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# Economic and environmental implications of incorporating distillers' dried grains with solubles in feed rations of growing and finishing swine in Argentina

**RESEARCH ARTICLE**

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## Abstract

The Argentinean swine industry has quickly expanded over the past decade, hence increasing the demand for swine feedstuffs. The growing supply of distillers' dried grains with solubles (DDGS) from the emerging Argentinean corn-based ethanol industry is a potential feedstuff for swine producers. Using a multi-objective linear programming model, this study examined the economic and environmental concerns (i.e. cost and phosphorus content) associated with introducing DDGS in swine feed rations. Results suggest that including DDGS in swine diets concurrently minimized cost and phosphorus content. The results were extrapolated to the entire Argentinean swine industry and show that the inclusion of DDGS in swine rations could potentially save the Argentinean swine industry about 19.21 million US dollars annually and reduce phosphorus content by up to 5%. In addition, sensitivity analysis of DDGS price was conducted and the potential demand for DDGS from swine by growth category was derived.

**Keywords:** Argentina, feed rations, optimization, swine, distillers' dried grains with solubles
**JEL code:** Q13, Q15

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## 1. Introduction

Argentinean pork consumption has significantly increased in the last decade due to an improvement in its price relative to other meat products (La Nacion, 2016). According to the Ministry of Agroindustry of Argentina (2016), domestic annual consumption of pork per capita increased by 45% between 2011 and 2016, from 8.64 to 12.54 kg per person. In addition, pork exports have also expanded by 113% over the same period (Ministry of Agroindustry of Argentina, 2016). To meet the rising demand for pork, Argentinean swine production has grown by 72% over the same period (Ministry of Agroindustry of Argentina, 2016).

Corn has been a primary feedstuff for swine production in Argentina. However, the Argentinean biofuels law of 2006, which initially mandates a blend of 5% of ethanol with gasoline and currently extends the blend to 12%, has resulted in an increased amount of corn being diverted to ethanol production. The amount of corn used for ethanol production has increased more than 20-fold between 2012 and 2016, extending from about 58 thousand metric tons (mt) to more than 1.22 million mt (United States Department of Agriculture (USDA), 2017). In 2016, corn-based ethanol accounted for about 50% of the ethanol production in Argentina. The Cordoba province produced the most corn-based ethanol in Argentina in 2016 and it is currently the second largest swine producer (Ministry of Agroindustry of Argentina, 2016) (Table 1).

Distillers' dried grains with solubles (DDGS), a co-product of corn-based ethanol, is a potential corn substitute for swine producers in this region. As a livestock feed, DDGS have a more concentrated nutritional value relative to traditional feed grains, such as corn and soybean meal, and can be used to meet the energy and protein requirements (Dooley, 2008). A number of studies have explored the potential of adding DDGS in the diet of ruminants (e.g. Anderson *et al.*, 2006; Klopfenstein *et al.*, 2008; Schingoethe *et al.*, 2009) and non-ruminants (e.g. Donohue and Cunningham, 2009; Masa'deh *et al.*, 2011; Stein and Shurson, 2009). Typically, the amount of DDGS to be included in the diet of an animal is conditional on the animal's ability to digest the high fiber content in the feedstuff (Hoffman and Baker, 2011). In addition, Jones *et al.* (2007) conducted a meta-analysis and suggested that economic factors and animal response to DDGS are also influential to the optimal inclusion rates of DDGS in the feed ration of beef cattle. Klasing (2012) indicated that among all factors, DDGS price is the most important to determine the amount of DDGS that would be included in animal diets.

The potential cost savings from introducing DDGS to feed rations of various livestock has been examined in the literature. Schmitz *et al.* (2009) found that the cost saving from substituting traditional feedstuffs, such as corn or soybean meal, with relatively economical DDGS in the Northeast US farms was highly affected by the relative price of these feedstuffs. In addition, the size of savings was higher in dairy rations as DDGS could be included in higher portions in ruminant than in non-ruminant rations. A study on a representative pig farm in Ontario showed that DDGS were a more cost-effective source of energy, amino acids and phosphorus compared to corn or soybean meal, and suggested the demand for DDGS is relatively inelastic (Skinner *et*

**Table 1.** Argentinean corn used for ethanol, DDGS[1] production and number of swine heads. (adapted from Ministry of Agroindustry of Argentina, 2016; Rosario Stock Exchange (personal communication, 2017)).

| Province | Number of corn-based ethanol plants | Corn used for ethanol (mt) | DDGS produced (mt) | Number of swine heads (million) |
|---|---|---|---|---|
| Córdoba | 3 | 861,908 | 267,191 | 1.13 |
| San Luis | 1 | 217,123 | 67,308 | 0.22 |
| Santa Fe | 1 | 145,563 | 45,124 | 0.77 |
| All others | 0 | 0 | 0 | 3.00 |
| Total | 5 | 1,224,594 | 379,624 | 5.12 |

[1] DDGS = distillers' dried grains with solubles.

*al.,* 2012). Previous research suggested that including DDGS in swine feed rations can potentially reduce the feed ration costs by 3 to 13% (Fabiosa, 2008; Schmitz *et al.*, 2009; Skinner *et al.*, 2012).

Several studies have also evaluated the effects of incorporating DDGS in feed rations on the environment. Hadrich *et al.* (2008) considered both feedstock and disposal costs related to the additional phosphorus into a total cost function for dairy feed ration because replacing corn and soybean meals with DDGS in ruminant diets may result in excess phosphorus than the required nutrition. Similarly, adopting DDGS in swine rations could result in higher nitrogen and phosphorus in manure. Skinner *et al.* (2012) found that the higher nutrient content of the manure from DDGS in the feed rations at small-scale farms could be used as fertilizer and decrease the need of adding inorganic phosphorus to their crops. In addition, incorporating DDGS in the diet of growing swine could increase the digestion of the organic phosphorus, which could reduce the need of adding inorganic phosphorus to the feed ration (Pedersen *et al.*, 2007; Widmer *et al.*, 2007). Given that inorganic phosphorus is a non-renewable resource, reducing its use in feed rations would have a positive impact on environmental sustainability (Suh and Yee, 2011).

As the potential for replacing corn with DDGS in Argentinean swine production has emerged, research is needed to determine the impact of introducing a novel ingredient on feed rations' cost and the environment. Particularly, there is a growing number of countries that have imposed restrictions on nutrient excretion to reduce water pollution (Boland *et al.*, 1998; Bridges *et al.*, 1995). This issue is important in the case of swine since about 75% of the phosphorus that they ingest is in the form of phytate, which is mostly excreted in their manure (Kemme *et al.*, 1999). However, little is known about how incorporating DDGS in swine feed rations will impact the environment. Also, the potential impact of adopting DDGS on Argentinean swine feed ration cost has yet to be analyzed.

Mathematical programming models are commonly used to evaluate the economic and environmental effects of different feed rations (Babic and Peric, 2011; Castrodeza *et al.*, 2005; Fabiosa, 2008; Pomar *et al.*, 2007; Tozer and Stockes, 2001; Yu *et al.*, 2001). Goal programming, or multi-objective linear programming (MOLP) modeling, is commonly used when the cost and environmental measurements of the feed ration cannot be simultaneously optimized. This linear programming (LP) model allows the decision maker to optimize the objectives by assigning weights (preferences) for each objective (Zhang and Rousch, 2002). Solutions can be compared across weights to determine how sensitive the results are to the assigned weights (Zhang and Rousch, 2002). A MOLP model is an appropriate approach to analyze the impact of DDGS on feed ration costs and the phosphorus content ingested by swine.

Therefore, the objective of this study was twofold: (1) determine the impact of including DDGS on the cost and phosphorus content in the feed ration in the Argentinean swine industry; and (2) explore the potential substitution between corn, soybean meals and DDGS in its swine industry. In this study, feed rations with and without DDGS were formulated for swine in three growth categories. A MOLP model was established to analyze both feed rations using cost minimization and phosphorus content minimization. The output from the LP models was used to estimate how incorporating DDGS as a feedstuff in swine production would impact the aggregate cost and phosphorus content in the feed ration ingested by the Argentinean swine industry. Given the outputs of the optimization models and the swine population in Argentina, the potential substitution of corn and soybean meal with DDGS in Argentinean swine industry feed rations was estimated. Finally, a sensitivity analysis using DDGS price was performed to address the potential changes in future Argentinean energy costs.

## 2. Methods and model specification

### *2.1 Optimization model*

A MOLP model was formed with one objective to minimize the feed ration cost ($C$) and another objective to minimize the total phosphorus ($P$) content in the feed ration for three swine growth stage categories: (1) 20 to 50 kg; (2) 50 to 80 kg; and (3) 80 to 120 kg. These growth categories were defined following the National Research Council (NRC, 1998) recommendations for swine nutrient requirements.

The target value for each objective in the MOLP model was first determined for each growth category using two different LP models. These target values correspond to the optimal cost and phosphorus content in one kilogram of swine feed rations in each growth period category. The LP models were defined as:

$$Minimize\ C_m=\sum_{i=1}^{n} c_i x_{im}, \qquad m=1,2,3 \tag{1}$$

$$Minimize\ P_m=\sum_{i=1}^{n} p_i x_{im}, \qquad m=1,2,3 \tag{2}$$

where $c_i$ is the cost of the ingredient $i$ ($i$=1,..., $n$) in US \$/kg for each growth category $m$ ($m$=1, 2, 3); $p_i$ is the percent of phosphorus in ingredient $i$, and $x_{im}$ is the percent of ingredient $i$ in the feed ration for each growth category. The two sole-objective functions for each growth category, $m$, were optimized under the following constraints:

$$\sum_{i=1}^{n} x_{im}=1, \qquad \forall\ m \tag{3}$$

$$lb_{jm}\leq\sum_{i=1}^{n} f_{ij}x_{im}\leq ub_{jm}, \qquad j=1,...,k, \qquad \forall\ m \tag{4}$$

$$0\leq x_{im}\leq ub_{im}, \qquad i=1,...,n, \qquad \forall\ m \tag{5}$$

where $f_{ij}$ is the proportion of nutrient content $j$ ($j$=1,..., $k$) observed in ingredient $i$; $lb_{jm}$ and $ub_{jm}$ are the lower and the upper bounds of nutrient $j$ in the feed ration for weight category $m$, respectively. Equation 3 assures that the share of ingredients sums to one. Equation 4 requires that the feed ration complies with the minimum and maximum amount of nutrients necessary for each growth category. Equation 5 limits the maximum amount of ingredient, $i$, that can be used in the feed ration for each growth category of swine.

After solving the two separate LP models, the target values for cost, $C^*_m$ and phosphorus content, $P^*_m$, were obtained and the following MOLP model was solved using a MINIMAX[1] algorithm for each growth category of swine as shown in Equation 6:

$$Min\ Q_m, \qquad m=1,2,3 \tag{6}$$

subject to the constraints in Equations 1-3 and additional constraints below:

$$w_{cm}\,(C_m-C_m^{\ *})/(C_m^{\ *})\leq Q_m, \qquad \forall\ m \tag{7}$$

$$w_{Pm}\,(P_m-P_m^{\ *})/(P_m^{\ *})\leq Q_m, \qquad \forall\ m \tag{8}$$

$$w_{Cm}, w_{Pm}\geq 0, \qquad \forall\ m \tag{9}$$

where $Q_m$ is a parameter that ensures the solution minimizes the maximum deviation from the target values of each objective ($C^*_m$ and $P^*_m$) for each growth category, $w_{Cm}$ and $w_{Pm}$ are the weights (preferences) assigned

[1] The MINIMAX algorithm minimizes the maximum weighted deviation from the objectives (Ragsdale, 2006).

to each objective. When these weights for ($w_{Cm}$, $w_{Pm}$) are set to equal, e.g. (1,1), it implies the decision maker has the same preference to both objectives in the MOLP. When the decision maker wants to stress one particular objective, a higher weight can be assigned to the objective over the other one. Based on different combinations of the weights between the two objectives, a trade-off relationship (or curve) can be potentially derived if those two objectives are competing with each other. In this study, a set of weights was used for ($w_{Cm}$, $w_{Pm}$), including {(1,1), (5,1), (10,1), (100,1), (1,5), (1,10) and (1,100)}, to represent the different preferences for the cost minimization and phosphorus minimization objectives. Equations 7 and 8 measure the percentage deviations from the target values, while Equation 9 is a non-negative constraint for the objective weights.

To assess the impact of using DDGS for each growth category, a feed ration that contained corn and soybean meal, along with typical supplements in a swine feed ration, was formulated. The alternative feed ration included the same ingredients plus DDGS. Synthetic phytase was not included in the feed ration to improve the absorption of phosphorus.

### *2.2 Estimating potential use of distillers' dried grains with solubles in Argentinean swine industry*

The results obtained from the optimization models in Equations 1-9 were used to estimate the displacement of soybean meal and corn with DDGS in the feed ration for the Argentinean swine industry. The total quantity of feedstuffs demanded by the swine industry in a given year was first determined. The total number of swine harvested in Argentina in 2016 (5.99 million head) was used to approximate the total number of finished pigs (Ministry of Agroindustry of Argentina, 2016).[2] The days on feed and daily intake were found following NRC (1998). The assumptions used were that growing swine need to gain 30 kg of live weight, or 26.26 pounds of carcass fat-free lean weight to progress from growth category 1 (20-50 kg) to category 2 (50-80 kg), and from category 2 to category 3 (80-120 kg). The assumption was also made that it would require 36.66 days on feed for swine within each of the first and second growth categories and 48.88 days within the third category. Daily as-fed feed intake quantities were assumed to average 1.855, 2.575 and 3.075 kg for growth categories 1, 2, and 3, respectively (NRC, 1998).

Total annual feed consumption by the Argentinean swine industry was found for each growth category by multiplying the total number of swine in Argentina by the number of days needed for swine to increase their fat-free lean weight to the next growth category and the daily feed intake needed in the current growth category.[3] Then, the composition of the optimal feed rations was calculated for each of the growth categories. In addition, the cost savings and the phosphorus reduction from adding DDGS in the Argentinean swine industry feed rations were generated. The difference in the cost and phosphorus content in the feed ration with and without DDGS were multiplied by the total feed demand from the industry, assuming a sufficient amount of DDGS were available for all feed rations used in the swine industry.

### *2.3 Sensitivity analysis of distillers' dried grains with solubles price*

DDGS price in Argentina could vary as a result of an expected higher cost of natural gas, which is a key input to corn-based ethanol refinement, and thus the production of DDGS. Raising the price of natural gas has been recently announced by the Argentinean government as part of its plan to deregulate energy prices after years of subsidizing them (Argentinean Ministry of Energy, 2017; Reuters, 2016). Therefore, a sensitivity analysis was conducted to determine how the changes in DDGS price impacts the demand for DDGS in swine feed rations, while maintaining constant prices for all other feed ingredients. The range of DDGS price in the sensitivity analysis was determined by the allowable increase and allowable decrease for DDGS price obtained from each optimization.

[2] Since the data provided by the Ministry of Agroindustry does not identify the classification of swine, it was assumed that the reported number of swine slaughtered in 2016 was a proxy number of finished pigs.
[3] The estimate of potential DDGS use was made assuming all swine producers adopt DDGS in the feed ration of each growth category in Argentina. Thus, the *ad-hoc* estimation should be considered as the upper bound of DDGS use in the Argentinean swine industry if DDGS supply is sufficient.

## 3. Data

The prices of Argentinean corn, soybean meal and DDGS were collected from an Argentinean broker of grains and a corn-based ethanol plant (Grimaldi Grassi S.A.; Picatto, personal Communication, 2017). The prices of the other ingredients included in the feed rations (i.e. monocalcium phosphate, calcium carbonate, salt, vitamin and mineral premix, and synthetic L-lysine) were provided by various industry sources in Argentina.[4] The representative compounder was assumed to be located in Villa Maria (Córdoba, Argentina). Therefore, the prices of the feedstuffs and the supplements were the final prices of these products delivered to this location. The prices included the value-added tax and were recorded on February 15$^{th}$, 2017. The prices in Argentinean Pesos (ARS) were converted to US dollars at the exchange rate of 15.6 ARS $ per US dollar (Banco Nacion, 2017).

The nutritional attributes of Argentinean DDGS were provided by ACA Bio Coop. Lda. (Picatto, personal communication, 2016),[5] while the related information of soybean meal and corn were from NRC (1998). The nutritional profiles of the supplements were provided by the companies that market these products in Argentina. The nutritional requirements for swine in the three growth categories that were analyzed in this study (i.e. 20-50 kg, 50-80 kg and, 80-120 kg) were taken from NRC (1998). Finally, the annual production of DDGS in Argentina was provided by the Rosario Stock Exchange (personal communication, 2017) and the number of swine slaughtered in 2016 was recorded from the Ministry of Agroindustry of Argentina (2016).

Table 2 shows the ingredients that were included in the evaluated swine feed rations along with their price that was estimated at a 90% dry matter basis. The maximum allowed level of each ingredient for swine feed ration in the model was based on Boggess *et al.* (2008). The upper bound of 20% associated with DDGS for growing and finishing swine diet was set to prevent digestibility issues following the recommendation of the US Grains Council (2012). The nutritional profiles of the ingredients can be found in Supplementary Table S1.

## 4. Results and discussion

The trade-off between cost and phosphorus minimization was first examined for the feed ration without DDGS. Figure 1A illustrates the conflicting relationship between the two objectives using growth category 1 (20-50 kg) as an example. In a feed ration that did not include DDGS, minimizing the cost increased phosphorus content, while minimizing the phosphorus content in the diet increased the feed ration cost. When

[4] Industry resources include personal communication (in 2017) with F. Rottaris, D. Ferrara, G. Alescio, J. Sosa, D. Corrado and C. Goñi.
[5] As DDGS is a relatively new feedstuff in Argentina, the official estimates of its nutritional profile across the ethanol industry is not available. Thus, the nutritional profile of DDGS obtained from the given company was used as a proxy of DDGS nutrition attributes for the industry.

**Table 2.** Price of feedstuffs and supplements at a 90% dry matter basis and maximum allowed level of ingredients in swine feed rations (adapted from Boggess *et al.,* 2008; and personal communication (in 2017) with: Picatto, Goñi, Dansa S.A., Grimaldi Grassi S.A., Quimica Oeste S.A., and Verdol S.A.).

| Ingredient | Abbreviation | US $/kg | Allowed level (%) |
|---|---|---|---|
| Soybean meal | SM | 0.315 | 40.00 |
| Corn | Corn | 0.165 | 80.00 |
| DDGS[1] | DDGS | 0.198 | 20.00 |
| Monocalcium phosphate | MP | 0.839 | 3.00 |
| Calcium carbonate | CC | 0.108 | 3.00 |
| Salt | Salt | 0.220 | 0.50 |
| Vitamin and mineral premix | V&M | 2.758 | – |
| L-lysine (78%) | L | 1.857 | 0.65 |

[1] DDGS = distillers' dried grains with solubles.

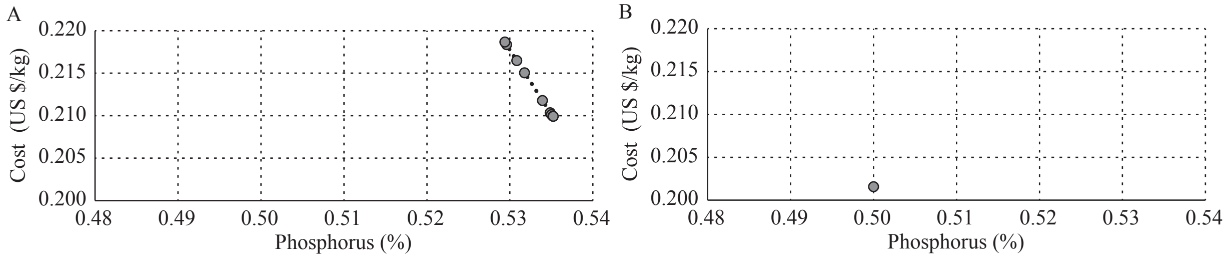


**Figure 1.** Trade-off between cost (US$/kg) and phosphorus content (%) in the feed rations for swine in growth category 1 (20-50 kg) without (1A) and with distillers' dried grains with solubles (1B).

DDGS were included in the swine diet, the cost and phosphorus content in the feed rations between the cost minimization and phosphorus minimization objectives were equal (Table 3). Thus, a single optimization solution is observed in Figure 1B despite the combination of weights (preferences) between the two objectives in the MOLP model. Similar findings were observed for other growth categories. Identical results between the MOLP model and the two separate LP models for a feed ration with DDGS suggest that adding DDGS to the rations of growing and finishing swine can simultaneously reduce feed costs and the potential for surface-water pollution caused by phosphorus excretion in swine's manure.

### *4.1 Estimated the potential use of distillers' dried grains with solubles by the Argentinean swine industry*

Table 4 presents the proportions of each ingredient in the optimal feed ration without DDGS and with DDGS when the objective was to minimize the feed ration cost.[6] When DDGS was introduced to the feed ration, it reached the maximum allowed usage (20%) for each growth category given its nutritional quality at a relative lower cost compared to corn and soybean meal. The respective nutritional composition of the feed rations by growth category is summarized in Supplementary Tables S2 and S3. DDGS were found to reduce soybean meal and corn usage by 10.01-12.54% and 6.56-9.24%, respectively, for the three growth categories. The use of monocalcium phosphate was also lowered by more than 60%.

Given the assumed total number of swine (5.99 million) in Argentina and the feed intake at each growth category, annual feedstuff demand was estimated to be around 1.87 million metric tons (mmt), which includes 407,061 metric tons (mt) for growth category 1, 565,057 mt for category 2, and 899,703 mt for category 3.[7] The annual demand for DDGS for the Argentinean swine industry would be up to 374,364 mt of DDGS for all growth categories, replacing approximately 209,434 mt of soybean meal and 147,270 mt

[6] The optimal feed ration with DDGS under the cost minimization objective also represents the optimal output from the phosphorus content minimization case (Table 3).

[7] Given the feeding period is less than one year (122 days), we assume that approximately each of the 5.9 million swine slaughtered went through each of the three growth stages in a given year.

**Table 3.** Cost and phosphorus content in swine feed ration including DDGS under sole objective optimization.[1]

| Objective | Growth category | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | |
| | Cost US $/kg | Phosphorus % | Cost US $/kg | Phosphorus % | Cost US $/kg | Phosphorus % |
| Cost minimization | 0.202 | 0.5 | 0.189 | 0.45 | 0.18 | 0.4 |
| Phosphorus minimization | 0.202 | 0.5 | 0.189 | 0.45 | 0.18 | 0.4 |

[1] DDGS = distillers' dried grains with solubles; growth category 1: swine weighting 20-50 kg, category 2: swine weighting 50-80 kg, and category 3: swine between 80-120 kg.

**Table 4.** Feed rations for swine in three growth categories by minimizing cost.[1]

| Ingredient[2] | Feed ration excluding DDGS (%) | | | Feed ration including DDGS (%) | | |
|---|---|---|---|---|---|---|
| | Growth category | | | Growth category | | |
| | 1 | 2 | 3 | 1 | 2 | 3 |
| SM | 25.62 | 19.2 | 15.97 | 15.61 | 9.32 | 3.43 |
| Corn | 70.25 | 76.89 | 80.00 | 61.39 | 67.64 | 73.44 |
| DDGS | – | – | – | 20.00 | 20.00 | 20.00 |
| MP | 0.81 | 0.65 | 0.47 | 0.34 | 0.22 | 0.09 |
| CC | 3.00 | 3.00 | 3.00 | 2.29 | 2.53 | 2.73 |
| Salt | 0.21 | 0.21 | 0.50 | 0.09 | 0.09 | 0.09 |
| V&M | 0.11 | 0.06 | 0.06 | 0.11 | 0.06 | 0.06 |
| L | 0.00 | 0.00 | 0.00 | 0.17 | 0.14 | 0.15 |

[1] DDGS = distillers' dried grains with solubles; growth category 1: swine weighting 20-50 kg, category 2: swine weighting 50-80 kg, and category 3: swine between 80-120 kg.

[2] SM = soybean meal; MP = monocalcium phosphate; CC = calcium carbonate; V&M = vitamin and mineral premix; L = L-lysine (78%).

of corn (Table 5), assuming the relative price of the other feed ingredients remains constant and the supply of DDGS is sufficient to meet the demand of the Argentinean swine industry.

*4.2 Estimated potential cost and phosphorus reduction in the Argentinean swine industry*

Table 6 summarizes the potential reduction in cost and phosphorus content from including DDGS in the Argentinean swine industry feed rations. Comparing the two feed rations when minimizing cost, the cost and the total phosphorus of the feed rations when DDGS were used 3.97-6.36%, and 5.69-6.59% lower, respectively. Similarly, when minimizing the total phosphorus in the swine feed ration, the feed rations with DDGS were 7.97-15.37% cheaper and had 4.36-5.51% less phosphorus content across all growth categories than the feed rations without DDGS. The cost savings in swine feed rations are consistent with Fabiosa (2008), which found savings of 2.64-9.88% in feed rations for finishing swine in the United States.

With DDGS in the feed rations for the 20-50 kg growth category (category 1), feed costs could be lowered by almost US $3.4 million (0.0083 US $/kg×407,061 mt/year in Table 5×1,000 kg/mt) under the assumptions of stable relative price of feedstuffs, full participation of the swine industry, and sufficient supply of DDGS to the Argentinean swine industry. Similarly, cost savings could reach more than US $4.8 million for swine in

**Table 5.** Estimated corn and soybean meal displacement in Argentinean swine feed rations.

| | Growth category[4] | | | Total |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Days of feeding[1] | 36.66 | 36.66 | 48.88 | 122.19 |
| Swine stock in 2016[2] | 5,986,561 | 5,986,561 | 5,986,561 | 5,986,561 |
| Feed intake (kg/day)[1] | 1.855 | 2.575 | 3.075 | |
| Total feed (mt/year) | 407,061 | 565,057 | 899,703 | 1,871,821 |
| Estimated DDGS[3] use (mt/year) | 81,412 | 113,011 | 179,941 | 374,364 |
| Soybean meal replaced (mt/year) | 40,756 | 55,817 | 112,861 | 209,434 |
| Corn replaced (mt/year) | 36,065 | 52,227 | 58,978 | 147,270 |

[1] Adapted from NRC, 1998.

[2] Adapted from Ministry of Agroindustry of Argentina, 2016.

[3] DDGS = distillers' dried grains with solubles.

[4] Growth category 1: swine weighting 20-50 kg; category 2: swine weighting 50-80 kg; and category 3: swine between 80-120 kg.

the growth category 50-80 kg and nearly US $11 million for the third growth category (80-120 kg). In total, the swine industry could potentially save US $19.21 million with the inclusion of DDGS in feed rations for growing and finishing swine.

Similarly, as shown in Table 6, including DDGS in the feed ration for swine between 20-50 kg could lower total phosphorus use by approximately 119 mt per year (0.0292%×407,061 mt/year in Table 5) or 5.51% of total phosphorus content. Phosphorus reduction in feed rations could be nearly 116 mt annually for swine between 50-80 kg and 196 mt for swine between 80-120 kg. Including DDGS in the feed rations would reduce the phosphorus content in feed by about 430 mt per year (or 5%) relative to rations without DDGS.

These estimates imply that adopting DDGS in the feed ration of swine in the three growth categories can potentially benefit the Argentinean swine industry in terms of both cost and quantity of phosphorus. The lower feeding costs would further enhance the competitiveness of Argentinean pork production to meet the growing domestic and international demand. In addition, lowering the total phosphorus content could help reduce the consumption of inorganic phosphorus by the swine industry in Argentina and decrease pollution from swine manure. It would also help the industry comply with environmental regulations. Argentina does not currently regulate the maximum amount of phosphorus that could be excreted; however, there is a possibility that Argentina will impose similar regulations on phosphorus excretion as observed in the European Union and the US (Boland *et al.*, 1998; Bridges *et al.*, 1995) given the projected growth in its pork production.

### *4.3 Sensitivity analysis*

Table 7 shows the cost-minimizing quantity of DDGS feed in the Argentinean swine industry by growth category under different prices. For swine weighing between 20-50 kg, DDGS were not included in the feed ration when the price was greater than US $252.72/mt. When the price was lowered to US $240.61-252.72/mt, DDGS consisted of 1% of the feed rations, implying that approximately 4,100 mt of DDGS per year (i.e. 1%×407,061 mt/year of total feed for swine weighing 20-50 kg; Table 5) would be fed. A maximum allowed DDGS inclusion level at 20% of DDGS was included in the feed ration when price was less than or equal to US $232.20/mt. The price of DDGS in Argentina was about US $198/mt in 2017 (or US $0.198/kg at 90% dry matter basis), thus DDGS were included at 20% in the optimal feed rations.

**Table 6.** Estimated cost savings and phosphorus reduction for the Argentinean swine industry if DDGS is used in the feed ration.[1]

| | Unit | Growth category | | | Total |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| Cost savings | | | | | |
| Cost of feed ration without DDGS | US $/kg | 0.2099 | 0.1978 | 0.1919 | |
| Cost of feed ration with DDGS | US $/kg | 0.2016 | 0.1893 | 0.1797 | |
| Cost savings from using DDGS | US $/kg | 0.0083 | 0.0086 | 0.0122 | |
| Estimated savings for the industry | Million US $ | 3.39 | 4.84 | 10.98 | 19.21 |
| Phosphorus (P) reduction | | | | | |
| P in the feed ration without DDGS | % | 0.5292 | 0.4705 | 0.4218 | |
| P in the feed ration with DDGS | % | 0.5000 | 0.4500 | 0.4000 | |
| Reduction of P | % | 0.0292 | 0.0205 | 0.0218 | |
| P in the feed ration without DDGS | mt | 2,154 | 2,658 | 3,794 | 8,607 |
| P in the feed ration with DDGS | mt | 2,035 | 2,542 | 3,598 | 8,177 |
| Reduction of P | mt | 118.73 | 115.88 | 195.75 | 430.37 |
| Reduction of P | % | 5.51 | 4.36 | 5.16 | 5.00 |

[1] DDGS = distillers' dried grains with solubles; P stands for phosphorus; growth category 1: swine weighting 20-50 kg, category 2: swine weighting 50-80 kg, and category 3: swine between 80-120 kg.

**Table 7.** DDGS used in the Argentinean swine industry by growth category.[1]

| Growth category | Price range (US $/mt) | DDGS used (mt) |
|---|---|---|
| 1: swine weighting 20-50 kg | 0.00-232.20 | 81,412.13 |
| | 232.20-239.41 | 72,560.61 |
| | 239.41-240.61 | 10,309.60 |
| | 240.61-252.72 | 4,096.03 |
| | 252.72-1E+33 | – |
| 2: swine weighting 50-80 kg | 0.00-232.20 | 113,011.44 |
| | 232.20-239.41 | 76,811.43 |
| | 239.41-240.61 | 54,767.15 |
| | 240.61-252.72 | 26,507.83 |
| | 252.72-1E+33 | – |
| 3: swine between 80-120 kg | 0.00-232.20 | 179,940.55 |
| | 232.20-233.40 | 130,576.11 |
| | 233.40-240.61 | 90,714.14 |
| | 240.61-272.89 | 54,338.95 |
| | 272.89-284.07 | 47,076.10 |
| | 284.07-325.86 | 40,175.69 |
| | 325.86-1E+33 | – |

[1] DDGS = distillers' dried grains with solubles.

Similarly, Table 7 shows that demand for DDGS by swine weighing between 50 and 80 kg reached zero when the price was higher than US $252.72/mt. As price decreased, the quantity of feed increased similar to the smaller growth category (20-50 kg). At the current price, annual DDGS feed demand was 113,011 mt for swine weighing between 50 and 80 kg in the Argentinean swine industry. For the heaviest growth category (80-120 kg), DDGS were excluded from the feed rations when the price was higher than US $325.86/mt. When the price declined to US $232.20/mt, the maximum allowed amount of DDGS that could be included in a feed ration was used. This implies that the demand for DDGS in the weight category of 80-120 kg would be less sensitive to increases in DDGS price.

Changes in DDGS price likely implies the use of corn and soybean meal could also change as DDGS price varies. Figure 2 shows the use of DDGS, soybean meal, and corn for swine feed rations by growth categories associated with the optimization output from the sensitivity analysis in DDGS price. For the lightest growth category, the proportion of DDGS and soybean meal used was similar when the price of DDGS was below US $232.2/mt. However, when the DDGS price fell in the range of US $239.41-240.6/mt, DDGS use rapidly decreased from 20 to 2.53% and was mostly replaced with soybean meal, which increased from 15.61 to 24.39% (Figure 2A). Similar changes also occurred for the middle growth category (Figure 2B) and heaviest growth category (Figure 2C). As the price of DDGS increased, both soybean meal and corn usage increased. However, in the heaviest growth category (80-120 kg; Figure 2C), when DDGS price was greater than US $240.60/mt, the lower use of DDGS was compensated with only an increase in soybean meal as the maximum amount of corn (80%) was already included in the ration.

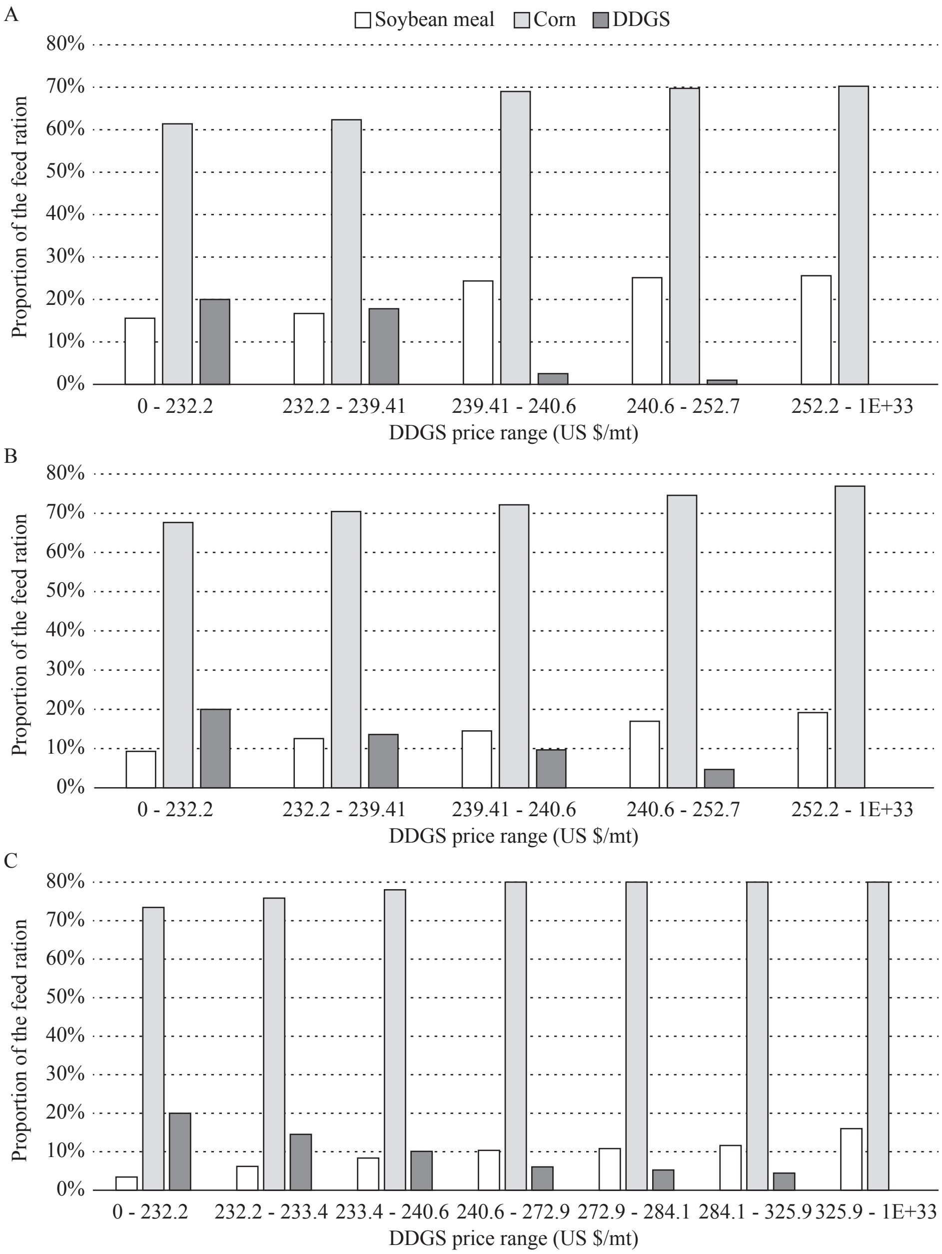


**Figure 2.** Composition of the feed ration for each growth category of swine given different distillers' dried grains with solubles (DDGS) price ranges. (A) Growth category 1: swine weighting 20-50 kg; (B) category 2: swine weighting 50-80 kg; (C) category 3: swine between 80-120 kg.

## 5. Conclusions

This study evaluated the cost and phosphorus advantage of including DDGS in feed rations for growing and finishing swine in Argentina. Results suggest that including DDGS in the feed rations achieved the goals of cost minimization and phosphorus minimization in feed rations concurrently; hence, avoiding the trade-off between cost and phosphorus content of feed rations when DDGS is not used. Also, the cost and the total phosphorus of the feed rations including DDGS were 3.97-6.36% and 5.69-6.59% lower, respectively, compared to the feed rations without DDGS. Using the estimated reduction in cost and phosphorus, along with the amount of feed consumed by swine at different growth categories, it was estimated that the swine industry could potentially achieve cost savings approaching US $19.21 million and a 5% reduction of total phosphorus if DDGS were adopted at 20% in the feed rations for all growing to finishing swine in Argentina.

In addition, including DDGS in the feed rations for the three growth categories in the swine industry could replace the use of corn and soybean meal by 147,270 mt and 209,434 mt, respectively. If the Argentinean swine industry replaces soybean meal and corn with DDGS in those quantities it would be demanding approximately 374,000 mt of DDGS. About 380,000 mt of DDGS was produced in 2016 and the production is projected to pass 440,000 mt in 2017 (USDA, 2017) given the recent increase in Argentinean corn-based ethanol production. Thus, utilization of DDGS could mitigate the price pressure on corn and stabilize the cost of the livestock and poultry industry in Argentina. The sensitivity analysis of DDGS price suggests that the demand for DDGS in swine feed rations varied by growth category. DDGS demand for swine weighing between (80-120 kg) was less elastic in comparison with the smaller growth categories.

A few caveats are related to this study. The estimated swine industry-wide cost savings or phosphorus reduction reported herein was based on the assumption that there would be sufficient DDGS supply to the swine industry and a full participation of adopting DDGS in feed rations in the industry. With a projected production of 440,000 mt in 2017 (USDA 2017), the needs of the swine industry would be satisfied if there is no other source of demand. Also, given the current biofuel mandate in Argentina, it is expected that the corn ethanol industry will continue to grow (USDA, 2017), hence, a greater supply of DDGS. Also, the relative price advantage of DDGS over other feedstuffs may not remain if the natural gas industry undergoes deregulation in the future.

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## Supplementary material

Supplementary material can be found online at https://doi.org/10.22434/IFAMR2017.0073.

**Table S1.** Nutritional profile of feedstuffs and supplements.
**Table S2.** Nutritional composition of the feed rations excluding DDGS.
**Table S3.** Nutritional composition of the feed rations including DDGS.

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