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# Defining quality of lactose sources used in swine diets

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## Summary

This paper reviews the process by which dried whey, a common ingredient in starter pig diets, is produced. The wide variability in quality of dried whey is explained. Also, this paper reports evaluations of other lactose sources—such as deproteinized whey and pure lactose—as alternatives to dried whey in starter pig diets.


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Milk products have been established as excellent sources of carbohydrates and protein in diets for weanling pigs. Dried whey is now considered an essential ingredient in diets for weanling pigs. However, dried whey is the most variable in quality of all the milk products.[1] In this paper, we review the process used to produce dried whey to provide insight into the causes of this variability, and evaluate other sources of lactose as alternatives to dried whey in the diets of starter pigs.

## Whey production

Zadow[2] broadly defined whey as the serum or watery part of milk remaining after the milk has been coagulated by acid or proteolytic enzymes and the curd separated off—one stage in the cheesemaking process. After pasteurization, whole milk is stored in large fermentation vats where either the enzyme rennet or another acid is added to curdle it. Curdling results in the formation of cheese curds and liquid whey. The two components are then separated, and the curds are processed further into cheese.

Protein, fatty acids, lactic acid, lactose contents, and pH in the whey can vary depending on the curdling process used.[3] Sweet whey results when the milk is curdled with rennet, and has a pH around 5.6. Acid whey results from curdling with lactic, acetic, citric, or hydrochloric acid and has a lower pH (5.13).

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If the whey originated from a cheese or casein factory, it usually contains some residual curd.[2] The removal of the curd residue is called "clarification." After clarification, whey goes through a separation to remove virtually all of the fat. The separated and clarified whey is pasteurized to ensure storage stability by decreasing the bacteria that can lead to the formation of lactic acid.[2]

To maintain high quality, whey should not stay in holding tanks too long. If whey is stored in the holding tanks for an extended period, it can decrease pH and protein recovery because lactic acid will form and initiate a chemical change called the Mailliard reaction.[4] The Mailliard reaction involves cross linking of an aldehyde group from the sugar and a free amino acid, which will decrease protein quality, specifically lysine availability. If severe, the Mailliard reaction can darken the color of the dried whey and impart an amine-type smell.[1] This reaction can occur during extended storage, which is why whey should be processed at the cheese plant of origin instead of being transported to another facility for drying. The subsequent neutralization that is necessary to compensate for the decreased pH that results from prolonged storage will also increase ash concentration.

The next step in processing liquid whey varies depending on the final product. If whey protein concentrate is produced, the liquid whey will be transferred to an ultrafiltration system. A pressurized membrane tube allows the permeate (deproteinized whey) to pass through the membrane and separates the whey protein concentrate. Whey permeate or deproteinized whey contains little to no protein and 83% lactose. Deproteinized whey, after ultrafiltration, is dried by the same procedures used for liquid whey.

## Drying methods

After liquid whey has been separated, clarified, and pasteurized, the next step is dehydration. Water is removed from whey in two stages.[5] The first stage removes approximately 90% of the water via evaporation with or without reverse osmosis, and the second step removes the remaining 10% of the water via spray or roller drying. Reverse osmosis separates water using a finer membrane than that used in ultrafiltration.[5] It does not remove all the water from liquid whey but can be used in combination with an evaporator to remove a portion of the water. Removing most of the water in liquid whey by evaporators is more economical.[5] Different types of evaporators are used in condensing whey, but all operate on the same principle, i.e., water boils at a lower temperature when it is in a vacuum. Thus, evaporators allow water to be removed at lower temperatures than would be needed for other drying methods.

If the whey product is dried immediately after evaporation, the finished product is unsatisfactory because it absorbs moisture too readily.[3] In order to produce a dry flowable powder, whey is crystallized into a-lactose. The a-lactose crystals have only one water molecule attached, making them low in solubility.[6]

Pure lactose can be removed at this point by centrifuging crystallized whey to remove the lactose crystals. Sweet whey crystals are removed most easily and are of the highest quality because they contain lower levels of mineral salts than acid whey crystals. To remove the salts and other impurities in the whey, wash water is added to the centrifuge and can potentially reduce ash levels up to 66%. The crystallized lactose then is refined to remove color, residual protein, and salt. Pure lactose also can be removed from deproteinized whey.

If the deproteinized whey is demineralized, less purification is necessary.[2] The demineralization step allows more a-lactose to be formed during crystallization.[5] The quality of crystalline or pure lactose is influenced by the degree of crystallization and the type of whey (acid or sweet) from which it originated.

The same final drying procedures would be used for the pure lactose as for whey or deproteinized whey. According to Masters,[7] three product characteristics must be considered when selecting a drying system:

- particle size,
- dried particle form, and
- the temperature to which the particle can be subjected.

The quality of milk products is related directly to the extent to which heat has denaturized the lactose and proteins.

There are presently two methods of drying used:

- spray; and
- roller drying.

## Roller drying

Roller drying uses a heated rotating cylinder, and the final dried product is removed by a scraping knife. Roller dryers result in excessive heating of the product, causing protein denaturing and poor solubility,[5] and can change the lactose to the b form.[6] The b-lactose absorbs moisture more readily than a-lactose, but b-lactose is sweeter.[6] Pollmann, et al.,[8] and Sohn, et al.,[9] indicated that growth performance of weanling pigs fed roller dried whey was inferior to that of pigs fed spray-dried whey. Pollmann, et al.,[8] also indicated that the lysine in roller-dried whey may be less available. Pettigrew, et al.,[10] found that pigs fed a diet containing spray-dried skim milk had superior growth performance and lower diarrhea scores than pigs fed a diet containing roller-dried whey and casein.

## Spray drying

Spray-drying is the preferred method of drying milk products, because it immediately removes moisture from the product.[5] Product is introduced into the spray-dryer by an atomizer, which introduces the product as small droplets to allow the water to evaporate quickly without the high temperatures that would lead to nutrient degradation.

There are several methods for spray-drying that differ according to how the hot dry air is introduced into the spray-dryer in relation to the product:

- **Cocurrent drying:** Evaporation is very fast, and the product is not subjected to heat degradation. With cocurrent systems, the product is in contact with much cooler air by the time it is at the desired moisture.[7] The fast evaporation of the product in combination with atomization allows the particle temperature to stay well below the drying air temperature.[7]
- **Counter-current drying:** This method is suitable only for nonheat-sensitive products because the driest product comes in contact with the hottest air, potentially causing heat denaturation.[7]
- **Mixed-flow drying:** This method incorporates both the cocurrent and counter-current systems, allowing a smaller drying chamber but producing the highest particle temperature.

Because they have the fastest evaporation time and the lowest particle temperature, cocurrent systems achieve the best product quality.

Dried whey leaves the drying chamber at 12%–14% moisture and a 50°–60°C outlet temperature. Ambient temperature and slightly moist conditions promote final crystallization to convert the rest of the lactose into the a-lactose form (95% total crystallized lactose content).

# Measures of dried whey quality

A thorough analysis of dried whey quality should include measurement of the following:

- lactose %,
- total protein %,
- nonprotein nitrogen %,
- fat %,
- titratable acidity %,
- ash %,
- pH, and
- solubility.

Acid whey has lower concentrations of lactose and protein than sweet whey, but contains higher titratable acidity (Table 1).[2] Titratable acidity is a direct measure of the amount of lactic acid that forms as a result of lactose fermentation. In addition, acid whey has higher concentrations of calcium, phosphorus, and potassium, resulting in a higher ash content than sweet whey.[6] Scott[3] thus recommends that sweet rather than acid whey be used for human use and livestock feeds to ensure their quality. Because sweet whey is the preferred source for animal feed, all future discussion will be in reference to sweet whey products and coproducts. (To verify that high-quality sweet whey is being used in diet formulations, the results of your analysis should be within the range of values shown in Tables 1 and 2. Table 2 lists some quality-control criteria that you can opt to evaluate to measure the quality of dried whey sources.)

According to Mahan,[11] values for titratable acidity in quality whey sources should range from 2.5–3.0 mmol HCl per 10 g of sample. However, there are several methods to measure titratable acidity, so it is important to use identical units when making comparisons. For example, the values in Table 1 report titratable acidities from whey products similar to those reported above by Mahan,[11] yet the concentrations reported are very different because different analytical methods were used. Mahan titrated a given amount of sample with HCl to a pH of 4.0 and expressed the titratable acidity in mmol of HCl per 10 g of solute titrated. Zadow[2] used NaOH to titrate the mixture to a given pH and expresses the titratable acidity as percent lactic acid.

If lactic acid increases during whey processing, it is often neutralized with alkali or neutralizing salts, which increase ash concentrations.[1] The normal ash content of an edible-grade dried whey, or for whey meeting specifications for human consumption, should be below 8.5%.[11] Ash levels exceeding 11% have been shown to have a laxative effect in pigs.[1]

Solubility is related to the amount of nutrient degradation that occurred during drying. Therefore, high solubility indicates a highly digestible lactose source. Solubility can be tested by reconstituting 10 g solids in 100 mL of water and heating the solution to 38°C (100°F). The solution then should be placed in a beaker for 15 minutes. No solids should precipitate out of solution during the next 15 minutes.

**Table 1**

General composition of dried whey

| | Sweet whey | | | Acid whey | | |
|---|---|---|---|---|---|---|
| Item | Mean | Min | Max | Mean | Min | Max |
| Lactose, % | 69.4 | 59.9 | 74.6 | 63.2 | 58.8 | 71.7 |
| Total protein, % | 13.0 | 11.1 | 16.6 | 11.7 | 8.0 | 12.6 |
| Nonprotein nitrogen, % | 0.5 | 0.2 | 0.7 | 0.6 | 0.5 | 0.7 |
| Ash, % | 8.3 | 7.1 | 10.7 | 10.6 | 7.3 | 12.2 |
| Fat, % | 1.0 | 0.4 | 1.5 | 0.5 | 0.3 | 0.7 |
| Titratable acidity, % | 0.1 | 0.1 | 0.2 | 0.4 | 0.3 | 0.4 |
| pH | 5.9 | 5.2 | 6.4 | 4.6 | 4.4 | 4.8 |

Source: Zadow[2]

**Table 2**

Recommended values for quality lactose sources

| Item | Dried whey | Deproteinized whey | Pure lactose |
|---|---|---|---|
| Lactose, % | > 71% | > 80% | > 99% |
| Ash, % | < 8.5% | < 9.2% | < 0.3% |
| Protein, % | > 11.5 | < 2.0 | < 0.3 |
| Solubility,* % | 100 | 100 | 100 |
| pH | 5.8–6.2 | 5.5–6.5 | 5.8–7.0 |

* To test solubility, reconstitute the product at 10% solids in 38°C (100°F) water for 15 minutes. None of the solids should precipitate out of solution after 15 minutes.

## Efficacy of dried whey and coproducts as feed ingredients

Mahan[11] observed the effect of feeding two dried whey sources to weanling pigs:

- an edible-grade whey (ash, 7.6%; protein, 12.6%; and titratable acidity, 2.24%); or
- a feed-grade source (ash, 10.7%; protein, 12.3%; and titratable acidity, 2.24%).

He found no differences in the performance of pigs fed a diet containing the feed-grade dried whey compared to the control pigs fed a diet with no added whey. However, pigs fed the diet containing edible-grade dried whey had a 15% improvement in average daily gain (ADG) (263 g versus 304 g) and 9% higher average daily feed intake (ADFI) (531 g versus 562 g) compared to the pigs fed the corn-soybean meal diet. This research demonstrates the benefit of using an edible-grade whey source in diets for weanling pigs.

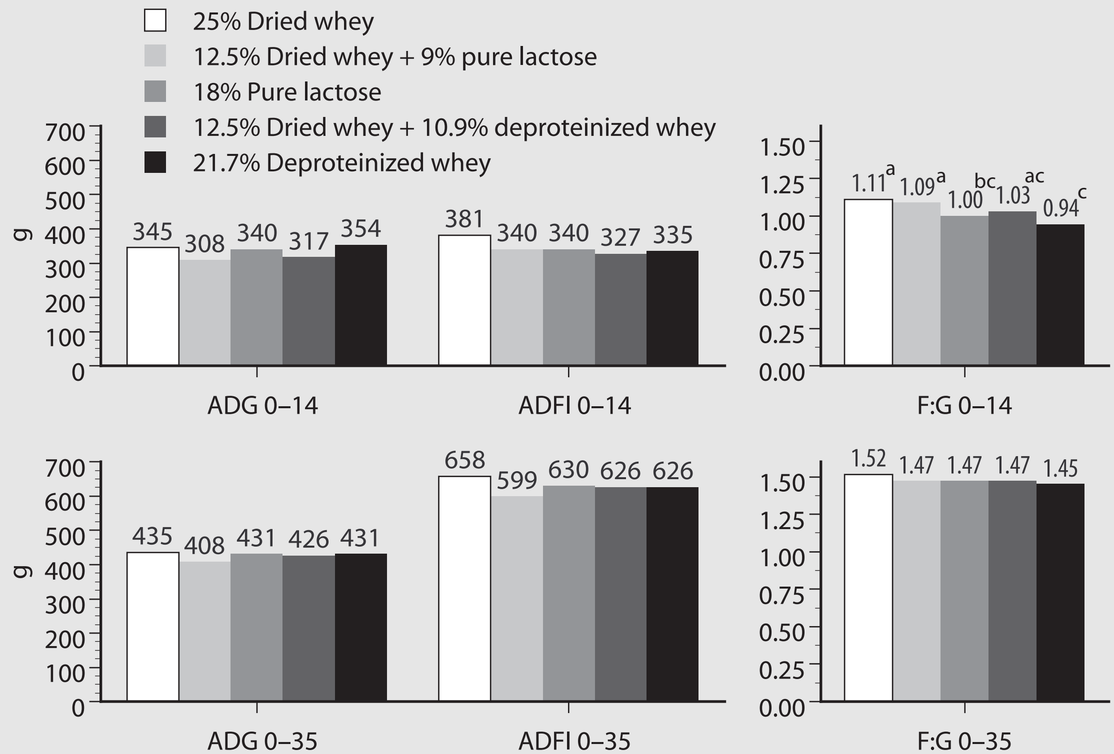
Recently, the feeding values of deproteinized whey and pure lactose were compared to that of dried whey in starter pig diets.[12] Two trials were conducted to determine the effects of replacing the lactose provided by spray-dried, edible-grade whey with deproteinized whey or pure lactose on pig performance. In the first experiment, 180 weanling pigs (initially 4.1 kg and 22 ± 4 days of age) were allotted to one of five treatment groups that were fed diets containing 18% lactose supplied by either:

- 25% dried whey,
- 12.5% dried whey and 9% pure lactose,
- 18% pure lactose,
- 12.5% dried whey and 10.9% deproteinized whey, or
- 21.7% deproteinized whey.

Casein was used to replace the lysine provided by dried whey in diets containing pure lactose and deproteinized whey. From days 0–14 after weaning, no differences were observed (Figure 1) in ADG or ADFI. Pigs fed diets containing 18% pure lactose or 21% deproteinized whey had increased feed:gain ratios (F:G) compared to pigs fed diets containing 25% dried whey or 12.5% dried whey and 9% lactose. Additionally, pigs fed diets containing 21% deproteinized whey had increased F:G compared to pigs fed the diet containing 10.9% deproteinized whey and 12.5% dried whey.

In the second experiment, 344 pigs (initially weighed an average of 4.4 kg and averaging 14 days of age) were fed diets containing one of four pure lactose sources used to replace the lactose provided by dried whey in the positive control diet (20% dried whey). In addition, a negative control diet was formulated with 7.2% pure lactose. Casein replaced the protein contributed by dried whey on a lysine basis. From

**Figure 1**




Effects of lactose source on starter pig performance

Source: Nessmith.[12] Means represent a total of 180 weanling pigs (initially 4.1 kg and 22 ± 4 d of age) with six pigs per pen and six replicate pens per treatment. Pigs were fed respective dietary treatments from d 0–14 postweaning, then all pigs were fed a common diet (1.35% lysine) from d 14–35 days of age.

abc means with different superscripts differ ($P < .05$)

day 0–14 after weaning, no differences were observed (Figure 2) in performance. However, pigs initially fed the positive control diet consumed more feed from days 15 to 28 than pigs fed the negative control diet.

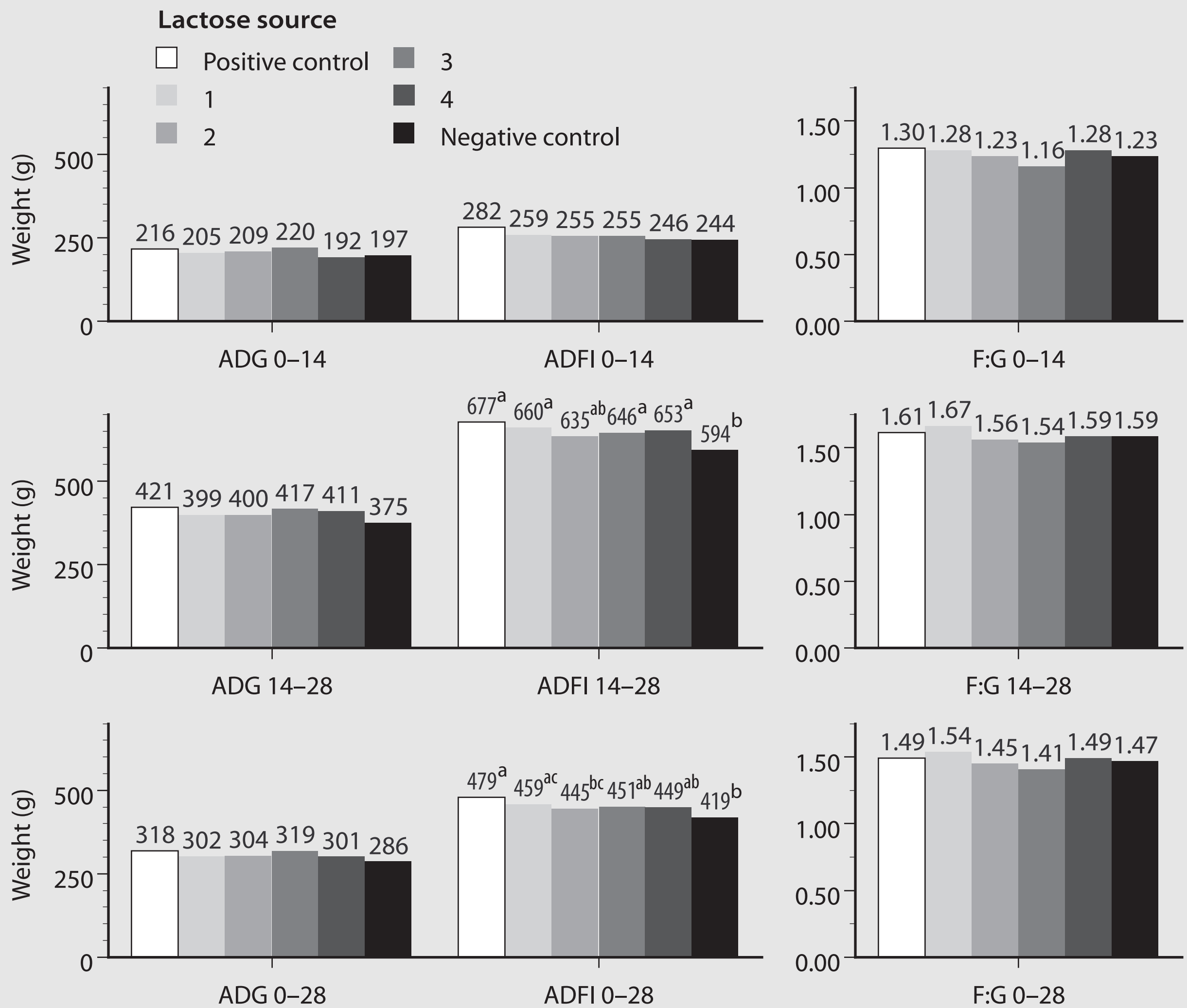
These results indicate that few differences exist between edible-grade lactose sources and high-quality dried whey. Both pure lactose and deproteinized whey contain little to no protein. Therefore, the protein fraction of dried whey should be replaced with a protein source such as fish meal or spray-dried blood meal. Other experiments have shown pure lactose to be a limited replacement for dried whey when the protein fraction of dried whey was replaced with synthetic amino acids.[13] Therefore, the protein replacement used should be an ingredient of high quality that has been shown to improve growth performance.

Many factors can affect the final quality of dried whey or its coproducts (crystalline lactose or deproteinized whey). It is important to purchase these ingredients from a trustworthy supplier who has predetermined written specifications defining and guaranteeing the necessary quality for use in swine diets (i.e., spray-dried edible-grade). Lactose sources (dried whey, deproteinized whey, and pure lactose) should come from a sweet-whey source, not an acid-whey source. The product should be analyzed periodically to ensure that quality specifications are being met. Although standards (Table 2) are established for chemical analysis, the only true method to evaluate a product is a growth assay. All alternative lactose sources should be tested in a growth study to ensure that they are equivalent to a product of established quality. Setting quality-control standards for ingredients will reduce variability of finished feed and improve pig growth performance.

## Implications

- Dried whey, although an excellent source of lactose for use in starter diets, can be extremely variable in product quality.
- Other lactose sources, such as pure lactose and deproteinized whey, are also excellent sources of lactose and can replace the lactose provided by dried whey in starter diets.
- Quality standards to differentiate between superior and inferior whey products and coproducts must be established.
- For dried whey and other lactose sources, quality control standards would include analysis of lactose, ash, protein, solubility, and pH, and in some cases, swine growth assays.

**Figure 2**




Effects of lactose source on weanling pig performance

Source: Nessmith.[12] Means represent a total of 344 weanling pigs (initially 4.4 kg and 14 d of age) with 7–11 pigs per pen and six replicate pens per treatment. Pigs were fed their respective dietary treatments from d 1–14 postweaning then all pigs were fed the same common diet (1.35% lysine) from d 14–28.

abc means with different superscripts differ ($P < .05$)

## References


1. Tomkins T. Factors affecting the quality of milk based products and milk substitutes, and performance of the young pig. *Proc 5th North Carolina Nutr Conf NCSU,* Raleigh, North Carolina. 1989; 13.

2. Zadow JG. *Whey and Lactose Processing*. Elsevier Science Publishing Co., Inc.:New York, New York. 1992.

3. Scott R. *Cheesemaking Practice.* Elsevier Science Publishing Co., Inc.:New York, New York. 1990.

4. Schachtele, A. Personal communication. Land O' Lakes Inc., Arden Hills, MN. 1996.

5. Robinson RK. *Modern Dairy Technology.* Elsevier Science Publishing Co., Inc.:New York, New York. 1983.

6. Sienkiewicz T, Riedel CL. *Whey and Whey Utilization*. Verlag Th. Mann, Gelsenkirchen:Buer, Germany. 1990.

7. Masters K. *Spray Drying Handbook*. Halsted Press:New York, New York. 1979.

8. Pollmann DS, Allee GL, Pope S. Effects of weaning age, source of whey, and lysine level on performance of starter pigs. *J Anim Sci*. 1983; 57 (Suppl.) 86.

9. Sohn KS, de Rodsa BS, Rose ML, Maxwell CV. Alternatives to fish meal and edible grade dried whey in early-weaned pig diets. *J Anim Sci.* 1993; 71(Suppl. 1):15 (Abstr.).

10. Pettigrew JE, Harmon BG, Curtis SE, Cornelius SG, Norton HW, Jensen AH. Milk proteins for artificially reared piglets. III. Efficacy of sodium caseinate and sweet dried whey. *J Anim Sci*. 1977; 45:261–268.

11. Mahan DC. Dried whey is not always dried whey. *Ohio Swine Res. Rep. No. 84–1*. 1983; 1.

12. Nessmith WB, Jr. *The Effects and Possible interactions between various carbohydrate and protein sources on weanling pig performance.* MS Thesis. Kansas State University, Manhattan. 1996.

13. Dove CR, Usery J. Substitution of lactose and amino acids for whey in the diets of pigs weaned at 10 days. *J Anim Sci*. 1996; 74 (Suppl. 1):56 (abstr).