Effects of expanded diets and phase feeding programme on growth performance, carcass traits and meat quality in growing-finishing pigs

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**ABSTRACT**

Two experiments were conducted to evaluate the effects of expanded diets and phase feeding programmes in growing-finishing pigs. In Exp. 1, a total of 72 pigs (25.88 ± 1.34 kg) were randomly allotted to 3 dietary treatments: (1) unexpanded corn–wheat–soybean meal (CWSBM)-based diets with two-phase feeding programme; (2) expanded CWSBM-based diets with two-phase feeding programme; (3) unexpanded CSBM-based diets with three-phase feeding programme. During 12–14 weeks and 1–14 weeks, pigs offered the expanded diets had lower feed conversion ratio (FCR) compared with those fed unexpanded diets (\(P < .05\)). In Exp. 2, 120 growing pigs (20.51 ± 0.62 kg) were randomly assigned to 3 dietary treatments: (1) unexpanded corn–soybean meal (CSBM)-based diets with two-phase feeding programme; (2) expanded CSBM-based diets with two-phase feeding programme; (3) unexpanded CSBM-based diets with three-phase feeding programme. During 15–17 weeks, pigs fed expanded diets had increased daily gain and decreased FCR compared with those fed unexpanded diet (\(P < .05\)). In conclusion, expanded CWSBM- or CSBM-based diets improved growth performance of growing-finishing pigs. Phase feeding programmes did not affect growth performance, carcass characteristics and meat quality in growing-finishing pigs fed CWSBM- or CSBM-based diets.

1. Introduction

In modern intensive swine production, feed is the single largest expense in swine production (Niemi et al. 2010; Renaudeau et al. 2013). Over the last decade, the drastic increase in feed cost has reduced the profit margins of swine production (Schmit et al. 2009). Therefore, in growing-finishing pigs, much attention has been given to maximize pigs’ growth at minimal feeding cost (Pomar et al. 2009). Many strategies such as feed processing, exogenous feed additives, and phase feeding programme provide opportunities to improve feed efficiency, growth performance and competitiveness of swine production (de Langea et al. 2010; Jezierny et al. 2010; NRC 2012; Zeng et al. 2015; Rojas and Stein 2016; Lee et al. 2017; Yun et al. 2018). Generally, insufficient nutrients may limit the potential growth of pigs, whereas excessive nutrients may reduce the economic profitability (Pomar et al. 2009; Hong et al. 2016). It is suggested that providing growing-finishing pigs diets into two or three phases is a useful technology to more precisely meet the requirements of pigs and control the feed cost (Han et al. 2001; Niemi et al. 2010). Additionally, expander processing is an important technology to improve the nutritional values and hygienic quality of diets (Chae and Han 1998). Several studies reported improved growth performance, nutrient digestibility, and carcass traits in pigs fed expanded diets compared with unexpanded diets (Park et al. 2003; Lundblad et al. 2012). However, the responses of pigs to expanded diets and phase feeding programmes are not always consistent (van der Poel et al. 1997; Callan et al. 2007). The objective of these two experiments was to determine the effects of expanded diets and phase feeding programmes on daily gain, daily feed intake, feed conversion ratio (FCR), carcass traits, and meat quality in growing-finishing pigs fed corn–wheat–soybean meal (CWSBM)- or corn–soybean meal (CSBM)-based diets.

2. Materials and methods

The experimental protocols were approved by the Animal Care and Use Committee of Dankook University.

2.1. Experimental design, animals, diets, and housing

In Exp. 1, a total of 72 crossbred [(Landrace × Yorkshire) × Duroc] pigs with an average initial body weight (BW) of 25.88 ± 1.34 kg were used in this 14-week experiment. Pigs were randomly allotted to one of three dietary treatments according to their sex and BW with six replicates and two gilts and two barrows per pen. Dietary treatments were as follows: (1) unexpanded CWSBM-based diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (2) expanded CWSBM-based diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (3) unexpanded CWSBM-based diets with three-phase feeding programme (phase I, phase II, and phase III diets for 5, 6, and 3 weeks, respectively).
The compositions of experimental diets used in Exp. 1 are presented in Table 1.

In Exp. 2, a total of 120 crossed [(Landrace x Yorkshire) x Duroc] growing pigs (20.51 ± 0.62 kg initial BW) were randomly assigned to 1 of 3 dietary treatments on the basis of their sex and initial BW (10 replicate pens with 2 gilts and 2 barrows per pen). Dietary treatments were as follows: (1) unexpanded CSBM-based diets with two-phase feeding programme (phase I and phase II diets for 8 and 9 weeks, respectively); (2) expanded CSBM-diets with two-phase feeding programme (phase I and phase II diets for 8 and 9 weeks, respectively); (3) unexpanded CSBM-diets with three-phase feeding programme (phase I, phase II, and phase III diets for 8, 6, and 3 weeks, respectively). The compositions of experimental diets used in Exp. 2 are presented in Table 2.

The expanded diets were expanded using a Kahl 12 annular gap expander (Amandus Kahl Nachf, Hamburg, Germany). Prior to expansion, the diets were conditioned at 80°C for approximately 5 s. Then, diets were expanded at 115°C for 5 s at 35-bar pressure.

All pigs were housed in an environmentally controlled facility with a slatted plastic floor. The target room temperature and humidity were 25°C and 60%, respectively. Each pen was equipped with a one-sided self-feeder and a nipple waterer to ad libitum access to feed and water throughout the experimental period.

### Table 1. Ingredient composition and chemical analysis of the experimental diets (as-fed basis, Exp. 1).

| Ingredients (%) | Phase I | Phase II | Phase III |
|-----------------|---------|----------|-----------|
| Corn            | 46.51   | 37.72    | 41.83     |
| Wheat           | 10.00   | 20.00    | 20.00     |
| Soybean meal    | 34.25   | 33.62    | 25.48     |
| Corn gluten meal| 2.00    | –        | –         |
| Rape seed meal  | –       | –        | 3.50      |
| Tallow          | 1.90    | 5.54     | 6.01      |
| Soybean oil     | 1.50    | –        | –         |
| Limestone       | 1.06    | 1.12     | 1.17      |
| DL-Methionine   | 0.46    | 0.39     | 0.41      |
| L-Lysine-HCl    | 0.42    | 0.15     | 0.20      |
| L-Threonine     | 0.17    | 0.09     | 0.12      |
| Vitamin premix a| 0.05   | 0.05     | 0.05      |
| Trace mineral premix b| 0.10| 0.10 | 0.10 |
| Calculated composition (%) |       |         |           |
| Digestible energy (kcal/kg) | 3580 | 3514 | 3515 |
| Crude protein   | 22.12   | 20.43    | 18.55     |
| Lysine          | 1.45    | 1.22     | 1.10      |
| Methionine + cysteine | 0.75 | 0.65 | 0.65 |
| Calcium         | 0.75    | 0.65     | 0.65      |
| Total phosphorus| 0.65    | 0.60     | 0.60      |
| Crude fat       | 5.55    | 7.27     | 7.96      |
| Crude fibre     | 3.24    | 3.29     | 3.25      |
| Analysed composition (%) |       |         |           |
| Crude protein   | 22.01   | 20.36    | 18.57     |
| Calcium         | 0.72    | 0.67     | 0.65      |
| Total phosphorus| 0.65    | 0.62     | 0.57      |

aProvided per kg of complete diet: 15.000 IU vitamin A, 3750 IU vitamin D₃, 37.50 mg vitamin E, 2.55 mg vitamin K₃, 3 mg vitamin B₁₂, 7.5 mg vitamin B₉, 4.5 mg vitamin B₆, 24 μg vitamin B₁₂, 51 mg niacin, 1.5 mg folic acid, 126 mg biotin, and 13.5 mg pantothenic acid.

bProvided per kg of complete diet: 50 mg Mn (as MnO₂), 70 mg Zn (as ZnSO₄), 36 mg Fe (as FeSO₄·7H₂O), 0.23 mg Se (as Na₂SeO₃·5H₂O).

### Table 2. Ingredients and calculated content of energy and nutrients in experimental feeds (as fed basis, Exp. 2).

| Ingredients (%) | Phase I | Phase II | Phase III |
|-----------------|---------|----------|-----------|
| Corn            | 54.86   | 58.83    | 63.11     |
| Wheat           | 2.00    | 2.00     | 2.00      |
| Palm kernel meal| –       | 1.44     | 0.19      |
| Soybean meal    | 20.57   | 15.72    | 7.43      |
| Corn-DDGS       | 5.00    | 5.00     | 8.00      |
| Rapeseed meal   | 3.00    | 3.00     | 5.00      |
| Rice bran       | 2.00    | 2.00     | 2.00      |
| Wheat bran      | 2.50    | 2.50     | 2.50      |
| Tallow          | 3.50    | 3.00     | 3.00      |
| Molasses        | 3.00    | 3.00     | 3.50      |
| Limestone       | 1.42    | 1.67     | 1.47      |
| DL-Methionine   | 0.08    | 0.02     | 0.02      |
| L-Tryptophan    | 0.04    | 0.06     | 0.03      |
| Vitamin premix a| 0.20   | 0.20     | 0.20      |
| Total phosphorus| 0.62    | 0.58     | 0.56      |
| Calculated composition (%) |       |         |           |
| Digestible energy (kcal/kg) | 3550 | 3573 | 3459 |
| Crude protein   | 19.00   | 17.11    | 14.88     |
| Lysine          | 1.27    | 1.07     | 0.97      |
| Methionine + cysteine | 0.68 | 0.62 | 0.50 |
| Calcium         | 0.80    | 0.70     | 0.60      |
| Total phosphorus| 0.65    | 0.60     | 0.60      |
| Crude fat       | 6.88    | 7.53     | 6.54      |
| Crude fibre     | 2.96    | 2.89     | 2.88      |
| Total phosphorus| 0.62    | 0.58     | 0.56      |

2.2. Sampling and measurements

In Exp. 1, individual BW was recorded at the beginning, week 5, week 11, and week 14 of the experiment. In Exp. 2, individual BW was recorded at the beginning, week 2, week 8, week 14, and week 17 of the experiment. In both experiments, feed consumption was measured weekly on a pen basis during the experiments. Then, daily feed intake, daily gain, and FCR were calculated.

At the end of both experiments, all pigs were slaughtered at a local commercial facility. Following exsanguinations and evisceration, carcasses were split down the midline and hot carcass weights were recorded. At 45 min post mortem, backfat thickness (between the third and fourth last ribs level) was measured using a real-time ultrasound instrument (Piglot 105; SFK Technology, Herlev, Denmark).

After chilling at 2°C for 24 h, one 2.54-cm-thick longissimus muscle (LM) was obtained between the 10th and 11th ribs. Subjective meat colour, marbling, and firmness scores were evaluated according to NPPC (1991) standard. Immediately after the subjective scores were determined, the lightness (L*), redness (a*), and yellowness (b*) values were measured at three locations on the surface of each sample using the Minolta CR-410 chromometer (Konica Minolta Sensing Inc., Osaka, Japan). Also, Chroma ($C^* = (a^* + b^* )^{1/2}$) and Hue angle...
Effects of expanded CWSBM- and CSBM-based diets and phase feeding programme on growth performance in growing-finishing pigs are shown in Table 3 and Table 4, respectively. In Exp. 1, feeding programmes on growth performance in growing-finishers were conducted using a digitizing area-line sensor (MT-10S; M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water:meat area was then calculated, giving a measure of WHC (a smaller ratio indicates increased WHC).

3.1. Growth performance

Effects of expanded corn–wheat–soybean meal (CWSBM)-diets and phase feeding programme on growth performance in growing-finishing pigs are shown in Table 3 and Table 4, respectively. In Exp. 1, expanded diets had no significant effects on either daily gain or daily feed intake throughout the experiment (P > .05). However, during 12–14 weeks and 1–14 weeks pigs offered the expanded diets had lower FCR compared with those in unexpanded diets (P < .05). No differences on daily gain, daily feed intake, and FCR were observed between three-phase feeding programme and two-phase feeding programme.

In Exp. 2, Feed intake was not affected by treatments throughout the experiment (P > .05). From 1 to 2, 3 to 8, 9 to 14, 1 to 17 weeks, expanded diets had no significant effects on daily gain and FCR (P > .05). However, from 15 to 17 weeks, pigs fed expanded diets had increased daily gain and decreased FCR compared with those fed unexpanded diets (P < .05). There was no significant difference on daily gain, daily feed intake and FCR between two-phase feeding programme and three-phase feeding programme throughout the experiment (P > .05).

3.2. Carcass characteristics and meat quality

In Exp. 1, as shown in Table 5, expanded diets or phase feeding programmes had no significant effects on carcass traits and meat quality (P > .05). However, in Exp. 2, the meat firmness in sensory evaluation was higher in pigs fed expanded diets than this in pigs fed unexpanded diets (Table 6; P < .05). No differences were observed on other meat quality measurements and carcass characteristics between the expanded and unexpanded dietary treatments (P > .05). Phase feeding programmes did not affect meat quality and carcass characteristics (P > .05).

4. Discussion

4.1. Effects of phase feeding programme

Meeting the rapidly changing nutrient requirements precisely is important to maximize potential growth of pigs and reduce

| Items                      | Two-phase feeding unexpanded diets | Two-phase feeding expanded diets | Three-phase feeding unexpanded diets | SEMb | P-value |
|----------------------------|-----------------------------------|----------------------------------|-------------------------------------|------|---------|
| Daily gain (g)             |                                   |                                  |                                     |      |         |
| 1–5 weeks                  | 666                               | 683                              | 683                                 | 10   | 0.395   |
| 6–11 weeks                 | 784                               | 799                              | 795                                 | 7    | 0.325   |
| 12–14 weeks                | 895                               | 904                              | 908                                 | 8    | 0.415   |
| 1–14 weeks                 | 765                               | 780                              | 779                                 | 6    | 0.192   |
| Daily feed intake (g)      |                                   |                                  |                                     |      |         |
| 1–5 weeks                  | 1529                              | 1550                             | 1530                                | 8    | 0.134   |
| 6–11 weeks                 | 2447                              | 2413                             | 2420                                | 19   | 0.613   |
| 12–14 weeks                | 2803                              | 2741                             | 2789                                | 25   | 0.371   |
| 1–14 weeks                 | 2086                              | 2065                             | 2072                                | 10   | 0.447   |
| Feed conversion ratio (g/g)|                                   |                                  |                                     |      |         |
| 1–5 weeks                  | 2.297                             | 2.269                            | 2.241                               | 0.034| 0.580   |
| 6–11 weeks                 | 3.122                             | 3.022                            | 3.046                               | 0.032| 0.112   |
| 12–14 weeks                | 3.133c                           | 3.031d                          | 3.072c,d                            | 0.030| 0.044   |
| 1–14 weeks                 | 2.726c                           | 2.647c,d                         | 2.660c,d                            | 0.023| 0.039   |

aDietary treatments were as follows: (1) unexpanded CWSBM-based diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (2) expanded CWSBM-based diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (3) unexpanded CWSBM-based diets with three-phase feeding programme (phase I, phase II, and phase III diets for 5, 6, and 3 weeks, respectively).

bStandard error of the mean.

c,dMeans in the same row with different superscripts differ (P ≤ .05).
It is recognized that phase feeding could meet the requirements in agreement with age and physiological condition of pigs (Jongbloed and Lenis 1992; Paik et al. 1996). In Exp. 1, compared with two-phase feeding programme, we fed pigs in three-phase feeding programme with increased nutrient density diet (phase I) during 1–5 weeks. In Exp. 2, in three-phase feeding programme, we provided reduced nutrient density (phase III) during 15–17 weeks. Data from both experiments showed that growth performance, carcass traits, and meat quality were not affected by phase feeding programmes indicating that the supply of nutrients from both three-phase feeding programme and two-phase feeding programme were sufficient to meet the genetic potential of pigs. In agreement with our results, Choi et al. (2010) who reported that three- or four-phase feeding programmes had no effect on growth performance, carcass characteristics and meat quality.

| Table 4. Effects of expanded corn–wheat–soybean meal (CSBM)-diets and feeding programme on growth performance in growing-finishing pigs (Exp. 2). |
|-----------------|-----------------|-----------------|-----------------|
|                  | Two-phase feeding unexpanded diets | Two-phase feeding expanded diets | Three-phase feeding unexpanded diets |
| Daily gain (g)   |                                |                                |                                |
| 1–2 weeks        | 648                            | 630                            | 641                            |
| 3–8 weeks        | 697                            | 708                            | 702                            |
| 9–14 weeks       | 787                            | 806                            | 785                            |
| 15–17 weeks      | 847d                           | 869e                           | 856e,c,d                       |
| 1–17 weeks       | 752                            | 763                            | 751                            |
| Daily feed intake (g) |                                |                                |                                |
| 1–2 weeks        | 1149                           | 1160                           | 1177                           |
| 3–8 weeks        | 1567                           | 1582                           | 1580                           |
| 9–14 weeks       | 2355                           | 2385                           | 2372                           |
| 15–17 weeks      | 2603                           | 2577                           | 2562                           |
| 1–17 weeks       | 1993                           | 2004                           | 1999                           |
| Feed conversion ratio (g/g) |                                |                                |                                |
| 1–2 weeks        | 1.773                          | 1.842                          | 1.837                          |
| 3–8 weeks        | 2.247                          | 2.236                          | 2.251                          |
| 9–14 weeks       | 2.990                          | 2.961                          | 3.020                          |
| 15–17 weeks      | 3.073d                         | 2.964e,d                       | 2.992c,d                       |
| 1–17 weeks       | 2.652                          | 2.625                          | 2.660                          |

Dietary treatments were as follows: (1) unexpanded CSBM-based diets with two-phase feeding programme (phase I and phase II diets for 8 and 9 weeks, respectively); (2) expanded CSBM-diets with two-phase feeding programme (phase I and phase II diets for 8 and 9 weeks, respectively); (3) unexpanded CSBM-diets with three-phase feeding programme (phase I, phase II, and phase III diets for 8, 6, and 3 weeks, respectively).

Standard error of the mean.

Means in the same row with different superscripts differ (P ≤ .05).

| Table 5. Effect of expanded corn–wheat–soybean meal (CWSBM)-diets and phase feeding programme on carcass traits and meat quality in growing-finishing pigs (Exp. 1). |
|-----------------|-----------------|-----------------|-----------------|
|                  | Two-phase feeding unexpanded diets | Two-phase feeding expanded diets | Three-phase feeding unexpanded diets |
| Meat colour      |                                |                                |                                |
| L*              | 58.85                         | 58.41                         | 58.29                         |
| a*              | 16.27                         | 16.41                         | 16.45                         |
| b*              | 6.42                          | 6.55                          | 6.60                          |
| Hue angle, H°   | 21.53                         | 21.75                         | 21.87                         |
| Chroma, C*      | 17.49                         | 17.68                         | 17.73                         |
| Sensory evaluation |                                |                                |                                |
| Colour          | 3.28                          | 3.31                          | 3.31                          |
| Firmness        | 2.59                          | 2.59                          | 2.63                          |
| Marbling        | 2.31                          | 2.31                          | 2.34                          |
| Cooking loss (%) | 33.95                         | 34.87                         | 33.91                         |
| Drip loss (%)   |                                |                                |                                |
| d1              | 7.78                          | 7.62                          | 7.61                          |
| d3              | 13.62                         | 13.40                         | 13.50                         |
| d5              | 18.57                         | 18.85                         | 18.78                         |
| d7              | 24.14                         | 23.81                         | 23.94                         |
| pH              | 5.43                          | 5.45                          | 5.48                          |
| Longissimus muscle area (cm²) | 57.40                         | 58.46                         | 58.28                         |
| Water holding capacity (%) | 53.25                         | 54.51                         | 54.39                         |
| Carcass weight (kg) | 90.9                          | 92.2                          | 91.5                          |
| Backfat thickness (mm) | 20.3                          | 21.3                          | 21.8                          |

Dietary treatments were as follows: (1) unexpanded diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (2) expanded diets with two-phase feeding programme (phase II and phase III diets for 5 and 9 weeks, respectively); (3) expanded diets with three-phase feeding programme (phase I, phase II, and phase III diets for 5, 6, and 3 weeks, respectively).

Standard error of the mean.

feed cost (Moore et al. 2013). It is recognized that phase feeding could meet the requirements in agreement with age and physiological condition of pigs (Jongbloed and Lenis 1992; Paik et al. 1996). In Exp. 1, compared with two-phase feeding programme, we fed pigs in three-phase feeding programme with increased nutrient density diet (phase I) during 1–5 weeks. In Exp. 2, in three-phase feeding programme, we provided reduced nutrient density (phase III) during 15–17 weeks. Data from both experiments showed that growth performance, carcass traits, and meat quality were not affected by phase feeding programmes indicating that the supply of nutrients from both three-phase feeding programme and two-phase feeding programme were sufficient to meet the genetic potential of pigs. In agreement with our results, Choi et al. (2010) who reported that three- or four-phase feeding programmes had no effect on growth performance, carcass characteristics and meat quality.
quality in growing-finishing pigs. Similarly, Hong et al. (2016) found that phase feeding with low energy and low protein diets showed no adverse effects on growth performance and carcass characteristics in growing-finishing pigs. In finishing pigs, Lee et al. (2000) reported that phase feeding programmes (one, two, three, or four) did not affect growth performance, nutrient digestibility, and carcass traits including carcass weight and backfat thickness. Hong et al. (2016) also reported that phase feeding (Subdivision of phase through dietary protein levels and metabolizable energy) had no influence on growth performance and carcass characteristics in growing-finishing pigs.

### 4.2. Effects of expanded diets

Expander processing has been initially designed to improve the quality of livestock diets (Van Zuilichem et al. 1997; O’Doherty et al. 2001). In Exp. 1, pigs fed expanded CWSBM-based diets had improved FCR than pigs offered unexpanded CWSBM-based diets during 12–14 and 1–14 weeks. In Exp. 2, expanded CSBM-based diets increased daily gain but decreased FCR compared with unexpanded CSBM-based diet. In agreement with our results, using CWSBM-based diets, Yang et al. (2001) reported that expanded diets improved FCR, whereas expanded diets had no effects on daily gain and daily feed intake. Park et al. (2003) also observed that expanded wheat–soybean meal-based diets improved the growth performance, as seen in the increased gain to feed ratio in finishing pigs. Millet et al. (2012) found that expanded diets reduced daily feed intake and FCR but had no effect on daily gain in weaning–finishing pigs fed barley–wheat–soybean meal-based diets. Expander processing treatment may improve the nutritional quality of diets by making more nutrients accessible to digestive enzymes (Vande Ginste and De Schrijver 1998). Although nutrient digestibility was not measured in the present study, Park et al. (2003), Laurinen et al. (1998), Callan et al. (2007), Yang et al. (2007), and Lundblad et al. (2012) reported that expander processing enhanced nutrient digestibility in pigs. Therefore, in the present study, the improvement in growth performance might be explained by increased nutrient digestibility. In contrast, O’Doherty and Keady (2001) and O’Doherty et al. (2001) found no difference in growth performance of growing and finishing pigs fed expanded or unexpanded diets. The reason for these differences could be attributed to age of the animal, diet composition and feed processing conditions.

In Exp. 1, carcass traits and meat quality were not influenced by expanded diets. Similarly, in Exp. 2, expanded diets had no effects on carcass characteristics and meat quality, with the exception of the increased meat firmness in sensory evaluation in pigs fed expanded diets. These agree with O’Doherty and Keady (2001), Yang et al. (2001), and Park et al. (2003), who reported that expanded diets had no effects on carcass traits and meat quality. Whereas, O’Doherty et al. (2001) found that expander processing decreased carcass weight but backfat thickness was unaffected by expander processing when pigs offered diets containing pollard, rapeseed meal, peas and copra meal. Additionally, Callan et al. (2007) observed that pigs fed expanded wheat–soybean meal-based diets had reduced backfat thickness compared with pigs offered the unexpanded diets but carcass weight was not influenced. The reasons for increased meat firmness observed in Exp. 2 are not apparent, which warrant further investigations.

In conclusion, our results demonstrated that expanded diets improved growth performance but had no effects on carcass traits and meat quality. Additionally, two- or three-phase
feeding programme had no effects on growth performance, carcass traits, and meat quality.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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