Translational Animal Science, 2023, **7**, txad051
https://doi.org/10.1093/tas/txad051
Advance access publication 16 May 2023
Housing and Management

The effect of timing of Improvest administration on growth performance and carcass characteristics in gilts

Manuel A. Vasquez-Hidalgo[†], Martha A. Mellencamp[‡], Deborah Amodie[‡], Lucina Galina Pantoja[‡], and Kimberly A. Vonnahme[‡,1]

[†]Department of Animal Sciences, North Dakota State University, Fargo, ND 58102, USA
[‡]Zoetis Inc., Parsippany, NJ 07054, USA
[1]Corresponding author: kimberly.vonnahme@zoetis.com

ABSTRACT

Improvest (**IMP**; Zoetis Inc., Parsippany, NJ) has been approved by the U.S. Food and Drug Administration for use in gilts. Improvest is administered twice: the first dose should be administered no earlier than 9 wk of age and the second dose (D2) at least 4 wk after the first dose. The aim of this study was to determine how the timing of IMP before harvest affects growth performance and carcass characteristics in gilts. A total of 1,632 gilts were allocated to four groups (12 pens/treatment; 34 gilts/pen): 1) a control group did not receive IMP; 2) T-early gilts received IMP on day 7 (day 0 = 10 wk postweaning), and D2 on day 40 (i.e., 35 d prior to first removal for harvest); 3) T-medium gilts received IMP on day 21 and D2 on day 56 (i.e., 19 d prior to first removal for harvest); 4) T-late gilts received IMP on day 35 and D2 on day 70 (i.e., 5 d before first removal for harvest). Pigs were selected for harvest by visual observation on days 75, 89, 103, and 117: 1) the heaviest 7 gilts/pen for each treatment on day 75; 2) the heaviest 10 gilts/pen of each treatment at day 89; 3) the heaviest 10 gilts/pen of each treatment on day 103; and 4) the remaining 7 gilts/pen on day 117. Weights and feed disappearance were recorded every 2 wk and during harvest dates to calculate average daily gain (**ADG**), average daily feed intake (**ADFI**), and feed efficiency (Gain:Feed; G:F). Generalized linear mixed models of SAS were used to analyze all variables. The increase in ADFI over Control gilts was observed 15 d post D2 and continued through 77 d post D2, with advantages in ADG occurring between 15 and 35 d post D2. Control and IMP treated gilts had similar G:F 15 to 33 d post D2. The overall ADG and ADFI from day 0 to market, final live weights, and hot carcass weights were significantly greater ($P \leq 0.05$) in IMP gilts compared to Control. When G:F based on live weight was averaged across all groups (i.e., from day 0 to market), T-early had the lowest ($P \leq 0.05$) G:F compared to Control, T-medium, and T-late gilts, which did not differ. Carcasses from IMP gilts had increased ($P < 0.01$) backfat, but similar ($P = 0.5$) Longissimus muscle depth, compared to Control. Within a cohort of similar aged gilts finishing during the summer, this study indicates that the trajectory of growth is enhanced within a similar window post D2 of IMP. Gilts treated with IMP had heavier carcasses with increased backfat and similar Longissimus muscle depth.

Key words: carcass characteristics, gilts, gonadotropin-releasing factor antagonist, growth performance, immunization timing, Improvest

INTRODUCTION

Improvest (**IMP**; Zoetis Inc., Parsippany, NJ), a gonadotropin releasing factor (**GnRF**) antagonist, was initially developed as an immunological alternative to physical castration of male pigs (i.e., for the control of boar taint while overcoming the disadvantages of physical castration; Bradford and Mellencamp, 2013). More recently, studies have also investigated the effects of IMP in female pigs in North America. The induced suppression of estrus, via the suppression of ovarian activity, during late finishing phase can avoid the associated reduction in feed intake by sexually maturing gilts (Latorre et al., 2013; Bohrer et al., 2014; Rodrigues et al., 2019). A meta-analysis verified that gilts immunized against GnRF have a greater average daily feed intake (**ADFI**) and average daily gain (**ADG**), greater final live weight, and more backfat while being less lean compared to their untreated counterparts (Poulsen Nautrup et al., 2020).

In both sexes, IMP is administered twice to be effective (Bohrer et al., 2014; Scheid et al., 2014). The first dose, which should not be administered before 9 wk of age, primes the immune system but does not create physiological changes (Scheid et al., 2014; Oliviero et al., 2016; Lugar et al., 2017). The second dose (D2) of IMP creates an effective immune response and should be administered at least 4 wk after the first dose. While the timing of D2 to harvest has been delineated for males (McCauley et al., 2003; Oliver et al., 2003; Kowalski et al., 2021), there is limited information on the optimal timing of D2 to harvest for growth in the gilt. However, it has been shown that after D2, gilts experience increased ADG, increased ADFI, variability in feed efficiency (i.e., no change, increased, or decreased feed efficiency), increased live weight, and increased backfat (Oliver et al., 2003; Bohrer et al., 2014; Daza et al., 2014; Van den Broeke et al., 2016; Rodrigues et al., 2019; Poulsen Nautrup et al., 2020). In the studies included in a meta-analysis, D2 was between 4 and 10 wk prior to harvest in gilts raised in production settings and meta-regression revealed a decreasing difference in ADG, ADFI, and feed conversion ratio (Gain:Feed; G:F) between immunized and untreated gilts with an increasing time between D2 and harvest (Poulsen Nautrup et al., 2020). Recently, Allison et al. (2021) reported that in a finishing facility in Brazil, gilts administered the second dose of Improvest 4, 6, or 8 wk prior to harvest, had increased ADFI for Improvest treated gilts 6 and 8 wk prior to harvest compared to control and gilts administered

Received February 7, 2023 Accepted May 15, 2023.

IMP 4 wk prior to harvest. All IMP-treated gilts were reported to have an increased ADG compared to control gilts (Allison et al., 2021). Feed efficiency was similar in control gilts and gilts administered D2 of IMP 4 and 8 wk prior to harvest, with gilts administered D2 of IMP 6 wk prior to harvest being less efficient compared to control and 4 wk gilts. It is important to understand how these findings would be translated to US based market gilts.

The objective of the current study was to evaluate the impact of the interval between D2 and harvest on growth performance, feed efficiency, and carcass characteristics in gilts administered IMP at three time points prior to harvest and to gilts that did not receive IMP. We hypothesized that there was an optimal timing when IMP would be administered relative to harvest where an increase in ADFI and ADG would be optimal without having detrimental impacts on feed efficiency.

MATERIALS AND METHODS

The study was conducted at a commercial wean-to-finish swine facility in the Midwest of the US. The experimental protocol was reviewed and approved by the Zoetis Ethical Review Board. The study was conducted between April and August 2021.

Animals, housing, and experimental groups

A total of 1,632 gilts were used in this study which were similar in genetics as they were progeny from a single Duroc-based sire line and crossbred dams. The pigs were negative for porcine epidemic diarrhea virus and *Mycoplasma hyopneumoniae* and tested positive for porcine delta coronavirus. The swine influenza virus status was unknown but assumed positive. All pigs were vaccinated against porcine reproductive and respiratory syndrome virus, porcine circovirus and *M. hyopneumoniae*, ileitis, and erysipelas.

The start of the study was 10 wk after weaning (weaning occurred at ~21 d of age) and was considered the beginning of the finisher phase (day 0; Table 1). The following allotment procedure was used to create replicates of four pens for four treatment groups: pens from a nursery with 72 gilts per pen, weaned on the same day, were used as source pens for this study. The allotment started with the first two source pens. From each of the two source pens, the heaviest 8 gilts and the lightest 8 gilts were visually identified and marked with a unique paint color. From each pen, two replicate pens were formed, each containing 4 heavy, 4 light, and 26 unmarked gilts (i.e., 2 pens × 34 gilts). In case of weight differences between the pens, unmarked gilts were exchanged to achieve a similar mean live weight. All source pens were adjusted so each pen contained 34 gilts. The procedure was repeated with the next source pens until 48 pens (12 × 4 replicate pens) were created. In total, 48 pens with 34 pigs per pen were placed in four rooms (i.e., 3 pens/treatment/room for a total of 12 pens per treatment). Each pen was equipped with one feeder and one (2 rooms) or two (2 rooms) drinkers. Over the course of study, four different finishing diets were fed (Table 2), accounting for the different requirements with increasing live weight. The same diet was fed to all four treatment groups and met or exceeded the nutrient requirements of swine (National Research Council, 2012).

The four similar replicate pens were then allotted randomly to one of four treatment groups, including a control

Table 1. Experimental timeline and key events that took place during the project

Day of study	Date	Weeks post weaning	Event	Days from Dose 2 (D2) of Improvest to market		
				T-early	T-medium	T-late
0	4/23/2021	10	Pen weight and feed disappearance recorded			
7	4/30/2021	11	Improvest (IMP) dose 1 (D1) administered to T-early[1]			
14	5/7/2021	12	Pen weight and feed disappearance recorded			
21	5/14/2021	13	IMP D1 administered to T-medium[1]			
27	5/20/2021	13.9	Pen weight and feed disappearance recorded			
35	5/28/2021	15	IMP D1 administered to T-late[1]			
40	6/2/2021	15.7	IMP D2 administered to T-early; Pen weight and feed disappearance recorded			
55	6/17/2021	17.9	Pen weight and feed disappearance recorded			
56	6/18/2021	18	IMP D2 administered to T-medium			
66	6/28/2021	19.4	Pen weight and feed disappearance recorded			
70	7/2/2021	20	IMP D2 to administered T-late			
75	7/7/2021	20.7	Harvest group 1	35	19	5
89	7/21/2021	22.7	Harvest group 2	49	33	19
103	8/4/2021	24.7	Harvest group 3	63	47	33
117	8/18/2021	26.7	Harvest group 4	77	61	47

[1]Duration between first and second Improvest doses were 33 d (T-early) and 35 d (T-medium and T-late).

Table 2. Ingredient composition and calculated nutrient content of finishing diets fed to all treatment groups (as fed-basis)[1]

	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Corn, fine	62.56	67.66	72.35	75.98
Corn germ meal	19.00	16.06	13.35	11.26
Soybean meal	15.16	13.29	11.56	10.23
Limestone	1.16	1.10	1.05	1.01
Monocalcium phosphate (21% P)	0.51	0.42	0.34	0.28
Salt	0.45	0.47	0.49	0.50
Lysine dry (98%)	0.42	0.35	0.28	0.23
Fat, yellow grease	0.35	0.35	0.35	0.35
Alimet (88%)	0.14	0.10	0.06	0.03
Threonine (98%)	0.09	0.07	0.05	0.03
Trace mineral premix	0.08	0.06	0.04	0.03
Vitamin premix	0.03	0.02	0.02	0.01
Copper chloride (54%)	0.03	0.03	0.03	0.03
Phytase	0.02	0.02	0.02	0.02
Skycis 100	0.02	0.01	0.02	0.02
Calculated analysis, unit				
Metabolizable energy, kcal/kg	3219.3	3254.6	3285.5	3311.9
Crude protein, %	16.38	15.14	13.99	13.11
Crude fat, %	3.09	3.17	3.24	3.29
Crude fiber, %	3.04	2.82	2.62	2.46
ADF, %	4.49	4.10	3.74	3.46
NDF, %	12.16	11.25	10.40	9.75
Ash, %	3.63	3.37	3.13	2.95
Moisture, %	12.65	12.74	12.83	12.89
Phosphorus, total, %	0.50	0.46	0.43	0.40
Phosphorus, available, %	0.25	0.22	0.20	0.18
Calcium, total, %	0.60	0.56	0.51	0.48
Sodium, %	0.20	0.21	0.21	0.22
Chloride, %	0.40	0.40	0.39	0.39
Magnesium, %	0.18	0.17	0.17	0.16
Potassium, %	0.61	0.57	0.54	0.51
Copper, mg/kg	170.20	167.01	164.08	161.82
Iodine, mg/kg	0.22	0.17	0.13	0.09
Iron, mg/kg	228.28	192.04	158.66	132.91
Manganese, mg/kg	42.96	35.32	28.29	22.86
SE, added, mg/kg	0.22	0.17	0.13	0.09
Zinc, mg/kg	157.95	127.85	100.11	78.72
Lysine, Total, %	1.08	0.95	0.83	0.75
Lysine, SID, %	0.94	0.82	0.72	0.64
Isoleucine, total, %	0.61	0.56	0.52	0.49
Isoleucine, SID, %	0.52	0.47	0.44	0.41
Leucine, total, %	1.41	1.34	1.27	1.22
Leucine, SID, %	1.20	1.14	1.09	1.05
Met + Cys, total, %	0.63	0.56	0.50	0.46
Met + Cys, SID, %	0.54	0.47	0.42	0.38
Threonine, total, %	0.69	0.62	0.56	0.51
Threonine, SID, %	0.56	0.50	0.45	0.41
Tryptophan, total, %	0.18	0.16	0.15	0.14
Tryptophan, SID, %	0.15	0.14	0.13	0.12
Valine, total, %	0.76	0.71	0.66	0.62
Valine, SID, %	0.63	0.58	0.54	0.50

[1]Phase 1 was fed from ~45 to 59 kg body weight; phase 2 was fed from 59 to 81 kg body weight; phase 3 was fed from 81 to 95 kg body weight; phase 4 was fed from 95 kg to market.

group (no IMP) and three groups of pigs which received IMP at different time points: gilts in the early treatment group (T-early) received two, 2-mL IMP (0.4 mg gonadotropin releasing factor analog-diphtheria toxoid conjugate/2 mL) injections on days 7 and 40 which was 35 d prior to the first removal of pigs for harvest (day 75; Table 1). The pigs in the medium and late treatment groups (T-medium and T-late) received their first dose of IMP on days 21 and 35, respectively. The second doses were administered 35 d after their initial dose (i.e., days 56 and 70). The first marketing event corresponded to 19 and 5 d after D2 for T-medium and T-late, respectively.

At days 75, 89, 103, and 117, an equivalent number of pigs per pen were selected visually for harvest based on the greatest body weight estimates (day 75 = 7 pigs/pen; day 89 = 10 pigs/pen; day 103 = 10 pig/pen; day 117 = 7 pigs/pen). Pigs were individually tattooed to allow for pen identification. Pigs were shipped (243 km) to a USDA inspected commercial harvest facility that uses carbon dioxide stunning. Pigs were off feed for approximately 8 h before harvest. Individual weights were recorded and carcass traits were measured immediately after slaughter. The collection of carcass composition data was taken at the same time the hot carcass weights were recorded. Carcass composition was determined using Fat-O-Meater (SFK Technology A/S, Herlev, Denmark) readings at the 10th rib for backfat depth and Longissimus muscle depth, and thereafter the predicted carcass lean was calculated from a proprietary equation provided by the harvest facility.

Data collection

The experimental unit was the pen. Pen body weights and feed disappearance (i.e., a volumetric measurement of feed remaining in the feed at the time of collection of pen weights was taken using a calibrated measuring stick) were collected at days 0, 14, 27, 40, 55, 66, and just prior to each harvest time (i.e., days 75, 89, 103, and 107). The weight of the pigs that were marketed was also weighed. The measurements allowed for the calculation of ADG, ADFI, and gain to feed ratio (G:F). Additionally, the following overall results were calculated: overall final body weight was the average of all final live weights at each harvest time, and live ADG, live ADFI, and live G:F were calculated over the entire study period (days 0 to 117). Average daily gain and G:F were also expressed in relation to the carcass weight by multiplying the live ADG by carcass yield (i.e., to assume carcass ADG), and dividing the carcass ADG by overall ADFI for carcass G:F. As mentioned above, carcass traits (i.e., hot carcass weight, carcass yield, backfat depth and Longissimus muscle depth, and percentage lean) were evaluated separately for each harvest group and averaged across all harvest times for an overall value. Additionally, the occurrences and causes of morbidity and mortality were recorded for each treatment group.

Statistical analyses

Variables that were measured or calculated on a pen basis at different time points such as weight, ADG, ADFI, and G:F were analyzed by a linear mixed model approach for repeated measures. Using the SAS Proc Mixed procedure (SAS 9.4, Cary, NC) these variables were analyzed with a model that considered the fixed effect of treatment, day, and the interaction of treatment × day as well as the random effects of room, block-within-room and the residual error. The day was the repeated factor.

The covariance structure in the repeated measures analysis was investigated using several structural assumptions, namely, compound symmetry, Power, first order autoregressive, heterogeneous first order autoregressive, and unstructured. The assumption which gave the minimum value of the Akaike's Information Criterion was selected in the final analysis.

Treatment least squares means (**LSMeans**) were calculated and compared for each group, regardless of the overall treatment effect. Comparison of treatment LSMeans were performed by the two-sided *t*-test at the 5% level of significance. Comparisons for treatment × day LSMeans were also performed, even if there was no overall significant difference observed for this interaction.

Variables that were measured or calculated on a pen basis at a single time point such as initial weight, harvest group weights, carcass measurements, etc. were analyzed with a model that considered the fixed effect of treatment as well as the random effects of room, block-within-room and the residual error. Least square means for each treatment group were computed and compared by the two-sided *t*-test at the 5% level, even if there was no significant overall treatment effect.

Carcass variables that were recorded on a per animal basis were used with a model that considered the fixed effect of treatment and the random effects of room, block-within-room, treatment × block-within-room (which is the pen) and the residual error. Least square means were calculated and compared as mentioned previously.

All variables expressed as a percentage were transformed by the arcsine (square-root) transformation to stabilize the variance and normalize the data. Least square means from these data were back-transformed and presented as geometric means. A *P*-value of ≤0.05 was used in all tests of statistical significance. All treatments were compared to each other. Mortality and morbidity were summarized.

RESULTS

Growth performance parameters

Starting body weights were similar ($P = 0.379$) between treatment groups (Table 3). Body weight increased in all treatment groups between days 0 and 66, and while the interaction reached significance (i.e., $P = 0.050$), upon LSMeans separation, no differences ($P \geq 0.097$) were found between treatments during any of these days. On day 75 (after the first removal of gilts for harvest) body weight was greater ($P \leq 0.001$) in treatment groups T-early and T-medium (i.e., 35 and 19 d post D2) compared to T-late (5 d post D2) and control, which did not differ ($P = 0.443$). On day 89, Control gilts were lighter ($P \leq 0.002$) than all IMP treated gilts. While weights were similar ($P = 0.850$) between T-early (i.e., 49 d post D2) and T-medium (i.e., 33 d post D2) gilts, both were heavier ($P \leq 0.03$) than T-late gilts (19 d post D2). On days 103 and 117, Control gilts were lighter ($P < 0.001$) than IMP treated gilts, with no differences in weights among the IMP treatments ($P \geq 0.14$), with a tendency for T-early gilts to be lighter ($P = 0.066$) than T-late gilts on day 117.

There were no differences in ADG until days 27 to 40 (Table 3), where Control gilts had an increased ($P = 0.034$) ADG compared to T-late, but were similar ($P \geq 0.084$) to the other IMP groups. Average daily gain across IMP groups was similar ($P \geq 0.072$) from days 27 to 40. After the D2 of IMP

was administered to the T-early gilts (i.e., day 40), ADG from days 40 to 55 was increased ($P \leq 0.001$) in T-early vs. all other groups, which did not differ ($P \geq 0.534$). From days 55 to 66, T-early had an increased ($P = 0.048$) ADG vs. Control gilts, with T-medium and T-late being intermediate ($P \geq 0.123$) (i.e., D2 for T-medium was on day 56; D2 for T-late was on day 70). The ADG for days 66 to 75 was greatest ($P \leq 0.007$) in T-medium gilts, followed by T-early gilts which were greater ($P \leq 0.001$) than Control and T-late gilts, which did not differ ($P = 0.133$; i.e., T-late was administered D2 on day 70). From days 75 to 89, ADG was lowest ($P \leq 0.001$) in Control gilts, with T-medium having a greater ($P = 0.043$) ADG compared to T-early, with T-late being similar ($P \geq 0.120$) to both T-early and T-medium (i.e., days from D2 to day 89: T-early: 49 d; T-medium: 33 d; T-late: 19 d). Average daily gain from days 103 to 117 was similar ($P \geq 0.118$) among Control, T-early, and T-medium, which were all less ($P \leq 0.033$) than the ADG from T-late (i.e., T-early and T-medium were 77 and 61 d post D2, respectively).

When the overall ADG was calculated for live weight and carcass weight, IMP treatment groups were similar ($P \geq 0.155$) and significantly ($P < 0.001$) greater than control. For the ADG based on live weight were calculated between +50 g/d and +60 g/d, whereas the differences based on carcass weight, differences versus control were between +20 g/d and +30 g/d.

There were no differences in treatment groups for ADFI from days 0 to 14 or days 14 to 27. From days 27 to 40, Control gilts had an increased ($P = 0.033$) ADFI compared to T-late, with T-early and T-medium being intermediate. While there were no differences ($P \geq 0.163$) in ADFI among control, T-medium, and T-late gilts from days 40 to 55 and days 55 to 66, T-early had greater ($P \leq 0.018$) intake compared to all groups (i.e., D2 of T-early occurred on day 40). From days 66 to 75, T-early and T-medium were similar ($P = 0.121$) in their intake, and greater ($P < 0.001$) than all other groups. The ADFI of T-late was greater ($P = 0.009$) than Control pigs; (i.e., D2 for T-medium was on day 56; T-late on day 70). From days 75 to 89, T-medium had the greatest ($P \leq 0.03$) ADFI, followed by T-early and T-late which did not differ ($P = 0.332$), with Control being the lowest. By the third harvest group (i.e., days 89 to 103), T-medium and T-late (which were 47 and 33 d post D2, respectively) had the greatest ($P \leq 0.035$) ADFI, followed by T-early (i.e., 63 d post D2), then Control gilts. From days 103 to 117, T-late had the greatest ($P \leq 0.05$) ADFI, followed by T-early and T-medium, which did not differ ($P = 0.109$), followed by control. Overall ADFI, calculated from day 0 to market was greatest in T-early, followed by T-late, with T-medium being intermediate, and control having the lowest ADFI throughout the experiment.

Gain:feed was similar until days 40 to 55 (Table 3). T-early gilts had an increased ($P \leq 0.017$) G:F ratio compared to all other treatments, which did not differ ($P \geq 0.411$). From days 66 to 75, G:F was greatest ($P \leq 0.046$) in T-medium (i.e., 19 d post D2), followed by Control, then T-early (i.e., 35 d post D2), with T-late (i.e., 5 d post D2) being similar to Control ($P = 0.534$) and T-early ($P = 0.062$) gilts. The G:F ratio was similar ($P = 0.123$) between groups between days 75 and 89 and days 89 to 103 (Table 3). The G:F ratio between days 103 and 117 was greatest ($P \leq 0.028$) in Control gilts, compared to IMP gilts, which did not differ ($P \geq 0.235$). Overall, when the G:F ratio was calculated using live weight gain, T-early had a lower ($P \leq 0.013$) G:F compared to all other groups, which did not differ ($P \geq 0.314$). When G:F was calculated on a carcass weight basis, Control and T-late gilts were similar ($P = 0.067$) in feed efficiency, with Control gilts being greater ($P \leq 0.040$) than T-early and T-medium gilts. T-late gilts had a greater ($P = 0.036$) G:F than T-early with T-medium being intermediate ($P \geq 0.060$).

Carcass characteristics

The live weights for gilts sold at each harvest day were in Table 4. There were no differences ($P \geq 0.091$) in live weights for the heaviest seven gilts per pen on day 75 (i.e., days post D2 for T-early, T-medium, and T-late were 35, 19, and 5, respectively). On days 89, 103, and 107, all IMP treated gilts were heavier ($P \leq 0.004$) than the Control gilts but were similar ($P \geq 0.066$) to each other. Therefore, the overall live weight at harvest was greater in IMP treated gilts compared to Control.

Hot carcass weights were similar ($P \geq 0.354$) on day 75. On day 89, T-early (i.e., 49 d post D2) gilts were heavier ($P < 0.001$) than Control gilts, similar ($P = 0.482$) to T-medium (i.e., 33 d post D2), and similar ($P = 0.063$) to T-late (i.e., 19 d post D2) gilts. T-medium gilts were heavier ($P = 0.005$) than Control gilts and similar ($P = 0.234$) to T-late gilts with T-late and Control gilts being similar ($P = 0.080$) in weight. At the third harvesting time point (i.e., day 103), all IMP gilts were heavier ($P \leq 0.002$) than Control gilts, while being similar ($P \geq 0.179$) to each other. Likewise on day 117, all IMP gilts were heavier ($P \leq 0.015$) than Control gilts, while being similar ($P \geq 0.154$) to each other. When the average of all four harvest groups was calculated, all IMP gilts were heavier ($P < 0.001$) than Control gilts, while being similar ($P \geq 0.412$) to each other.

When carcass yields were calculated on day 75, Control gilts were similar ($P = 0.504$) to T-late (i.e., 5 d post D2) gilts, but greater ($P \leq 0.20$) than T-early (i.e., 35 d post D2) and T-medium (i.e., 19 d post D2), which did not differ ($P = 0.160$). Moreover, T-late gilts had a greater ($P = 0.003$) carcass yield compared to T-medium gilts but were similar (P = 0.084) to T-early gilts. By the second harvest date, Control gilts had a carcass yield greater ($P \leq 0.053$) than T-early (i.e., 49 d post D2), T-medium (i.e., 33 d post D2), and T-late (i.e., 19 d post D2). All IMP treatments were similar ($P = 0.099$) on day 89. On day 103, carcass yield was similar ($P = 0.825$) between Control and T-early gilts which both were greater ($P \leq 0.048$) than T-medium and T-late which did not differ ($P = 0.469$). By day 117, carcass yield was similar ($P \geq 0.519$) among Control, T-early (i.e., 77 d post D2), and T-medium (i.e., 61 d post D2), and all were greater ($P \leq 0.014$) than T-late (i.e., 47 d post D2). Overall, carcass yields were greatest ($P \leq 0.031$) in Control gilts, followed by T-early gilts which were greater ($P = 0.033$) than T-late gilts with T-medium gilts having carcass yields similar ($P \geq 0.060$) to T-early and T-late gilts.

On day 75, T-early gilts had the greatest ($P \leq 0.033$) backfat, with all other groups being similar ($P \geq 0.235$). By day 89, T-early gilts (i.e., 49 d post D2) had greater ($P \leq 0.002$) backfat than T-medium gilts (i.e., 33 d post D2), and T-late (i.e., 19 d post D2) and Control gilts which did not differ ($P = 0.135$). T-medium gilts had greater ($P \leq 0.013$) backfat than T-late and Control gilts. By the third harvest group, T-early and T-medium gilts had similar ($P = 0.533$) backfat, which was greater ($P \leq 0.010$) than T-late and Control gilts. T-late gilts had greater ($P = 0.002$) backfat than Control gilts on

Table 3. The effect of harvest time after second Improvest dose on growth performance of gilts

	Treatment[1]				SEM	*P*-value	
	Control (n = 12)	T-early (n = 12)	T-medium (n = 12)	T-late (n = 12)		Treatment × day interaction	Treatment groups
Body weight, kg							
Day 0	43.5	43.5	43.4	43.5	1.43	0.050	0.379
Day 14	55.1	54.8	55.1	54.8	1.50		
Day 27	66.5	66.5	66.8	66.5	1.53		
Day 40	78.8	78.4	79.0	78.3	1.56		
Day 55	92.0	93.1	91.9	91.5	1.65		
Day 66	101.3	103.3	101.8	101.5	1.65		
Day 75[2]	110.4[b]	113.7[a]	112.9[a]	110.9[b]	2.24		<0.001
Day 89[3]	121.0[c]	126.3[a]	126.3[a]	124.1[b]	2.46		<0.001
Day 103[4]	129.6[b]	135.8[a]	136.4[a]	136.0[a]	2.72		<0.001
Day 117[5]	131.7[b]	138.1[a]	141.4[a]	142.2[a]	2.73		<0.001
Average daily gain, kg/d							
Days 0 to 14	0.81	0.79	0.82	0.79	0.03	0.018	
Days 14 to 27	0.89	0.91	0.91	0.90	0.03		
Days 27 to 40	0.97[a]	0.93[ab]	0.96[ab]	0.92[b]	0.03		
Days 40 to 55	0.93[b]	1.03[a]	0.90[b]	0.92[b]	0.03		
Days 55 to 66	0.79[b]	0.86[a]	0.85[ab]	0.85[ab]	0.04		
Days 66 to 75[2]	0.87[c]	1.01[b]	1.09[a]	0.91[c]	0.05		<0.001
Days 75 to 89[3]	0.98[c]	1.10[b]	1.17[a]	1.15[ab]	0.03		<0.001
Days 89 to 103[4]	0.95[c]	1.01[bc]	1.08[b]	1.20[a]	0.03		<0.001
Days 103 to 117[5]	0.83[b]	0.86[b]	0.94[b]	1.08[a]	0.05		0.002
Start to end (live)	0.88[b]	0.93[a]	0.94[a]	0.93[a]	0.01		<0.001
Start to end (carcass)	0.66[b]	0.69[a]	0.69[a]	0.68[a]	0.01		<0.001
Average daily feed intake, kg/d							
Days 0 to 14	1.95	1.92	1.95	1.92	0.08	<0.001	
Days 14 to 27	2.18	2.19	2.17	2.18	0.08		
Days 27 to 40	2.42[a]	2.39[ab]	2.39[ab]	2.36[b]	0.08		
Days 40 to 55	2.44[b]	2.57[a]	2.35[b]	2.39[b]	0.09		
Days 55 to 66	2.44[b]	2.83[a]	2.51[b]	2.53[b]	0.09		
Days 66 to 75[2]	2.57[c]	3.15[a]	3.06[a]	2.74[b]	0.06		<0.001
Days 75 to 89[3]	2.69[c]	3.23[b]	3.35[a]	3.18[b]	0.05		<0.001
Days 89 to 103[4]	2.72[c]	3.17[b]	3.44[a]	3.47[a]	0.16		<0.001
Days 103 to 117[5]	2.55[c]	2.91[b]	3.19[b]	3.55[a]	0.15		< 0.001
Start to end	2.37[c]	2.59[a]	2.55[ab]	2.52[b]	0.05		< 0.001
Gain:feed ratio, kg:kg							
Days 0 to 14	0.420	0.417	0.425	0.419	0.007	0.007	
Days 14 to 27	0.414	0.422	0.426	0.418	0.008		
Days 27 to 40	0.404	0.394	0.406	0.396	0.008		
Days 40 to 55	0.383[b]	0.406[a]	0.387[b]	0.389[b]	0.006		
Days 55 to 66	0.325[ab]	0.306[b]	0.340[a]	0.337[a]	0.008		
Days 66 to 75[2]	0.329[b]	0.310[c]	0.345[a]	0.324[bc]	0.015		< 0.001
Days 75 to 89[3]	0.359	0.336	0.345	0.360	0.010		0.123
Days 89 to 103[4]	0.353	0.329	0.316	0.351	0.019		0.123
Days 103 to 117[5]	0.324[a]	0.295[b]	0.290[b]	0.302[b]	0.009		0.007
Start to end (live)	0.375[a]	0.363[b]	0.371[a]	0.373[a]	0.004		0.006
Start to end (carcass)	0.279[a]	0.269[c]	0.273[bc]	0.274[ab]	0.003		0.003

[1]Control = no Improvest (IMP); T-early = pigs administered 2 mL IMP on days 7 and 40; T-medium = pigs administered 2 mL IMP on days 21 and 56; T-late = pigs administered 2 mL IMP on days 35 and 70.
[2]Remaining weight after the removal of harvest group 1 (i.e., heaviest 7 gilts per visual observation); these data were not included in the repeated measures analysis. *P* value is for this day only.
[3]Remaining weight after the removal of harvest group 2 (i.e., heaviest 10 gilts per visual observation); these data were not included in the repeated measures analysis. *P* value is for this day only.
[4]Remaining weight after the removal of harvest group 3 (i.e., heaviest 10 gilts per visual observation); these data were not included in the repeated measures analysis. *P* value is for this day only.
[5]Remaining gilts for harvest group 4 (i.e., 7 gilts), body weight on day 117 corresponds to the weight of harvest group 4; these data were not included in the repeated measures analysis. *P* value is for this day only.
[*]Treatment × day interaction for data included in the repeated measures analysis. Main effects *P* values were as follows: body weight: Trt: $P = 0.832$; day: $P < 0.001$; ADG: Trt: $P = 0.001$; day: $P < 0.001$; ADFI: Trt: $P < 0.001$; day: $P < 0.001$; Gain:Feed: Trt: $P = 0.088$; day: $P < 0.001$.
[abc]LSMeans ± SEM within a row with different superscripts differ, $P \leq 0.05$.

day 103. By day 117, all IMP treated gilts had similar ($P \geq 0.142$) backfat and were greater ($P < 0.001$) than Control gilts. This resulted in gilts with the greatest duration (i.e., T-early > T-medium > T-late > Control; $P < 0.001$) post D2 having greater ($P < 0.001$) overall backfat (Table 4).

There were no differences ($P > 0.16$) on any harvest day of treatment on Longissimus muscle depth (Table 4). Therefore, when percentage lean was calculated based on backfat and Longissimus muscle depth, there were differences at each harvest date as was reflected in the backfat data. On day 75, T-early gilts (i.e., 35 d post D2) had the least ($P \leq 0.047$) percentage lean compared to all other groups, which did not differ ($P \geq 0.151$). On day 89, T-early (i.e., 49 d post D2) had a lower ($P \leq 0.013$) percentage lean than all groups, and T-medium (i.e., 33 d post D2) and T-late (i.e., 19 d post D2), while similar ($P = 0.3826$), were both less ($P \leq 0.020$) lean than Control gilts. By day 103, Control gilts were leaner ($P \leq 0.004$) than all IMP treated gilts. T-late gilts (i.e., 33

Table 4. The effect of harvest time after second Improvest dose on carcass characteristics in gilts

Harvest time after second Improvest dose	Treatment[1]				SEM	*P*-value
	Control ($n = 12$)	T-early ($n = 12$)	T-medium ($n = 12$)	T-late ($n = 12$)		
Harvest live weight, kg						
Day[2] 75	123.6	126.6	126.5	124.5	2.59	0.245
Day 89	129.5^{b}	134.8^{a}	134.7^{a}	133.0^{a}	2.35	<0.001
Day 103	135.7^{b}	141.8^{a}	141.6^{a}	141.7^{a}	2.82	<0.001
Day 117	131.7^{b}	138.1^{a}	141.4^{a}	142.2^{a}	2.73	<0.001
Overall[3]	130.3^{b}	135.5^{a}	136.2^{a}	135.5^{a}	2.44	<0.001
Hot carcass weight, kg						
Day[2] 75	92.9	94.2	93.5	93.3	2.3	0.822
Day 89	96.9^{b}	100.2^{a}	99.6^{a}	98.5^{ab}	2.1	0.004
Day 103	100.9^{b}	105.4^{a}	104.4^{a}	104.1^{a}	2.4	<0.001
Day 117	97.4^{b}	101.8^{a}	104.4^{a}	103.3^{a}	2.2	0.002
Overall[2]	97.2^{b}	100.6^{a}	100.6^{a}	100.0^{a}	2.1	<0.001
Carcass[4] yield, %						
Day[2] 75	75.01^{a}	74.20^{bc}	73.73^{c}	74.79^{ab}	0.403	0.002
Day 89	74.53^{a}	74.04^{b}	73.62^{b}	73.74^{b}	0.384	0.004
Day 103	74.22^{a}	74.15^{a}	73.52^{b}	73.29^{b}	0.310	0.010
Day 117	73.98^{a}	73.71^{a}	73.83^{a}	72.66^{b}	0.314	0.011
Overall[3]	74.51^{a}	74.11^{b}	73.75^{bc}	73.70^{c}	0.291	<0.001
Backfat depth, cm						
Day[2] 75	2.01^{b}	2.13^{a}	1.93^{b}	1.93^{b}	0.09	0.006
Day 89	1.98^{c}	2.39^{a}	2.21^{b}	2.08^{c}	0.06	<0.001
Day 103	2.06^{c}	2.46^{a}	2.41^{a}	2.26^{b}	0.05	<0.001
Day 117	1.85^{b}	2.26^{a}	2.34^{a}	2.31^{a}	0.04	<0.001
Overall[3]	1.98^{d}	2.31^{a}	2.24^{b}	2.13^{c}	0.05	<0.001
Longissimus muscle depth, cm						
Day[2] 75	6.83	6.86	6.93	6.86	0.08	0.584
Day 89	7.01	7.04	7.09	6.91	0.06	0.169
Day 103	6.96	7.04	6.93	7.06	0.08	0.285
Day 117	6.73	6.71	6.68	6.55	0.07	0.315
Overall[3]	6.88	6.91	6.91	6.86	0.05	0.499
Lean[4], %						
Day[2] 75	54.24^{a}	53.70^{b}	54.62^{a}	54.42^{a}	0.465	0.009
Day 89	54.26^{a}	52.73^{c}	53.41^{b}	53.64^{b}	0.288	<0.001
Day 103	53.70^{a}	52.24^{c}	52.23^{c}	53.03^{b}	0.184	<0.001
Day 117	54.22^{a}	52.59^{b}	52.13^{bc}	52.09^{c}	0.216	<0.001
Overall[3]	54.09^{a}	52.81^{c}	53.08^{b}	53.28^{b}	0.233	<0.001

[1]Control = no Improvest (IMP); T-early = pigs administered 2 mL IMP on days 7 and 40; T-medium = pigs administered 2 mL IMP on days 21 and 56; T-late = pigs administered 2 mL IMP on days 35 and 70.
[2]Day 75: harvest group 1 = removal of the heaviest 7 gilts per pen per visual observation; day 89: harvest group 2 = removal of the heaviest 10 gilts per pen per visual observation; day 103: harvest group 3 = removal of the heaviest 10 gilts per pen per visual observation; day 117: harvest group 4 = removal of the last 7 gilts per pen.
[3]Overall = (variable of interest on days 75 + 89 + 103 + 117)/4.
[4]GMeans ± SEM within a row with different superscripts differ, $P \leq 0.05$.
[abcd]LSMeans ± SEM within a row with different superscripts differ, $P \leq 0.05$.

d post D2) were leaner ($P \leq 0.001$) than T-early (i.e., 63 d post D2) and T-medium (i.e., 47 d post D2) gilts which did not differ ($P = 0.962$). The fourth harvest resulted in Control gilts remaining leaner ($P < 0.001$) than all IMP treated gilts with T-early gilts being leaner ($P = 0.040$) than T-late, with T-medium being intermediate ($P \geq 0.06$). When the overall average percentage lean was calculated, Control gilts were leaner ($P < 0.001$) than all IMP treated gilts. T-medium and T-late gilts were similar ($P = 0.153$), and leaner ($P \leq 0.045$) than T-early gilts.

Morbidity and mortality

Morbidity and mortality were not statistically analyzed. There was a total of nine mortalities due to lameness (n = 3); poor body condition (n =1); umbilical hernia (n = 4) and other (n =1) from Control (n = 2); T-early (n = 2); T-medium (n = 1); and T-late (n = 4). There were pigs removed from the study due to causes of morbidity (lameness, n = 12; poor body condition, n = 1; rectal prolapse, n = 3; umbilical hernia, n = 2; rectal stricture, n = 4; and other, n = 20) from Control (n = 6); T-early (n = 16); T-medium (n = 13); and T-late (n = 7).

DISCUSSION

Results from our study confirm the effectiveness of IMP in improving most performance parameters and changing carcass characteristics towards a heavier and fatter body type in gilts. This is in accordance with summary effects calculated in meta-analysis for the subgroup of conventionally raised gilts, i.e., being comparable to the production system used in our study (Poulsen Nautrup et al., 2020).

As reported in many studies, body weights were significantly greater than control after D2 in all IMP treatment groups, resulting in greater final live weights at harvest. What is unique about the current study was the delineation of the timing post D2 of IMP on when increases in ADG and ADFI begin within a cohort of market gilts. Alison et al. (2021) previously documented in three independent studies, that the timing of IMP injections prior to harvest is influencing these phenotypes.

Across all treatment groups (T-early, T-medium, and T-late) IMP increased the ADG and ADFI, with the increase in ADG being mainly driven by the increase in ADFI. It has been reported that the feed intake increases in the second week after D2, peaks 3 to 4 wk after D2 and then slowly declines (Allison et al., 2021). A similar pattern was also observed in our study, as the ADFI became significantly greater after D2 in all IMP groups, with the difference to control peaking on days 75 to 89 for T-early (which was 35 to 49 d post D2); days 89 to 103 for T-medium (which was 33 to 47 d post D2), and on days 103 to 107 for T-late (which was 33 to 47 d post D2). After the peak, the difference in ADFI compared to Control decreased in T-early and T-medium but remained statistically higher until the end of study. In the T-late group it can be rationally assumed that in most gilts, harvest was earlier than the onset of a decreasing difference compared to control.

A similar pattern has been reported for the ADG that shows a marked rise with the increasing ADFI, also peaking 3 to 4 wk after D2 and a decline that is more rapid than observed for the ADFI (Allison et al., 2021). In our study ADG showed a similar pattern in T-early and T-medium, resulting in statistically greater ADG vs. control after D2 (i.e., 35 to 49 d post D2 for T-early and 19 to 33 d for T-medium), followed by decreasing differences until ADG was similar compared to Control at the end of the finishing period in T-early and T-medium. In T-late, ADG was significantly greater compared to Control after only 5 d post D2, but remained greater through the end of the study; it may have also returned to Control levels but was not observed, which again was most likely attributed to a too short interval between D2 and harvest. A significant decrease of the difference in ADFI and ADG between IMP and untreated gilts with an increasing time between D2 and harvest was also seen in the meta-regression run for the subgroup of conventionally raised gilts and was explained by a declining impact of IMP on gonadal function (Poulsen Nautrup et al., 2020).

Most authors report no impact of IMP on the feed efficiency in gilts (McCauley et al., 2003; Oliver et al., 2003; Van den Broeke et al., 2016), which also corresponds to the summary effect size in meta-analysis calculated for the subgroup of conventionally raised gilts. However, in subgroup analysis for gilts raised for the production of high-quality dry-cured products, which had on average longer intervals between D2 and harvest, feed efficiency was negatively affected in IMP gilts (Poulsen Nautrup et al., 2020). Allison et al. (2021) also found a trend toward a worse feed efficiency in those groups with an increasing time between D2 and harvest. The authors explained the change in feed efficiency in IMP-treated gilts by the weekly patterns in ADFI and ADG, as the increase in ADG tailed off more quickly than that in ADFI, gradually shifting the impact on feed efficiency from favorable to unfavorable (Allison et al., 2021). A similar pattern was observed in our study: In T-early and T-medium the G:F ratio was significantly higher after D2, but the difference became rapidly smaller, resulting in significantly lower G:F ratios in the last measurement period. In T-late, G:F was not significantly different compared to the control group until the last period (days 130 to 117), when it became significantly lower. Thus, our study confirms that an increasing time between D2 and harvest has a negative impact on the feed efficiency in gilts.

In our study, most changes on carcass traits in IMP-treated gilts compared to untreated gilts are in accordance with findings from the meta-analysis (Poulsen Nautrup et al., 2020), with the exception of carcass yield. Whereas in the meta-analysis, carcass yield was not different in IMP and untreated gilts (Poulsen Nautrup et al., 2020), the overall carcass yield was lower in all IMP groups compared to control in our study. The difference versus Control was increasing with a decreasing time between D2 and harvest. This pattern, however, is in-line with findings of the recent study published by Allison et al. (2021), who found the lowest carcass yield in the group with the smallest interval between D2 and harvest (4 wk) and the highest carcass yield in the group with the longest period (8 wk). Differences were not statistically significant versus control. When considering the different harvest groups in our study, it was shown that the carcass yield in T-early had nearly recovered to Control values in harvest group 2, which was true for T-medium in the last harvest group (i.e., day 117). Carcass yield is similar to Control gilts with an increasing time between D2 and harvest. Apparently, the time period was too small to recover carcass yield in the T-late group. There is no distinct explanation for the results but Allison et al. (2021) assumed that among others, the shrinkage of the female genital tract contributes to an increase in carcass yield, whereas the higher feed intake might reduce it through increases in gut fill and

intestinal mass, with the decrease of the genital tract being expected to increase with the duration of IMP and the impact of the ADFI expected to decrease especially when the relative increase in ADFI over control starts to decline. It is worth mentioning, however, that HCW was consistently higher compared to control despite the overall lower carcass yield in all three IMP treatment groups in our study.

Muscle depth was similar to control in all treatment groups and not affected by the time between D2 and harvest. As such, outcomes are consistent with results from meta-analysis (Poulsen Nautrup et al., 2020), and outcomes of the recent study using different time intervals between D2 and harvest (Allison et al., 2021). Thus, we conclude that neither IMP, nor the time between D2 and harvest, have an impact on muscle depth in gilts.

In all three IMP treatment groups overall backfat depth was greater and overall lean percentage smaller compared to control. The negative correlation between backfat and lean meat percentage could be expected (Allison et al., 2021) as one is often used to calculate the other, and our findings are in line with previous studies, which showed a lower leanness of IMP-treated gilts, thereby offsetting the often criticized "over-leanness" of untreated female pigs (Poulsen Nautrup et al., 2020). The effect on leanness was influenced by the time between D2 and harvest, as the difference in backfat and lean percentage compared to Control was greatest in T-early and lowest in T-late. The increasing fatness with an increasing time between D2 and harvest has been shown to be favorable in pigs destined for high-quality dry-cured ham production. A time-period between 9 and 12 wk between D2 and harvest has been reported to be the optimum timing of IMP in these gilts, resulting in an increased carcass fatness and intramuscular fat as desired for dry-cured ham production and consumption (Pérez-Ciria et al., 2021).

A final remark refers to the inclusion of four harvest groups in our study. By considering different harvest groups per pen, our study design reflects an often-used practice that accounts for the different growth of individual pigs. As a consequence, in T-early treatment, the time intervals between D2 and harvest were between 35 and 77 d post D2; 19 to 61 d for T-medium, and 5 to 47 d for T-late. Therefore, overall results represent mean values for differing time points relative to D2 for IMP administered. The performance parameters (i.e., ADFI, ADG, and G:F) were also interpreted on a 1- or 2-weekly basis, therefore on a calendar basis, not a time post D2 basis. With the separate analyses of the four harvest groups, we were able to evaluate differences in carcass traits for the different intervals between D2 and harvest. Allison et al. (2021) also investigated the impact of changing the interval between D2 and harvest in gilts but used one fixed harvest day for all pigs per trial. As their results are comparable to our findings, we conclude that the outcomes and statements are valid regardless of the harvest protocol.

CONCLUSIONS

Within a cohort of similar aged gilts finishing during the summer, this study indicates that the trajectory of growth is enhanced within a similar window post D2 of IMP. Gilts treated with IMP had heavier carcasses with increased backfat and similar Longissimus muscle depth.

Acknowledgments

The authors appreciate the excellent oversight of the study by the animal caregivers.

Conflict of Interest Statement

At the time of the study, MAM, DA, LPG, and KAV were employed by Zoetis, Inc., the manufacturer of Improvest.

LITERATURE CITED

Allison, J. R. D., C. A. da Silva, M. A. Callegari, C. P. Dias, K. L. L. de Souza, E. R. de Oliveira, J. V. Peloso, E. Poleze, C. K. Mah, D. Lin, et al. 2021. Immunization against gonadotropin-releasing factor (GnRF) in market gilts: effect on growth and carcass parameters, and impact of immunization timing. *Res. Vet. Sci.* 136:127–137. doi:10.1016/j.rvsc.2021.02.003.

Bohrer, B. M., W. L. Flowers, J. M. Kyle, S. S. Johnson, V. L. King, J. L. Spruill, D. P. Thompson, A. L. Schroeder, and D. D. Boler. 2014. Effect of gonadotropin releasing factor suppression with an immunological on growth performance, estrus activity, carcass characteristics, and meat quality of market gilts. *J. Anim. Sci.* 92:4719–4724. doi:10.2527/jas.2014-7756.

Bradford, J. R., and M. A. Mellencamp. 2013. Immunological control of boar taint and aggressive behavior in male swine. *Anim. Front.* 3:12–19. doi:10.2527/af.2013-0028.

Daza, A., M. A. Latorre, A. Olivares, and C. J. López-Bote. 2014. The effect of immunocastration and a diet based on granulated barley on growth performance and carcass, meat and fat quality in heavy gilts. *Animal.* 8:484–493. doi:10.1017/S1751731113002292.

Kowalski, E., E. Vossen, S. Millet, B. Ampe, S. DeSmet, and M. Aluwe. 2021. Effect of terminal sire line and timing second vaccination on effectiveness of immunocastration, performance, and meat quality. *Meat Sci.* 175:108451. doi:10.1016/j.meatsci.2021.108451.

Latorre, M. A., A. Daza, A. Olivares, and C. J. Lopez-Bote. 2013. The effect of immunocastrationon growth performance and meat quality of heavy gilts. *J. Anim. Sci.* 91:372–373. doi:10.1017/S1751731113002292.

Lugar, D. W., M. L. Rhoads, S. G. Clark-Deener, S. R. Callahan, A. K. Revercomb, K. J. Prusa, and M. J. Estienne. 2017. Immunological castration temporarily reduces testis size and function without long-term effects on libido and sperm quality in boars. *Animal.* 11:643–649. doi:10.1017/S1751731116002081.

McCauley, I., M. Watt, D. Suster, D. J. Kerton, W. T. Oliver, R. J. Harrell, and F. R. Dunshea. 2003. A GnRF vaccine (Improvac®) and porcine somatotropin (Reporcin®) have synergistic effects upon growth performance in both boars and gilts. *Aust. J. Agric. Res.* 54:11. doi:10.1071/ar02037.

National Research Council. 2012. *Nutrient Requirements of Swine: Eleventh Revised Edition*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

Oliver, W. T., I. McCauley, R. J. Harrell, D. Suster, D. J. Kerton, and F. R. Dunshea. 2003. A gonadotropin-releasing factor vaccine (Improvac) and porcine somatotropin have synergistic and additive effects on growth performance in group-housed boars and gilts. *J. Anim. Sci.* 81:1959–1966. doi:10.2527/2003.8181959x.

Oliviero, C., A. Ollila, M. Andersson, M. Heinonen, L. Voutila, T. Serenius, and O. Peltoniemi. 2016. Strategic use of anti-GnRH vaccine allowing selection of breeding boars without adverse effects on reproductive or production performances. *Theriogenol.* 85:476–482. doi:10.1016/j.theriogenology.2015.09.027.

Pérez-Ciria, L., G. Carcò, F. J. Miana-Mena, O. Mitjana, M. V. Falceto, and M. A. Latorre. 2021. Immunocastration in gilts: a preliminary study of the effect of the second dose administration time on growth, reproductive tract development, and carcass and meat quality. *Animals.* 11:510. doi:10.3390/ani11020510.

Poulsen Nautrup, B., I. Van Vlaenderen, and C. K. Mah. 2020. The effect of immunization against gonadotropin-releasing factor in market gilts: meta-analyses of parameters relevant for pig producers, pork packers and retailers/consumers. *Res. Vet. Sci.* 131:159–172. doi:10.1016/j.rvsc.2020.04.012.

Rodrigues, L. A., F. R. C. L. Almeida, J. V. Peloso, F. N. A. Ferreira, J. Allison, and D. O. Fontes. 2019. The effects of immunization against gonadotropin-releasing hormone on growth performance, reproductive activity and carcass traits of heavy weight gilts. *Animal.* 13:1326–1331. doi:10.1017/S1751731118003099.

Scheid, I. R., F. T. T. Oliveira, A. C. Borges, T. F. Braga, R. A. Soncini, S. Mathur, J. R. D. Allison, and D. P. Hennessy. 2014. A single dose of a commercial anti-gonadotropin releasing factor vaccine has no effect on testicular development, libido or sperm characteristics in young boars. *J Swine Health Prod.* 22:185–192. doi:https://www.aasv.org/jshap/issues/v22n4/v22n4p185.pdf.

Van den Broeke, A., F. Leen, M. Aluwé, B. Ampe, J. Van Meensel, and S. Millet. 2016. The effect of GnRH vaccination on performance, carcass, and meat quality and hormonal regulation in boars, barrows, and gilts. *J. Anim. Sci.* 94:2811–2820. doi:10.2527/jas.2015-0173.