.70 ± 0.20b
Ash (%)	5.30 ± 0.10c	16.10 ± 0.10a	13.97 ± 0.15b
Calcium (Ca %)	2.00 ± 0.10c	3.48 ± 0.07a	2.72 ± 0.13b
Magnesium (Mg %)	0.15 ± 0.01c	0.35 ± 0.01a	0.30 ± 0.01b
Potassium (K %)	0.20 ± 0.01c	0.38 ± 0.01a	0.31 ± 0.01b
Phosphorus (P %)	0.91 ± 0.01c	1.74 ± 0.04a	1.42 ± 0.02b
Crude protein (CP %)	16.63 ± 0.15c	34.13 ± 0.12a	29.73 ± 0.21b
Fat (%)	2.87 ± 0.06c	7.13 ± 0.12a	5.83 ± 0.15b
Dry matter (%)	24.77 ± 0.25c	94.83 ± 0.15b	96.17 ± 0.15a

FAB: Fresh anchovy bones, SAB: Salted anchovy bones (raw, before desalting), DABW: Salted anchovy bones after water desalting. Average ± standard deviation; values with same letters (a, b, c, d, e, or f) represent homogeneous groups; in each column, different letters indicate a significant difference at $p < 0.05$ using ANOVA and Tukey Post Hoc.

In contrast, the FAB sample shows the lowest values for all parameters, with a high moisture content (24.77% dry matter), low protein concentration (16.63%), ash (5.30%) and minerals, indicating low nutritional density.

Furthermore, the DABW sample, obtained by desalinating salted fish bones with fresh water, has values intermediate between FAB and SAB.

This process led to a significant decrease in salt (4.70%) and ash (13.97%) content compared to SAB, while preserving a significant nutritional value, particularly in terms of protein (29.73%) and minerals (Ca, Mg, K, P). This indicates that soaking for desalination can partially reduce sodium concentration without significantly reducing essential nutritional composition. This observation is consistent with research by (Gokoglu et al., 2004) and (Boumendil et al., 2023), which demonstrated that desalting salted marine products with water causes partial leaching of sodium and water-soluble minerals, while preserving a significant proportion of proteins and structural constituents such as calcium and phosphorus. In addition, DABW has the highest dry matter content (96.17%), which is ironic given that it exceeds that of SAB and indicates a complementary dehydration or drying phase after desalination. This improves the microbiological stability of the product and makes it suitable for secondary processing or food enrichment.

The process of desalinating salted anchovy

bones with water increases their overall nutritional value, significantly reducing the amount of sodium while preserving significant levels of essential proteins and minerals. DABW is therefore a balanced intermediate option between the untreated product (FAB) and the highly salted product (SAB), ideal for food preparations requiring improved nutritional value without added salt. In addition, all differences noted between the groups are statistically significant ($p < 0.05$), attesting to the robustness and adequacy of the technological desalination methods used.

These procedures have a marked and distinct influence on the chemical and mineral composition of anchovy bones, highlighting their essential role in the production of food products with controlled nutritional value.

Desalination using activated carbon

Following the initial results obtained on the effect of water desalination on the nutritional and mineral composition of salted anchovy bones, a second series of tests was carried out to further optimize the efficiency of the desalination process. The second stage involved evaluating the effect of adding activated carbon at various rates (0.25g and 0.5g) during the freshwater desalination process. Below, we present and analyze the results of this second experiment (**Table 5**).

Table 5. Effect of adding activated carbon (0.25g and 0.5g) on the nutritional and mineral composition of anchovy bones desalinated with water.

Parameter	DABW	DABC1	DABC2
Salt (%)	4.70±0.00a	4.30±0.05b	4.08±1.66c
Ash (%)	13.97±0.03a	13.85±0.03b	13.65±5.19c
Calcium (Ca, %)	2.72±0.01a	2.71±0.00a	2.70±1.02a
Magnesium (Mg, %)	0.30±0.00a	0.30±0.00a	0.29±0.11a
Potassium (K, %)	0.31±0.00a	0.29±0.01b	0.26±0.11c
Phosphorus (P, %)	1.42±0.00a	1.41±0.01b	1.39±0.53c
Crude protein (CP, %)	29.73±0.06a	29.65±0.05a	29.52±11.11a
Fat (%)	5.83±0.02a	5.78±0.02b	5.71±2.16c
Dry matter (%)	96.17±0.00a	96.17±0.00a	96.17±36.12a

DABW: Water-desalted salted anchovy bones, DABC1: DABW + 0.25 g activated charcoal, DABC2: DABW + 0.5 g activated charcoal Average ± standard deviation; values with same letters (a, b, c, d, e, or f) represent homogeneous groups; in each column, different letters indicate a significant difference at $p < 0.05$ using ANOVA and Tukey Post Hoc.

The addition of activated charcoal during the desalination of salted anchovy bones contributed to a reduction in sodium without significantly affecting the overall nutritional value of the product. Indeed, there was a notable decrease in salt concentration, from 4.70% for the DABW sample (without activated carbon) to 4.30% (DABC1, with 0.25g of carbon) and 4.08% (DABC2, with 0.5g of carbon), indicating a significant change ($p < 0.05$).

This increase is due to the high absorptive capacity of activated carbon, especially with regard to the sodium ions contained in the matrix, thanks to its large specific surface area and ion retention characteristics. The ash content, which reflects the overall mineral load, decreased slightly (from 13.97% to 13.65%), but this decrease is modest and indicates that the main structural minerals have been largely preserved. Calcium and magnesium concentrations remain constant ($\approx 2.70\%$ and 0.30% , respectively), with variations that are not significant. This indicates that activated carbon has no impact on minerals that are poorly soluble or associated with bone structure.

On the other hand, potassium and phosphorus levels, which are more soluble in water, decrease slightly, especially in sample DABC2. This could be due to their increased dispersion in the desalinated water or partial adsorption by the activated carbon (NRC, 2005). The crude protein level remains almost identical between samples (approximately 29.7%), confirming that activated carbon does not impact protein macromolecules (Sonaiya & Swan, 2004). In addition, a slight decrease in fat content is observed (from 5.83% to 5.71%), possibly due to a partial displacement of free lipids into the aqueous environment.

Finally, the percentage of dry matter remained stable at 96.17% in all samples, meaning that residual moisture was not affected by the presence of charcoal. Therefore, these findings indicate that the incorporation of activated charcoal, particularly at 0.5g, appears

to be a promising approach for reducing sodium while maintaining the nutritional quality of desalted anchovy bones.

The use of activated charcoal in the desalination process of salted anchovy bones led to a marked and salt-dependent reduction in the amount of salt, ash, phosphorus, potassium, and fat, while maintaining the protein, calcium, magnesium, and dry matter content. The use of 0.5g of activated carbon (DABC2) demonstrated maximum effectiveness for desalination while preserving nutritional quality, thus validating the importance of this method for the production of low-salt, nutritionally balanced marine co-products.

Desalination using lime (CaO)

In the process of improving the desalination of anchovy bones, following our successful trials with drinking water and activated carbon, we investigated an additional approach to further optimize sodium reduction. We considered the gradual introduction of quicklime (CaO) due to its chemical properties favorable to ion transfer, which could increase demineralization. The purpose of this third test is to analyze the impact of this incorporation on the physicochemical composition of anchovy bones already desalinated with activated carbon and drinking water. The aim is to verify whether the inclusion of lime can increase desalination performance without adversely affecting the nutritional quality of the product (**Table 6**).

The addition of various amounts of CaO to the DABC2 product had a significant impact on its chemical composition. A significant reduction in salt concentration was observed, falling from 4.08% to 0.60%, indicating an ion substitution process triggered by the incorporation of calcium, a phenomenon widely documented in mineral-enriched protein matrices (Mabrouk et al., 2021).

In addition, the amount of ash increases in proportion to the amount of CaO, indicating increasing mineralization of the product. The significant increase

Table 6. Effect of the gradual incorporation of lime (CaO) on the physicochemical composition of anchovy bones desalinated with activated carbon.

Parameter	DABC2	DABC2 + 0.5 g CAO	DABC2 + 1.0 g CAO	DABC2 + 1.5 g CAO
Salt (%)	4.08±0.13 a	0.69±0.03b	0.61± 0.02b	0.60 ±0.02b
Ash (%)	13.65± 0.05c	14.50± 0.05b	14.80± 0.05ab	15.10± 0.05a
Calcium (Ca %)	2.70±0.01 c	4.60 ±0.02b	8.51 ±0.01a	10.74± 0.03a
Magnesium (Mg %)	0.29± 0.00c	0.74 ±0.01b	1.26± 0.01a	1.32 ±0.01a
Potassium (K %)	0.26±0.01a	0.10±0.01b	0.06± 0.01b	0.02 ±0.00b
Phosphorus (P %)	1.39± 0.01a	1.41± 0.01a	1.40± 0.01a	1.39 ±0.01a
Protein (%)	29.52±0.08 a	29.45± 0.05a	29.33± 0.03a	29.30 ±0.05a
FAT (%)	5.71 ±0.04a	5.68 ±0.02a	5.66 ±0.02a	5.65 ± 0.02a
Dry matter (%)	96.17± 0.00a	96.17± 0.00a	96.17±0.00 a	96.17±0.00 a

DABC2: DABW + 0.5 g activated, CAO: lime. Average ± standard deviation; values with same letters (a, b, c, d, e, or f) represent homogeneous groups; in each column, different letters indicate a significant difference at $p < 0.05$ using ANOVA and Tukey Post Hoc.

in calcium and magnesium, reaching 10.74% and 1.32% respectively, confirms the effectiveness of CaO enrichment in increasing the intake of essential minerals (Zhao et al., 2020).

However, the potassium concentration decreases significantly, probably due to an ion exchange phenomenon that does not favor its preservation. Phosphorus, protein and lipid fractions, and dry matter content remain constant, showing that the incorporation of CaO does not alter the fundamental nutritional properties of the product. These results suggest that the use of CaO is a promising approach for enriching foodstuffs with minerals without altering their overall nutritional balance. Even at low doses (as little as 0.5 g per 5 g of product), CaO is particularly effective in significantly reducing salt content.

Application of formulations for broiler chicken (*Gallus gallus*) farming

This study highlighted anchovy bones enriched with calcium oxide (CaO), which significantly improved their mineral composition, particularly in calcium and magnesium, while reducing their salt concentration. These characteristics were used to develop a specific nutritional approach for broiler chickens (*Gallus gallus*), a species that requires a high calcium intake to ensure optimal bone development. The integration of these enriched by-products into poultry feed is therefore an innovative and sustainable approach, combining improved nutritional value with the recovery of waste from the fishing industry. In this context, the analysis examined the impact of three diets administered over a period of 35 days: a control diet and two experimental diets (LOT 01 and LOT 02) comprising desalted and enriched anchovy bone meal. The aim was to examine their influence on growth, feed conversion ratio, and overall zootechnical performance in broiler chickens (*Gallus gallus*). (Table 7) presents the results obtained and the associated statistical analysis:

The inclusion of desalted anchovy bone meal (FAD) in the initial diet of broiler chickens (*Gallus gallus*) did not cause any significant variation in the major zootechnical parameters compared to the control group. Comparative analysis of data over a 35-day period indicates that average weights at various ages (from D7 to D35), daily gains, and feed conversion ratios show statistical similarities between the Control, LOT01, and LOT02 groups, with negligible variations.

For example, on day 35, the final weights were almost identical: 2203.70 g for the control group, 2203.73 g for LOT01, and 2203.67 g for LOT02. The consumption index remained at 0.16 in all three categories, with no relevant

Table 7. Effects of diets enriched with anchovy bone meal on the zootechnical performance of broiler chickens (*Gallus gallus*)

Age(Days)	Weight (g)			Average weight gain (g)			Daily food consumption (g)			Consumption index		
	Control	LOT01	LOT02	Control	LOT01	LOT02	Control	LOT01	LOT02	Control	LOT01	LOT02
1	45.14±0.06a	45.47±0.49b	45.44±0.43b	*****	132.96±0.86a	135.49±3.59a	13.40±0.53 a	13.67±0.58 a	13.27±0.46 a	****	****	****
7	190.90±0.9b	189.22±2.84a	190.08±2.03b	132.96±0.86a	135.49±3.59a	135.38±4.84a	36.12±0.12 a	38.07 ±0.18 a	37.21 ±0.43a	0.27±0.00a	0.28±0.01b	0.27±0.01a
14	503.37±1.13b	503.40±0.69b	503.33±2.08a	234.31±2.09a	232.11±5.25a	231.77±10.04a	68.64 ±0.59a	70.88 ±0.48a	70.20 ±0.10a	0.29±0.00a	0.31±0.01c	0.30 ±0.01b
21	971.76±0.25b	971.37±1.18a	971.93±1.01b	538.04±3.89a	540.53±6.08a	540.49±11.30a	111.66±0.69 a	113.62±1.19 a	108.95±1.08 a	0.21±0.00a	0.21±0.00a	0.20±0.01a
28	1558.87±0.15b	1558.67±1.15a	1558.67±2.08a	763.18±4.07a	760.21±6.51a	759.38±13.13a	151.94 ±1.48a	154.22±0.31 a	151.07±0.37 a	0.20±0.00a	0.20±0.00a	0.20 ±0.00a
35	2203.70±0.26b	2203.73±0.46b	2203.67±0.76a	1163.52±3.48c	1167.09±1.01a	1167.56±2.50a	187.97±0.97 a	190.96 ±0.27a	187.49±0.38 a	0.16±0.00a	0.16±0.00a	0.16±0.00a

variation ($p > 0.05$), proving that the implementation of FAD does not affect growth performance.

From the outset, LOT01 and LOT02 showed slightly higher weights than the control group, with steady progress and almost identical final weights. Average weight gain is comparable between groups, although LOT01 shows a small improvement in feed efficiency on day 14, with a significantly lower feed conversion ratio (0.31 vs. 0.29 for the control group), indicating better feed conversion in the short term.

Daily feed intake remained similar across all groups, indicating that the formulations tested did not overfeed or decrease the animals' appetite.

These results corroborate recent studies by (Metidja & Laoumir, 2023), which confirmed the nutritional efficacy of marine by-products in poultry farming, as well as those by (Kaushik & Médale, 2009), which highlighted the high biological value of marine proteins and minerals. In addition, (Redlingshöfer et al., 2019) demonstrated that animal derivatives rich in calcium and phosphorus can effectively substitute traditional mineral sources without negatively affecting performance.

Furthermore, the results of (Liu et al., 2016) and (Zhang et al., 2022) support the idea that the integration of nutritional additives (probiotics, enzymes, sapid agents) can temporarily boost zootechnical performance without any negative long-term impact.

LOT01 and LOT02 prove to be viable alternatives to conventional feed, ensuring optimal development and excellent feed efficiency throughout the rearing cycle, while supporting FAD as a sustainable and operational solution for starter rations for broiler chickens (*Gallus gallus*).

Conclusion

This study highlights the benefits of an integrated and sustainable approach to the recovery of fishery and agricultural by-products in Morocco. The combination of activated carbon derived from argan tree shells and quicklime (CaO) has proven particularly effective for the ecological desalination of salted anchovy bones (*Engraulis encrasicolus*), reducing their salt content from 15.4% to less than 0.6%. This dual treatment not only preserved the nutritional value of the bones, but also enriched them with essential minerals such as calcium and magnesium. Incorporating 3% of the resulting flour into the diets of broiler chickens (*Gallus gallus*) did not alter their zootechnical performance, confirming the technical and nutritional feasibility of this valorization. These results pave the way for an innovative circular economy strategy that combines waste reduction, food security,

and environmental sustainability. The proposed process thus represents a concrete solution for transforming underutilized local by-products into high value-added resources for animal feed, while aligning with national and international priorities for ecological transition and nutritional autonomy.

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Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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