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# Growth Performance, Welfare and Behavior Indicators in Post-Weaning Piglets Fed Diets Supplemented with Different Levels of Bakery Meal Derived from Food By-Products

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**Abstract:** This study aimed to evaluate the effect of different levels (15% and 20% $w.w^{-1}$) of bakery meal (BM) inclusion on growth performance, welfare and behavior indicators in post-weaning piglets. Sixty post-weaning castrated male piglets were selected and divided in 3 feeding treatments: standard post-weaning diet with no BM added (CON), standard post-weaning diet with 15% $w.w^{-1}$ BM added (BM 15) and standard post-weaning diet with 20% $w.w^{-1}$ BM added (BM 20). Body weight (BW), average daily gain (ADG), feed intake (FI) and feed conversion ratio (FCR) were recorded individually on a weekly basis. Additionally, welfare, quality behavior indicators, wounds and tail-biting incidence were assessed. The supplementation with BM in piglets' diet had a significant impact on ADG and FCR during certain periods of the trial. BM 15 piglets showed higher ADG and lower FCR in the last week of the experiment compared to CON piglets (1278.57 ± 7.14 g vs. 905.00 ± 47.86 g and 1.69 ± 0.04 g vs. 2.35 ± 0.08 g, respectively). Overall, BM inclusion had no significant effect on performance, quality behavior characteristics and welfare ($p > 0.05$). The inclusion of BM at either 15% or 20% $w.w^{-1}$ illustrated no detrimental effects on the overall growth parameters, welfare and behavior indicators for post-weaned piglets.

**Keywords:** bakery meal; post-weaning piglets; performance; behavior; welfare

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## 1. Introduction

Feed cost constitutes up to 85% of the total production costs of a livestock farm [1]. More specifically, feed cost accounted for approximately 70% of the total pig cost in Spain over the period from 2010 to 2014, while the significant fluctuation of feed prices further increases economic risk [2]. The pork industry, especially in EU countries, is facing lower profit margins per animal, leading to the need for new nutritional strategies to increase its competitiveness and the farmers' revenue [2,3]. Concurrently, food wastage within the food production and consumption value chain remains a major global problem [4]; it is estimated that approximately one third of food produced for human consumption is either lost or wasted, amounting to a financial loss of about US$1 trillion per year [5]. In order to reduce food losses and minimize animal production costs, researchers have been focused on the evaluation of new sources of feed ingredients, such as agro-industrial by-products, former food products (FFPs), etc., as alternatives to conventional feed ingredients. A key advantage of these alternative feed ingredients is the reduced dependence in animal production on cereals, which are also consumed by humans [6].

Among the alternative feed ingredients that can be used in animal ration formulations, bakery FFPs and by-products can be an excellent choice due to their energy content; high palatability; low levels of anti-nutritional agents, such as fiber, tannins, glucosinolates and heat-labile trypsin inhibitors; and their constant availability on the market [7,8]. Dried bakery meal (BM) is a mixture of breads, cookies, cakes, crackers, doughs, chips, pasta, snacks, nuts, cereals, flour, baked goods and related food by-products that have been separated from non-edible materials, mixed, ground and heat-treated [9,10]. These FFPs are economical feed ingredients consisting of processed and ready-to-eat bakery products that are no longer suitable for human consumption due to manufacturing or packaging defects [10]. The use of FFPs in animal feed production is regulated by feed legislation, in which there is a clear distinction between former food and food waste, that enables their marketing as a safe feedstuff that cannot be degraded to food waste [11].

Feeding FFPs to livestock enables losses of high-quality food materials to be reduced, returned to the supply chain and re-used [12,13]. Moreover, this practice aligns with the concept and principles of circular economy, which implies the reduction of food waste generated in the food systems, re-use of food by-products, nutrient recycling and a shift in nutrition towards more diverse and more efficient food patterns [14]. In the European Union, the use of FFPs has already been implemented in animal feed production. However, it remains limited (3.5 million tons/year) [15] compared to the total discarded food (88 million tons/year) [16].

The inclusion of BM derived from food by-products as a feed ingredient in animal diets has been mainly investigated as an alternative poultry and swine nutritional management practice [17–20]. It can be assumed that 1 ton of BM is equivalent to 850 kg of corn, 90 kg of soybean meal (44% w.w$^{-1}$ protein content) and 60 kg of fat/oil [9]. The nutritional evaluation of six different mixtures of bakery by-products used in pig rations showed that their nutritional composition is comparable to that of cereals [15]. BM has protein and amino acid contents similar to those of corn (10.8% crude protein, 0.27% lysine and 0.10% tryptophan) but higher fat content (11%). It is also rich in starch, as wheat flour is the main ingredient in most bakery products. The starch contained in BM is thermally processed, increasing its digestibility and nutritional value, rendering BM ideal for feeding growing pigs [8].

However, there is a scarcity of research evidence regarding the optimal inclusion rate of BM in piglets' post-weaning diets, as well as its impact on growth performance and welfare. In fact, despite the obvious advantages concerning feed sustainability due to the more efficient use of natural resources (i.e., land, water, energy etc.), it is reported that the main limiting factor of the use of FFPs is the lack of information on their nutritional properties and their safe use in animal diets [13]. Therefore, the purpose of this study is to systematically assess the effect of different levels (15% and 20% w.w$^{-1}$) of BM inclusion on the growth performance welfare and behavior indicators in post-weaning piglets. The experimental trial was conducted in a commercial pig farm, employing different batches of BM produced from various locally collected bakery FFPs, to closely simulate the constraints and conditions of real, commercial-scale use of BM.

## 2. Materials and Methods

### *2.1. Bakery Meal Production*

BM was produced in three different production batches. The bakery FFPs for BM production consisted of pasta, cookies, cereals, chocolates, pastry, breads, croissants, etc. that were still edible but not meant for human consumption. The amount of each bakery FFP in the production batch changed depending on the availability of the by-products; chocolates were always less than 10% w.w$^{-1}$ in all production batches. The bakery FFPs were collected and gathered at a BM producing plant in northern Greece, unpacked, ground and thermally treated. The thermal treatment comprised at least 20 min of retention time, at 133 °C and 3 bar. During the thermal treatment, the BM weight was reduced by approx. 60% w.w$^{-1}$ due to moisture removal. The produced BM was a crumbling/coarse brown powder, which was put into 20-kg bags and stored in a dry and cool place under ambient conditions. Two samples from each batch of BM production were collected for physicochemical and microbiological analysis.

### 2.2. Bakery Meal Characterization

The physicochemical analysis of the basic nutrients was performed according to European Commission (EC) Regulation No. 152/2009 [21] for the following parameters: dry matter, crude protein, ash, crude fats and crude fiber. The carbohydrate content and the gross energy were calculated based on the proximate analysis. The sugar content was measured via an enzymatic method used for mono- and di-saccharides analysis in plant and food products (Megazyme K-SUFRG 04/18 assay kit, Megazyme, Wiklow, Irland). The starch content was also determined enzymatically, employing the Megazyme K_TSA_100A assay kit. The concentrations of mono-, poly-unsaturated and saturated fatty acids were determined according to the EC Regulation No. 2568/91 [22]. The extracted fatty acids, via the Soxhlet extraction method (Soxtherm SOX412-MACRO, Gerhardt GmbH & Co. KG, Königswinter, Germany), were analyzed via GC-FID (GC-2010 Plus, Shimadzu Co., Japan) employing a Supelco SP2560 column, after alkaline transesterification according to Dedousi et al. [23]. The peroxide value (PV) of lipids was determined according to the EU 2568/91 method [22] based on the free iodine titration after oxidation of a potassium iodide solution. The concentrations of aflatoxins B1, B2, G1 and G2 and mycotoxins Deoxynivalenol (DON) and Zearalenone (ZON) were analyzed according to available protocols [24,25]. The BM was also microbiologically characterized via real-time PCR methods for the following parameters: Enterobacteriaceae [26], *Salmonella* spp. [27], *Campylobacter* spp. [28] and African swine fever virus (ASFV). More specifically, the presence of ASFV was determined by using the commercial real-time PCR assay ID Gene African Swine fever Duplex (IDvet, Innovation Diagnostics Inc., Grabels, France). The kit includes an endogenous positive control that is used for ensuring the correct DNA amplification. Additionally, the method was validated for the detection of ASFV in the BM by spiking the ASFV positive control in the crude sample. The results concerning the characterization of the BM are summarized in Table 1.

**Table 1.** Nutrient analysis, amino acid composition profile, aflatoxin and mycotoxin concentrations and microbiological characterization of the BM used in this study. Data are presented as mean values ± SD; the data comprise three production batches and six samples in total.

| Parameter | | Amino Acids (g/kg) | |
|---|---|---|---|
| Moisture and volatiles (g/100 g) | 9.48 ± 3.79 | Alanine | 11.5 ± 8.4 |
| Ash (g/100 g) | 7.54 ± 2.20 | Arginine | 9.4 ± 5.7 |
| Fat (g/100 g) | 21.13 ± 4.37 | Aspartic acid | 18.0 ± 7.5 |
| Proteins (g/100 g) | 25.91 ± 4.96 | Glutaminic acid | 31.0 ± 19.1 |
| Crude fibers % (g/100 g) | 1.35 ± 1.33 | Glycine | 25.2 ± 11.4 |
| Carbohydrates (g/100 g) | 34.47 ± 9.20 | Histidine | 9.6 ± 9.4 |
| Sugars (g/100 g) | 5.79 ± 6.33 | Isoleucine | 10.3 ± 3.5 |
| Starch (g/100 g) | 19.33 ± 2.95 | Leucine | 13.8 ± 8.4 |
| Energy (kcal/100 g) | 431.7 ± 35.7 | Lysine | 15.5 ± 8.0 |
| Fatty Acid (FA) Composition | | Methiononine | 11.2 ± 9.9 |
| Monounsaturated FA—MUFA (% w.w$^{-1}$) | 35.6 ± 7.5 | Phenyalanine | 12.8 ± 3.8 |
| Polyunsaturated FA—PUFA (% w.w$^{-1}$) | 14.2 ± 3.8 | Proline | 23.5 ± 24.7 |
| Saturated FA—SFA (% w.w$^{-1}$) | 50.2 ± 13.7 | Serine | 11.9 ± 4.9 |
| Iodine value (meq $O_2$/kg) | <0.5 *–2.0 | Threonine | 10.1 ± 4.5 |
| | | Tryptophane | 1.3 ± 0.7 |
| | | Tyrosine | 8.3 ± 3.7 |
| | | Valine | 12.3 ± 4.9 |
| **Aflatoxins and Mycotoxins (μg/kg)** | | **Microbiological characterization (cfu/g)** | |
| Aflatoxin B1 | <0.5 *–4.5 | *Enterobacteriaceae* | <9.0 *–270 |
| Aflatoxin B2 | <0.5 *–1.0 | *Campylobacter* spp. | ND |
| Aflatoxin G1 | <0.5 *–1.5 | *Salmonella* spp. | ND |
| Aflatoxin G1 | <0.5 * | ASFV [3] | ND |
| SUM of aflatoxins | <2.0 *–7.0 | | |
| ZON [1] | <2.0 *–31 | | |
| DON [2] | <40 *–244 | | |

* This value is the detection limit of the assay. ND: not detected; [1] Zearalenone; [2] Deoxynivalenol; [3] African swine fever Virus.

### 2.3. Animals, Diets and Experimental Design

The experiment was conducted at the facilities of a commercial pig farm located in Nea Tenedos, Chalkidiki, Greece (40°21′48.3″ N, 23°15′49.7″ E). Sixty post-weaning castrated male piglets with intact tails (Pietrain breed, 28 days old, with mean body weight 8.57 ± 0.20 kg) were selected for the study. The piglets were randomly allocated into six consecutive pens (10 piglets.pen$^{-1}$, space allowance 0.15 m$^2$/piglet). Each pen had a perforated plastic floor, was equipped with a feeder and nipple drinkers and was enriched with iron chains serving as a toy for the piglets. The stocking density in each pen met the requirements of EU directives [29]. All pens were at the same facility in order to obtain the same environmental conditions for all groups. Piglets had ad libitum access to feed and water. During the experimental period, the temperature and relative humidity were automatically controlled and followed recommendations for the post-weaning production phase [30].

After a seven-day adaptation period, the piglets were divided into 3 feeding treatment groups: standard post-weaning diet with no BM added (CON), standard post-weaning diet with 15% w.w$^{-1}$ BM added (BM 15) and standard post-weaning diet with 20% w.w$^{-1}$ BM added (BM 20), with 20 piglets.group$^{-1}$, 2 replicates-pens.group$^{-1}$ and 10 piglets.replicate-pen$^{-1}$. A two-phase feeding program was applied for each dietary treatment, consisting of a growing 1 diet, fed from 28 to 60 days of age, and a growing 2 diet, fed from 60 to 84 days of age. In total, 6 diets were formulated (Table 2). In the BM diets, conventional ingredients, mainly corn and soya, were replaced with BM to formulate all rations on an isonitrogenous and isocaloric basis. The rations were offered as mash and met the National Research Council (NRC) energy requirements. The duration of the trial was 56 days.

**Table 2.** Physical and chemical composition of experimental diets (dry matter basis).

| | Growing 1 (Days 28–60) | | | Growing 2 (Days 60–84) | | |
|---|---|---|---|---|---|---|
| **Items** | **CON** | **BM 15** | **BM 20** | **CON** | **BM 15** | **BM 20** |
| Ingredient composition | | | | | | |
| Maize meal | 25.00 | 25.00 | 20.00 | 25.00 | 25.00 | 22.00 |
| Corn | 10.00 | 5.00 | 8.00 | 15.30 | 8.30 | 8.30 |
| Wheat pollard | 30.00 | 25.00 | 19.00 | 32.00 | 29.00 | 27.00 |
| Bakery meal | 0.00 | 15.00 | 20.00 | 0.00 | 15.00 | 20.00 |
| Wheat | 5.00 | 5.00 | 5.00 | 7.00 | 7.00 | 8.00 |
| Soya 47 | 14.60 | 10.00 | 9.00 | 15.00 | 10.00 | 9.00 |
| Vitamin and mineral premix | 6.00 | 6.00 | 6.00 | 2.50 | 2.50 | 2.50 |
| Soybean oil | 2.00 | 1.60 | 0.60 | 0.00 | 0.00 | 0.00 |
| Whey | 5.00 | 5.00 | 10.00 | 0.00 | 0.00 | 0.00 |
| NatuPro | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Zinc Oxide | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Mycotoxin binders | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Marble powder | | | | 0.80 | 0.80 | 0.80 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Chemical composition | | | | | | |
| Dry matter (%) | 87.5 | 88.7 | 89.2 | 88.4 | 89.8 | 91.1 |
| Crude protein (%) | 15.26 | 14.42 | 14.43 | 14.25 | 13.62 | 13.27 |
| Crude fiber (%) | 3.59 | 3.28 | 3.23 | 3.21 | 2.95 | 2.71 |
| Ether extract (%) | 3.01 | 6.36 | 7.43 | 4.74 | 7.65 | 8.18 |
| Crude ash (%) | 3.24 | 3.35 | 3.46 | 2.69 | 2.84 | 3.32 |
| Gross energy (Mj/kg) | 15.57 | 16.04 | 16.22 | 13.98 | 14.59 | 14.14 |
| Metabolizable energy (Mj/kg) | 12.71 | 13.17 | 13.28 | 11.46 | 12.04 | 11.67 |

### 2.4. Production Traits

Body weight (BW) was measured individually at the beginning of the trial (28 day of age) and then weekly, on a weighing platform (accuracy 0.5 kg) until the end of the experiment (84 days of age). Feed intake (FI) and mean average daily gain (ADG) per pig were calculated at weekly intervals as well as for the whole experimental period (28–84 days of age). Similarly, based on FI and ADG, the feed conversion ratio (FCR) per pig was determined at weekly intervals and throughout the study. Orts were collected and weighed once a week in order to calculate FI. Mortality rate was recorded daily. Body condition score and health status were also evaluated on a weekly basis.

### 2.5. Welfare Assessment

Welfare and quality behavior indicators were assessed at the beginning of each evaluation day (10:00 a.m.) by the same evaluator. Welfare assessment was performed on a weekly basis according to the suggested methodology of the Welfare Quality® Assessment protocol for pigs [31]. The quality behavior characteristics (active, fearful, distressed, calm, bored, playful, sociable, feeding) were interpreted by individual visual observations, with a duration of 2 min in each pen. The number of piglets observed in each behavior category was noted, divided by the total number of pigs in each group and multiplied by 100.

Moreover, piglets were individually scored for wounds on the body and incidences of tail-biting during each 10 min observation period per pen. Wounds were inspected on both sides of the body. Piglets were assigned a score of 0 when there was no evidence of wounds, a score of 1 if all regions of the body had 5 to 10 lesions, and a score of 2 when >10 lesions were observed on a minimum of 2 zones of the body or if any zone had >15 lesions. Tail-biting incidence was evaluated using a 2-point scale; a score of 0 referred to no evidence of tail-biting, while a score of 2 was indicative of bleeding tail and/or swollen infected tail lesion and/or part of tail tissue missing and presence of crust [32].

### 2.6. Statistical Analysis

The data were tested for normality with the Shapiro–Wilk test before statistical analysis. The piglet was considered the experimental unit. The significance of the differences between welfare and quality behavior indicators among the groups was assessed via Chi-square test. One-way analysis of variance (ANOVA) was used to compare means of the examined parameters between different feeding treatments. Levene's test was performed to check homogeneity of variances. Post-hoc analysis was undertaken using the LSD test. Significance level was set at $p < 0.05$. Data were analyzed using IBM SPSS v.22.0 (Armonk, NY, USA: IBM Corp.).

## 3. Results

All animals remained clinically healthy throughout the study and no morbidity issues were reported, with the exception of two piglets that died during the study, one from BM 15 group at the 4th week and one from CON group in the 6th week. Post mortem findings were indicative of enzootic pneumonia. The available data of those animals were excluded from the statistical analysis.

The BM supplementation in the piglets' diet had a significant impact on ADG and FCR during certain periods of the trial. Specifically, BM inclusion had a significant effect on ADG from 57 to 63 and 78 to 84 days of age ($p = 0.035$ and $p = 0.004$, respectively). Moreover, the experimental diets had a significant impact on FCR from 28 to 35 ($p = 0.025$), from 57 to 63 ($p = 0.024$) and from 78 to 84 ($p = 0.003$) days of age, respectively.

The effect of different levels of BM inclusion on growth and performance characteristics among the three experimental groups are presented in Table 3. At 35 and 42 days of age, BM-fed piglets presented higher BW compared to the CON group. However, significant differences were observed only between the BM 15 and CON groups ($p = 0.029$ and 0.046, respectively). Similarly, ADG was significantly higher in the BM 15 group from 28 to 35 ($p = 0.039$) and 78 to 84 ($p = 0.003$) days of age compared to the CON group. A significant difference was reported between those groups during the fifth week of the trial, with ADG being lower in the BM 15 group ($p = 0.023$). Additionally, higher ADG was observed in the BM 20 group from 36 to 42 days of age ($p = 0.033$). Moreover, the BM 15 piglets had a higher FI from 36 to 42 and 50 to 56 days of life compared to the CON ($p = 0.008$) and BM 20 ($p = 0.004$) ones, respectively. From 57 to 63 days, FI was lower in the BM 20 group ($p = 0.013$). The best FCR was reported in the BM 15 group during the first and the last week of the experimental period ($p = 0.013$ and 0.003, respectively). From 36 to 42 days, FCR was lower in the BM 20 group compared to the CON group ($p = 0.022$). The BM 15 piglets had a higher FCR from 57 to 63 days of life compared to the CON and BM 20 groups ($p = 0.022$ and 0.012, respectively). Overall, none of the evaluated performance parameters differed significantly among the three groups ($p > 0.05$).

**Table 3.** Growth and performance characteristics of piglets fed the control and diets containing different levels of BM. Data are presented as mean ± SE values.

| Variables | CON | BM 15 | BM 20 |
|---|---|---|---|
| BW (kg) | | | |
| Day 28 | 8.66 ± 0.22 | 8.74 ± 0.12 | 8.32 ± 0.20 |
| Day 35 | 10.69 ± 0.065 [a] | 11.32 ± 0.15 [b] | 10.81 ± 0.12 [ab] |
| Day 42 | 12.26 ± 0.12 [a] | 13.42 ± 0.18 [b] | 13.21 ± 0.38 [ab] |
| Day 49 | 15.55 ± 0.50 | 15.55 ± 0.50 | 15.00 ± 1.00 |
| Day 56 | 19.50 ± 0.50 | 21.06 ± 0.06 | 20.50 ± 0.50 |
| Day 63 | 24.50 ± 0.50 | 25.28 ± 0.28 | 25.50 ± 0.50 |
| Day 70 | 31.06 ± 0.06 | 31.06 ± 0.06 | 31.00 ± 0.01 |
| Day 77 | 37.39 ± 0.39 | 36.89 ± 0.89 | 35.55 ± 0.50 |
| Day 84 | 43.72 ± 0.72 | 45.84 ± 0.84 | 44.50 ± 0.50 |
| Overall (28–84 d) | 35.06 ± 0.77 | 37.10 ± 0.83 | 36.19 ± 0.51 |
| ADG (g) | | | |
| 28–35 d | 289.64 ± 1.78 [a] | 368.57 ± 21.43 [b] | 355.71 ± 17.14 [ab] |
| 36–42 d | 225.00 ± 7.86 [a] | 300.71 ± 5.00 [ab] | 342.86 ± 37.15 [b] |
| 43–49 d | 462.86 ± 88.57 | 297.15 ± 45.72 | 256.43 ± 89.29 |
| 50–56 d | 571.43 ± 142.86 | 793.58 ± 79.29 | 785.72 ± 71.43 |
| 57–63 d | 714.29 ± 0.01 [a] | 602.86 ± 31.43 [b] | 714.29 ± 0.01 [ab] |
| 64–70 d | 936.43 ± 79.29 | 825.72 ± 31.43 | 785.72 ± 71.43 |
| 71–77 d | 904.29 ± 47.15 | 832.86 ± 188.57 | 642.86 ± 71.43 |
| 78–84 d | 905.00 ± 47.86 [a] | 1278.57 ± 7.14 [b] | 1285.71 ± 0.01 [b] |
| Overall (28–84 d) | 626.12 ± 13.80 | 662.50 ± 14.82 | 646.16 ± 9.02 |
| FI (Kg) | | | |
| 28–35 d | 3.33 ± 0.08 | 3.38 ± 0.12 | 3.44 ± 0.01 |
| 36–42 d | 4.14 ± 0.07 [a] | 4.67 ± 0.08 [b] | 4.40 ± 0.01 [ab] |
| 43–49 d | 6.40 ± 0.02 | 6.36 ± 0.06 | 6.49 ± 0.08 |
| 50–56 d | 7.32 ± 0.04 [ab] | 7.82 ± 0.23 [a] | 6.78 ± 0.28 [b] |
| 57–63 d | 8.96 ± 0.04 [b] | 8.98 ± 0.07 [b] | 8.55 ± 0.05 [a] |
| 64–70 d | 9.28 ± 0.28 | 9.06 ± 0.06 | 8.88 ± 0.08 |
| 71–77 d | 14.78 ± 0.28 | 14.60 ± 0.16 | 14.40 ± 0.15 |
| 78–84 d | 14.89 ± 0.29 | 15.09 ± 0.24 | 14.50 ± 0.10 |
| Overall (28–84 d) | 68.59 ± 0.29 | 69.95 ± 0.29 | 67.40 ± 0.10 |
| FCR | | | |
| 28–35 d | 1.65 ± 0.05 [a] | 1.31 ± 0.03 [b] | 1.38 ± 0.06 [b] |
| 36–42 d | 2.63 ± 0.05 [a] | 2.22 ± 0.08 [ab] | 1.85 ± 0.20 [b] |
| 43–49 d | 2.05 ± 0.39 | 3.13 ± 0.46 | 4.10 ± 1.39 |
| 50–56 d | 1.95 ± 0.48 | 1.42 ± 0.10 | 1.24 ± 0.06 |
| 57–63 d | 1.79 ± 0.01 [b] | 2.14 ± 0.01 [a] | 1.71 ± 0.01 [b] |
| 64–70 d | 1.42 ± 0.08 | 1.57 ± 0.07 | 1.63 ± 0.16 |
| 71–77 d | 2.34 ± 0.08 | 2.56 ± 0.39 | 3.25 ± 0.40 |
| 78–84 d | 2.35 ± 0.08 [a] | 1.69 ± 0.04 [b] | 2.56 ± 0.39 [b] |
| Overall (28–84 d) | 1.96 ± 0.04 | 1.89 ± 0.04 | 1.86 ± 0.03 |

[a, b] Mean values within a row with different superscripts differ significantly at $p < 0.05$.

The percentages of piglets observed in the 3 dietary treatments (CON, BM 15, BM 20) scoring for quality behavior characteristics (active, fearful, distressed, calm, bored, playful, sociable, feeding) are presented in Table 4. On the majority of the evaluation days, the addition of BM to the diets had no significant effect ($p > 0.05$) on quality behavior characteristics. At day 63, BM 15 piglets were evaluated as more active compared to CON ones ($p = 0.038$). Moreover, at day 70, BM 20 piglets were calmer compared to BM 15 and CON ones ($p = 0.008$ and 0.003, respectively).

**Table 4.** Percentage (%) of piglets observed in the 3 dietary treatments (CON, BM 15, BM 20) scoring for quality behavior characteristics (active, fearful, distressed, calm, bored, playful, sociable, feeding) at each evaluation day.

| | | Quality Behavior Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Active** | **Fearful** | **Distressed** | **Calm** | **Bored** | **Playful** | **Sociable** | **Feeding** |
| Day 35 | CON | 75.00 | 0 | 5 | 0 | 0 | 0 | 0 | 20.00 |
| | BM 15 | 80.00 | 0 | 0 | 0 | 0 | 0 | 0 | 20.00 |
| | BM 20 | 75.00 | 0 | 0 | 0 | 0 | 0 | 0 | 25.00 |
| Day 42 | CON | 65.00 | 0 | 0 | 0 | 0 | 0 | 0 | 35.00 |
| | BM 15 | 70.00 | 0 | 0 | 0 | 0 | 0 | 0 | 30.00 |
| | BM 20 | 75.00 | 0 | 0 | 0 | 0 | 0 | 0 | 25.00 |
| Day 49 | CON | 65.00 | 0 | 0 | 0 | 0 | 0 | 0 | 35.00 |
| | BM 15 | 60.00 | 0 | 0 | 0 | 0 | 0 | 0 | 40.00 |
| | BM 20 | 75.00 | 0 | 0 | 0 | 0 | 0 | 0 | 25.00 |
| Day 56 | CON | 50.00 | 0 | 0 | 0 | 0 | 0 | 0 | 50.00 |
| | BM 15 | 52.63 | 0 | 0 | 0 | 0 | 21.05 | 0 | 26.32 |
| | BM 20 | 15.00 | 0 | 0 | 15.00 | 5.00 | 25.00 | 0 | 40.00 |
| Day 63 | CON | 30.00 [a] | 0 | 0 | 5.00 | 5.00 | 5.00 | 5.00 | 50.00 |
| | BM 15 | 63.16 [b] | 0 | 0 | 0 | 0 | 5.26 | 0 | 31.58 |
| | BM 20 | 60.00 [ab] | 0 | 0 | 0 | 0 | 15.00 | 0 | 25.00 |
| Day 70 | CON | 26.32 | 0 | 0 | 31.58 [b] | 0 | 10.53 | 0 | 31.57 |
| | BM 15 | 42.10 | 0 | 0 | 26.32 [b] | 0 | 0 | 0 | 31.58 |
| | BM 20 | 15.00 | 0 | 0 | 85.00 [a] | 0 | 0 | 0 | 0 |
| Day 77 | CON | 42.10 | 0 | 0 | 10.53 | 0 | 10.53 | 0 | 36.84 |
| | BM 15 | 36.84 | 0 | 0 | 10.53 | 0 | 0 | 0 | 52.63 |
| | BM 20 | 40.00 | 0 | 0 | 20.00 | 0 | 10.00 | 0 | 30.00 |

[a, b] Means within a column at a particular age for each type of behavior with different superscripts differ significantly ($p < 0.05$).

Data regarding the impact of BM inclusion on body wounds and tail-biting incidence are presented in Table 5. The percentage of piglets assigned a body wound score of 0, 1 or 2 did not differ significantly among different experimental groups ($p > 0.005$). However, a significantly higher percentage of piglets with bleeding tails and/or swollen infected tail lesions and/or missing parts of tail tissue and presence of crust was reported in the BM 15 group in the 3rd week and peaked in the 5th week of the trial ($p < 0.005$).

**Table 5.** Percentage (%) of piglets observed in the 3 dietary treatments (CON, BM 15, BM 20) scoring for welfare indicators (body wounds, tail-biting incidence) on each evaluation day.

| | | Welfare Indicators | | | | |
|---|---|---|---|---|---|---|
| | | Body Wounds [1] | | | Tail Biting Incidence [2] | |
| | | Score | | | Score | |
| | | 0 | 1 | 2 | 0 | 2 |
| Day 35 | CON | 95.00 | 5.00 | 0 | 100 | 0 |
| | BM 15 | 95.00 | 0 | 0 | 100 | 0 |
| | BM 20 | 95.00 | 5.00 | 0 | 100 | 0 |
| Day 42 | CON | 95.00 | 5.00 | 0 | 100 | 0 |
| | BM 15 | 90.00 | 10.00 | 0 | 100 | 0 |
| | BM 20 | 85.00 | 15.00 | 0 | 100 | 0 |
| Day 49 | CON | 90.00 | 10.00 | 0 | $100^{b}$ | $0^{b}$ |
| | BM 15 | 95.00 | 5.00 | 0 | $80.00^{a}$ | $20.00^{a}$ |
| | BM 20 | 80.00 | 20.00 | 0 | $100^{b}$ | $0^{b}$ |
| Day 56 | CON | 85.00 | 10.00 | 5.00 | $100^{b}$ | $0^{b}$ |
| | BM 15 | 73.68 | 15.79 | 10.53 | $68.42^{a}$ | $31.58^{a}$ |
| | BM 20 | 70.00 | 25.00 | 5.00 | $100^{b}$ | $0^{b}$ |
| Day 63 | CON | 80.00 | 15.00 | 5.00 | $100^{b}$ | 0 b |
| | BM 15 | 63.15 | 26.32 | 10.53 | $68.42^{a}$ | $31.58^{a}$ |
| | BM 20 | 70.00 | 25.00 | 5.00 | $100^{b}$ | $0^{b}$ |
| Day 70 | CON | 63.16 | 21.05 | 15.79 | 100 | 0 |
| | BM 15 | 42.11 | 21.05 | 36.84 | 89.48 | 10.52 |
| | BM 20 | 55.00 | 35.00 | 10.00 | 100 | 0 |
| Day 77 | CON | 42.10 | 31.58 | 26.32 | 100 | 0 |
| | BM 15 | 26.31 | 26.32 | 47.37 | 89.48 | 10.52 |
| | BM 20 | 55.00 | 35.00 | 10.00 | 100 | 0 |

$^{a,b}$ Means within a column at a particular age (Day 35–Day 77) for each score category 0–2 with different superscripts differ significantly ($p$ < 0.05). [1] Body Wounds: Score 0: no evidence of wounds; Score = 1: all regions of the body had 5 to 10 lesions; Score = 2: >10 lesions were observed on a minimum of 2 zones of the body or any zone had >15 lesions. [2] Tail biting: Score 0: no evidence of tail biting; Score = 2: bleeding tail and/or swollen infected taillesion, and/or part of tail tissue missing and presence of crust.

## 4. Discussion

As asserted in the introduction, there is a notable scarcity of research data regarding the inclusion of BM in the rations of post-weaned piglets. Digestibility and the effect of bakery FFPs on growth performance have been mainly determined in growing–finishing pigs [33–36], reporting conflicting results regarding feed efficacy. However, in most cases, no depression in growth rate of the animals was observed.

Piglets are exposed to a variety of stressors during weaning, such as separation from the dam, changes in housing environment, mixing with unfamiliar litters and transition from milk to a solid diet [37]. The addition of BM to post-weaning diets could be a challenge for their immature digestive systems. Nevertheless, BM can replace a significant percentage of cereal grains in pig diets due to a chemical composition similar to that of wheat and barley [38]. In our study, the chemical analysis of experimental BM diets revealed that crude protein and metabolizable energy content were similar to conventional diets and comparable with other studies [1,39]. The main concern in using BM in pig rations is the variability in chemical and nutritional composition of each batch, according to the available raw materials. However, it has been demonstrated that the nutrient profile of BM is rather consistent regardless of the origin of production [40].

The inclusion of BM in post-weaning diets did not compromise the overall growth performance of the piglets in our trial. At weekly intervals, significant differences in BW, ADG and FCR were recorded among experimental groups. Although FI was lower in the CON group during the first weeks of the trial, overall performance and FCR were not affected as the experiment progressed. Overall, although BW and ADG values were numerically higher and FCR was better in the BM 15 and BM 20 groups, the differences were not statistically significant. Those results are in accordance with what Tiwari et al. [41] observed when they replaced maize in basal diets with different levels of bakery FFPs. The inclusion of 20% w.w$^{-1}$ bakery FFPs resulted in the highest total weight gain and ADG compared to 0%, 10% or 30% w.w$^{-1}$ levels, although the overall differences in growth performance at the end of the trial were not statistically significant. Similarly, Tretola et al. [42] did not report any depression in growth rate by using bakery, pasta and confectionary by-products at levels up to 30% w.w$^{-1}$ in post-weaning diets. No detrimental effects on growth and FCR were observed, even with high substitution of corn (50%) with bakery FFPs [43]. On the contrary, Luciano et al. [44] recorded a decrease in overall and ADG of pigs from day 15 to 35 as the concentration of BM increased in the diets, indicating that a total replacement of maize may not be beneficial during this crucial period. Narayanan et al. [45] performed a trial in 7-day-old piglets, in which the control group were fed swine starter feed and the experimental group were fed crumbled biscuits, ad libitum in both cases. The final body weights at the end of 8th week were 14.10 $\pm$ 2.27 kg and 10.97 $\pm$ 1.6 kg for the control and the experimental group, respectively. Thus, protein supplementation is necessary to obtain optimal growth when BM is provided as the only feed source.

The inclusion of BM has been more extensively studied compared to trials conducted in post-weaning piglets. In many of these studies, no significant differences in growth performance parameters were observed between control and experimental groups. These investigations have yielded valuable data on the optimal percentage of BM inclusion, providing insights into its potential as a sustainable dietary component. Indicatively, Manu et al. [46] concluded that discarded biscuits can make up to 30% of the ration of growing pigs, replacing corn at about 60% adversely affecting carcass yield and quality. Similarly, Barman et al. [43] and Tiwari and Dhakal [8] reported that bakery waste has no detrimental effect on growth characteristics when it replaces corn at 50% or 75%, respectively. These findings indicate the feasibility of using BM as a partial substitute for conventional ingredients in growing pig diets without compromising growth performance. However, it is important to consider the potential impact of higher levels of BM inclusion. Ojediran et al. [47] reported that replacing corn with biscuit dough at a level of 37.5% had a significant effect on the FCR of growing pigs. Similarly, Kumar et al. [36] indicated that the percentage of bread waste inclusion in diets should not exceed the level of 50% in order to eliminate the possibilities of FI decrease and gastrointestinal disorders. In light of the available literature and the goal of maintaining optimal animal performance, we chose to use the lowest inclusion rates of BM in our trial. This cautious approach aimed to minimize the risk of potential negative effects on the post-weaning piglets' growth and well-being. To further optimize the use of BM in post-weaning diets, additional research is warranted.

Welfare and performance of livestock are strongly correlated with gut health [48]. Tretola et al. [42] reported that the composition of gut microbiota changed after the inclusion of FFPs in the diets of post-weaning piglets. However, they did not measure the possible effect of this addition on welfare indicators. To our knowledge, the present study is the first one reporting the possible impact of BM incorporation in post-weaning diets on welfare and quality behavior indicators. No evidence of severe welfare issues was reported during the trial, with the exception of the tail-biting incidence in BM 15 group that was first reported at day 49 and lasted approximately three weeks. There are a variety of risk factors that can trigger this abnormal behavior, such as health issues, stress, feed, barn climate, stocking intensity and lack of enrichment materials [49]. In our case, it was a challenge to identify the cause of this outbreak, as preventative measures were applied in all groups. This behavior affected performance characteristics of the group, mainly FCR and ADG parameters, during the fifth week of the experiment. After the identification and separation of the biter, the remaining piglets recovered quickly, and their weight gain was compensated for during the remaining weeks of the trial.

## 5. Conclusions

The results obtained in the present study provide valuable insights into the potential utilization of BM in the formulation of post-weaning piglet diets. The inclusion of BM at either 15% or 20% w.w$^{-1}$ caused no detrimental effects on the overall growth parameters of the piglets. This finding is promising as it suggests that BM can be a sustainable and cost-effective alternative in piglet nutrition without compromising their growth performance. Moreover, the use of BM did not negatively impact the welfare and quality behavior indicators for post-weaned piglets. Despite the reported variability in specific physicochemical characteristics of the different BM batches, it is noteworthy that this variability did not seem to affect the reported results, and the use of the BM was successfully employed. This resilience in the face of batch variation highlights the feasibility and adaptability of incorporating BM into piglet diets, making it a reliable option for sustainable and circular food practices. While this study sheds light on the growth and welfare aspects of using BM in post-weaning piglet diets, there are still several unexplored areas that warrant further investigation. Future research should delve into assessing the impact of BM inclusion on other critical parameters, such as the gut microbiota composition, the carcass quality through meat analysis and taste panel assessment and the overall pig farm environmental and economic sustainability comprising a cost-benefit analysis. Understanding the effects of BM on these aspects will provide a more comprehensive evaluation of its potential benefits and implications for the pig farming industry.

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**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

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