THE EFFECTS OF THE CARBOHYDRATE AND PROTEIN FRACTIONS OF MILK PRODUCTS ON STARTER PIG PERFORMANCE

by

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INTRODUCTION

Producers are currently weaning pigs at four weeks of age or less to increase sow productivity. However, early weaning often results in a lag in performance, including decreased gain and feed intake and increased morbidity and mortality. Nutritionists are presented with an obvious challenge to devise an economical, nutritional regimen to eliminate the postweaning lag in the pig. In order to recommend a sound nutritional program, the weanling pigs biological status must be understood.

Three week old weanling pigs have very immature immune and enzymatic systems. A warm, dry, draft-free environment can help the immune system fight disease while it is maturing; however, the pig also needs time to develop an enzymatically mature digestive system. The enzymes most prevalent at weaning are capable of digesting milk products instead of the plant products which are normally fed. Feed intake is also very low the first two weeks after weaning. Thus, a highly nutritious and digestible diet is essential to maximize performance during this critical period. With these facts in mind, numerous researchers have designed complex, high nutrient density diets for early weaned pigs. These diets commonly contain 20 to 40% milk products, primarily dried whey and skim milk. These milk product additions have proven to be beneficial in increasing gain, intake and feed efficiency. However, limited research has been done to determine whether the protein or carbohydrate fraction of milk products is responsible for the improved performance.

Five trials were conducted to evaluate the components of milk products that are essential for performance of the 21-day old pig. The effect of protein and/or carbohydrate fractions of dried whey on pig performance and nutrient digestibility was studied. In addition, the effect of lactose level and protein source on starter pig performance was investigated. Criteria measured included average daily gain, average daily feed intake, feed efficiency, and digestibility of dry matter, energy and nitrogen.

PROCESSING

1. MILK PRODUCTS

Milk products originally used in the animal feed industry were waste by-products of the cheese-making process or milk designated unfit for human consumption (Scott, 1986). Once these products proved to be economical to produce and valuable feed ingredients for neonatal ruminants and nonruminants, higher quality sources became available. Milk processing methods and ultimate product quality have been shown to have an effect on the performance of weanling pigs (Pollmann et al., 1983b; Mahan, 1984) and young calves (Shillam and Roy, 1962). Robinson (1986) also explained that milk proteins are extremely delicate and can be denatured by heat treatment. Thus, processing techniques and their effects on product quality play a major role in determining the value of milk products in swine diets.

Since raw liquid milk contains approximately 90% water, the primary step in obtaining finished milk products used in the swine industry is the removal of the high moisture content. However, as figure 1 indicates, milk encounters a number of other processing steps before being marketed (Eckles et al., 1951; Webb and Whittier, 1970; Hall and Hendrick, 1971; Lampert, 1975; Warner, 1976; Kessler, 1981; Robinson, 1986; Scott, 1986)

The first processing step for all raw milk must encounter is pasteurization (Warner, 1976). Pasteurization is a process applied to a product with the object of minimizing possible health hazards arising from pathogenic microorganisms associated with milk, by heat treatment with minimal chemical, physical and organoleptic changes in the product. Pasteurization is designed to inactivate pathogenic organisms originating from within the udder, from the exterior of the teats and udder, and from the milking and storage equipment. There are many time-temperature combinations, ranging from 63 C for 30 minutes or 77 C for 15 seconds to 100 C for .01 second,approved for pasteurization of Grade A milk. (Robinson, 1986). Milk is immediately cooled to 10 C after heating. Pasteurization is a relatively mild form of heat treatment. Whey protein denaturation is low (between 5 and 15 percent) and there is relatively little loss of other heat sensitive nutrients (Robinson, 1986). Finot (1983) also found that practically no lysine was rendered unavailable by pasteurization.

After being pasteurized, milk is homogenized and sold for human consumption, separated to obtain butter and skim milk, or fermented to yield cheese and whey. Homogenization is simply the breaking up

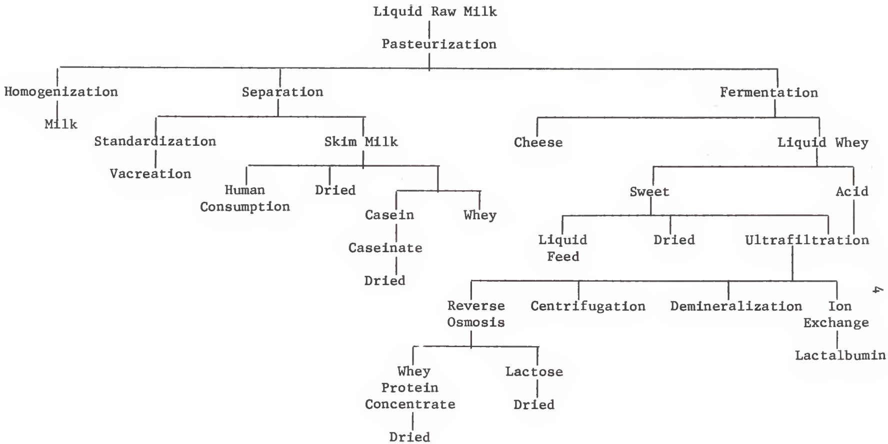
Liquid Raw Milk
Pasteurization
Homogenization
Milk
Separation
Standardization
Vacreation
Skim Milk
Human Consumption
Dried
Casein
Whey
Caseinate
Dried
Fermentation
Cheese
Liquid Whey
Sweet
Acid
Liquid Feed
Dried
Ultrafiltration
Reverse Osmosis
Centrifugation
Demineralization
Ion Exchange
Lactalbumin
Whey Protein Concentrate
Dried
Lactose
Dried

Figure 1.

of fat globules of milk into very fine particles by forcing them through minute openings to prevent separation and hardening of the fat during storage (Eckles et al, 1951).

Separation and fermentation are more detailed processes. Separation is a process whereby an essentially fat-free portion (skim milk) is separated from a fat-rich portion (cream). The process relies on the density difference between the milkfat in the globules and the aqueous phase in which they are dispersed (Robinson, 1986). If milk is allowed to stand, fat rises and creaming is observed with a fat-rich fraction collecting at the surface. Industry uses the density difference to separate skim milk and cream by centrifugation (Lampert, 1975). Early model separators were open or semi-open centrifuges which allow air to flow with the milk; however, entrainment of air in milk inhibits separation. Thus, hermetic or air-tight separators were developed to isolate the separation process from the atmosphere.

Exiting the separator, cream is standardized to the desired fat content by dilution using skim milk or other cream (Eckles et al., 1951). Heat treatment by vacreation then destroys pathogenic organisms and enzymes which may cause spoilage (Robinson, 1986). The vacreator mixes steam with cream and the condensed vapor plus volatiles are removed by flash evaporation under vacuum (Robinson, 1986). After heat treatment, the finished cream product (half-cream, coffee cream, sour cream, whipping cream or butter cream) is ready for packaging or churned into butter.

Separating cream from whole milk also yields skim milk. Skim milk may exit the process here for consumption by diet conscious humans enticed by the low fat and calorie content (Lampert, 1975). Skim milk that is not sold as fluid milk is dried for preservation or further processed to generate casein. Drying of all milk products is accomplished in the same basic manner. The bulk of the water (50 to 80%) is first removed by evaporation before the remainder of the surface absorbed water is removed in a drier (Hall and Hendrick, 1971). The vacuum evaporator used in industry is based on the fact that the boiling point of a liquid is lowered when milk is exposed to a pressure below atmospheric pressure (Robinson, 1986). Skim milk is brought to boil at approximately 70 C in an evaporator with negative pressure to remove the large moisture content. Since a relatively low temperature is used, nutrient denaturation is small (Robinson, 1986). Different types of evaporators remove variable portions of water; however, a drier must be used to completely dry the product.

The two type of driers currently being used in industry are roller and spray driers (Hall and Hendrick, 1971). The principle of roller drying is that milk is applied in a thin film upon the smooth surface of a continuously rotating, steam-heated, metal drum with the dried milk film being continuously scraped off by a stationary knife (Robinson, 1986). Protein denaturation associated with roller drying is high, as an extremely high drying temperature (95 to 150 C) is used (Lampert, 1975). In addition, Finot (1983) showed that roller drying renders 20 to 50% of the total lysine in skim milk unavailable while spray drying blocks only 0 to 2%.

Since there is more protein denaturation with roller driers, spray driers are used to dry nearly all whole milk and about 80% of all skim milk (Lampert, 1975). Spray drying is the instantaneous removal of moisture from a liquid (Robinson, 1986). The liquid is first converted into an atomized fog-like mist to increase the surface area. The atomized liquid is exposed to a flow of hot air that evaporates the moisture and carries the water vapor away while the dry milk particles fall to the bottom of the drying chamber (Lampert, 1975). The dried product is removed from the drying chamber and cooled as quickly as possible to minimize heat damage (Hall and Hendrick, 1971). Spray drying is a gentle drying method as the material to be dried is suspended in air and the drying time is very short (Robinson, 1986). The air inlet temperature can reach 215 C, but due to evaporation, the product temperature will only reach 65 to 75 C (Robinson, 1986). The skim milk is dried to 3 to 4% moisture before being packaged and stored at room temperature (Hall and Hendrick, 1971).

Dried skim milk is not graded by heat treatment; however, it is classified according to the heat treatment to which the raw milk has been subjected before being converted into powder (Robinson, 1986). The classification procedure is based upon the level of undenatured whey proteins in the dried skim milk. This Whey Protein Nitrogen (WPN) index is the amount of undenatured whey protein nitrogen in skim milk solids measured in milligrams per gram of dried skim milk.

The dried skim milk WPN index is normally 8 mg/g. According to the American Dry Milk Institute, Inc. (1971), the heat treatment classifications and corresponding WPN indexes for dried skim milk are low heat, not less than 6 mg/g; medium heat, between 1.5 and 6 mg/g; and high heat, not more than 1.5 mg/g. These levels correspond to less than 25%, 25 to 81% and over 81% denaturation of the whey protein, respectively.

The solubility index, which measures the volume of sediment from 50 ml of reconstituted milk, is another indication of skim milk quality. Robinson (1986) explained that denatured whey proteins will redisperse into a stable suspension when skim milk is reconstituted; however, casein coagulated by high heat treatment will not form a stable suspension, but will appear as sediment. Thus, the solubility index is mainly a measure of the coagulated casein. The American Dry Milk Institute (1971) requires that extra grade skim milk have a maximum solubility index of .5 ml of sediment per 50 ml of reconstituted skim milk or be 99% soluble. Obviously, the lower heat treated, lower denaturated, higher soluble, higher quality dried skim milk is desired for swine diets.

Further processing of skim milk may also yield casein. Very little casein is manufactured in the United States as the federally supported pricing structure for milk encourages the production of dried skim milk rather than casein (Webb and Whittier, 1970). New Zealand and Australia are the major casein producers in the world (Galesloot and Tinbergen, 1984). Acid casein and rennet casein, the two basic types of casein, are named according to the coagulating agent used in production (Lampert, 1975). Lactic, the most common casein, hydrochloric and sulfuric casein are the three types of acid casein produced commercially (Robinson, 1986). Acid casein is produced by adding a dilute acid to liquid skim milk to lower the pH to approximately 4.1. Lowering the pH will dissociate the calcium caseinate complex, causing the casein to coagulate into a gel-like curd (Webb and Whittier, 1970). The curd is washed and dried to produce dry acid casein (Lampert, 1975). Acid casein is insoluble in water and thus soluble caseinates are produced by adding dilute alkali to the acid curd or to water treated dry acid casein (Webb and Whittier, 1970). Calcium and sodium hydroxide are the alkalis most commonly used to produce caseinates. Thus, calcium and sodium caseinate are the caseinates most available to the feed industry. The soluble caseinates must then be roller or spray dried by the methods discussed previously. Drying method and temperature are again very important in maintaining product quality (Robinson, 1986). Rennet casein is usually used in the plastics industry (Robinson, 1986). It is produced by adding calf rennet extract to skim milk and allowing it to coagulate into the gel-like curd which is washed and dried (Lampert, 1975).

Separating casein from skim milk leaves whey as a by-product; however, since very little casein is produced in the United States, the majority of whey used in swine diets is a by-product from the cheese industry (Webb and Whittier, 1970). The method of obtaining whey and cheese from whole milk is very similar to the method of deriving whey and casein from skim milk (Lampert, 1975). In the making of cheese, lactic acid or rennet is added to the milk, causing it to coagulate and curdle (Kessler, 1981). After this fermentation process, the curd is removed and processed into cheese leaving liquid whey as the by-product (Scott, 1986). The liquid whey is segregated and classified according to acidity, as sweet or acid whey.

Sweet whey typically has a pH of 5.8 to 6.6 and titratable acidity of .1 to .2% (Robinson, 1986). Sweet whey is normally derived from the rennet processed or hard cheeses (Mozzarella, Cheddar, Gouda, Edars, etc), as rennet extract does not change the pH and acidity during curd formation (Robinson, 1986). Conversely, acid whey, the by-product of the cottage, ricotta or cream cheese industry, has a pH less than 5.0 and titratable acidity greater than .40% (Robinson, 1986). The feed industry desires sweet whey as the ash and mineral content are typically lower and the protein and lactose content are typically higher than that of acid whey (Robinson, 1986). Scott (1986) explains that industry may add neutralizers to acid whey to increase the pH and lower the acidity to levels representing sweet whey; however, ash levels will also increase and ultimate whey quality is affected. Therefore, the level of ash in whey must be monitored closely. Scott (1986) also theorized that a high quality liquid sweet whey must be used to obtain a dried whey suitable for human or livestock consumption.

Some sweet whey is fed to pigs in the liquid form; however, the majority is concentrated and roller or spray dried as previously discussed in the skim milk section (Hall and Hendrick, 1971). Since whey solids contain approximately 70% lactose, whey must also be crystallized before drying (Robinson, 1986). Crystallization is accomplished by concentrating whey until crystals form spontaneously, a difficult process to control routinely, or by seeding with small quantities of crystals (Webb and Whittier, 1970). Drying method and temperature have a tremendous effect on ultimate whey quality as whey proteins are easily denatured (Robinson, 1986). Renner (1983) found that roller drying reduced available lysine levels in whey by 35.3% while spray drying reduced those levels by only 3.5%. In a growth study, Pollmann et al. (1983b) also demonstrated that pigs fed roller-dried whey have lower average daily gains than pigs fed spray-dried whey. Scott (1986) believes that the product temperature simply becomes too high during roller drying causing whey proteins to be denaturated.

The remaining sweet whey and most acid whey is ultrafiltrated for further processing (Scott, 1986). Ultrafiltration will remove a majority of the water from whey. The semi-concentrated whey may then be subjected to reverse osmosis to remove varying lactose levels and some minerals which yields liquid whey protein concentrate (Scott, 1986). Whey protein concentrate is then spray dried to produce the product used in the swine and dairy industries.

Lactose removed during reverse osmosis is one source of crude lactose. Centrifugation is another method of separating lactose from liquid whey (Kessler, 1981). Crystallized whey is centrifuged, yielding crude lactose and the mother liquid, which contains the proteins and minerals (Robinson, 1986). The crude lactose is further dried to form a 99% lactose finished product (Webb and Whittier, 1970). The mother liquid from centrifuging is often dried down to produce delactosed whey, containing 22 to 24% protein (Webb and Whittier, 1970). Delactosed whey also contains the concentrated mineral portion, and thus, it must be closely analyzed before use as a feed ingredient.

Liquid whey may be demineralized before the lactose is separated. The minerals may also be removed from whey protein concentrate to produce a higher quality demineralized product. However, the most prominent use of demineralization is with whole whey (Scott, 1986). The two main methods for demineralizing whey are ion exchange and electrodialysis (Robinson, 1986). The ion exchange method is more popular since electrodialysis can only achieve 90% demineralization and is more expensive. Robinson (1986) explained that ion exchange is accomplished by trading cations in whey for ammonium ions and anions in whey for bicarbonate ions. The resulting ammonium bicarbonate is recovered for reuse while the demineralized whey is spray dried to create a high quality finished product.

Pure whey protein fractions may also be isolated from liquid whey (Kessler, 1981). Lampert (1975) explained that lactalbumin is the most prominent whey protein with smaller amounts of lactoglobulins and immunoglobulins also being present. Lactalbumin can be extracted by simply adding heat and acid to the whey until the protein fraction separates from the liquid (Webb and Whittier, 1970). However, heating also denatures the lactalbumin, rendering it insoluble and destroying the excellent value as a foodstuff (Galesloot and Tinbergen, 1984). Robinson (1986) lists two recent approaches to isolating whey protein without denaturizing the product. The first method involves passing whey through a column containing porous, silica microbeads which specifically absorb protein. The recovered protein fractions are undenatured and contain less than 3-4% ash. The second process developed by Bio-Isolates uses ion exchange to manufacture a 97% protein powder from whey. The product has a digestibility of 99%, biological value of 94% and protein efficiency ratio of 3.2. The protein efficiency ratio is lower for whey (3.0), whey protein concentrate (3.0), skim milk (2.8), casein (2.5) and heat treated lactalbumin (2.8), which provides further evidence of the effect of manufacturing on milk product quality (Galesloot and Tinbergen, 1984).

2. ISOLATED SOY PROTEIN

Soy protein products are available in a number of forms, varying in composition, particle size, solubility and percent protein (Wolf, 1971). The Federal Drug Administration classifies soy proteins according to protein level as soy flour (less than 65% protein), soy protein concentrate (65-89% protein), or isolated soy protein (90% and higher protein) (Campbell, 1979). Soy flour and soy protein concentrate contain a portion of the insoluble and partly indigestible soy carbohydrate fraction; however, all carbohydrate fractions are removed during the production of isolated soy protein. The process results in a highly digestible product (De, 1971).

Isolated soy protein production for industrial use began in the 1930's as a replacement for casein in paper coatings (Circle and Smith, 1972). Since an edible grade was developed in 1959, isolated soy protein has been compared to casein in infant formulas (Theuer, 1983), food products (Galesloot and Tinbergen, 1984) and starter pig diets (Mateo and Veum, 1980; and Giesting et al., 1985). As is the case in milk processing, the method of processing plays a major role in determining isolated soy protein quality. De (1971) found that industrial and edible grade isolated soy protein vary in amino acid composition and protein degradation. Edible isolated soy protein is usually derived from the highest quality soybeans and thus, varies less in composition (Meyer and Williams, 1975). The soybeans are cracked, dehulled, flaked, solvent extracted and desolventized before entering the protein isolation process as unheated, defatted flakes (Smith, 1977). Concentrating the protein by isoelectric separation is possible since soy protein globulins have a minimum solubility at pH 4.5, similar to that of milk (Meyer, 1967). The protein is solubilized by dilute alkali (pH 7-9), and the fibrous residue is removed by screening and centrifugation (Meyer, 1967). The remaining supernatant is adjusted to pH 4.5 to precipitate the major protein fraction into a fine white curd (Meyer and Williams, 1975). The curd is then separated and washed to remove soluble defatted flake constituents. The curd may be dried as such, or it can be neutralized with food-grade alkali to solubilize the protein and then be dried (Meyer and Williams, 1975). Isolated soy protein is customarily spray dried thus the heat damaging risk of roller drying is reduced (Meyer, 1967).

DRIED WHEY

The milk products processing section describes the numerous manufacturing steps that raw milk must encounter before yielding dried whey. Each step adds to the variability of the final product (Webb and Whittier, 1970). The original raw milk may also vary according to season, milking interval, stage of lactation and individual cow breed, condition, and feeding regimen (Eckles et al., 1951). Therefore, ultimate dried whey chemical analysis values may vary extensively. Hall and Hendrick (1971) gave the following ranges as examples:

	%
Lactose	65.0-88.0
Protein	1.0-17.0
Ash	0.7-10.0
Fat	0.5- 2.0
Dry Matter	85.0-98.0
Lactic Acid	0.1-12.0

Industry commonly uses less fluctuating values, as listed by Pond and Maner (1984), for lactose (71-74%), protein (12.0-13.4%), ash (7.9-10.3%), and dry matter (93-96.5%); however, when formulating starter diets containing dried whey, nutritionists must still be aware of the compositional variance. Analyzed values also indicate little about the heating severity and consequent protein denaturation related to whey processing (Robinson, 1986). Therefore, Pollmann et al. (1983b) and Mahan (1984) evaluated whey quality in starter pig diets.

Mahan (1984) compared the effects of edible grade and feed grade whey on starter pig performance. The whey sources were very similar in analysis, containing 12.3 to 12.6% protein, 2.24% titratable acidity and a white-yellow color. Ash content was the major difference between whey sources, as edible grade contained 7.6% compared to 10.7% for feed grade. A corn-soybean meal basal diet was used with 25% being the dried whey inclusion level. The feed grade whey source did not improve swine performance over that of pigs fed the basal diet; whereas, the edible grade source improved average daily gain and feed intake. Mahan (1984) concluded that a high quality, edible grade product must be used as whey quality appears essential for young swine. Stoner et al. (1986) also found no improvement in daily gain, feed intake or feed efficiency for pigs fed 0, 10 or 20% feed grade dried whey. In a subsequent trial, Stoner et al. (1985) discovered that pigs fed a diet containing 20% edible grade dried whey gained faster and were more feed efficient than pigs fed a corn-soybean meal diet.

Pollmann et al. (1983b) also demonstrated the importance of whey quality in a 2 x 3 factorial consisting of two whey sources (roller dried, spray dried) and three lysine levels (.90, 1.05, 1.20%). At the lowest lysine level, whey source did not effect average daily gain or feed efficiency. However, as lysine level increased, pig performance improved and whey source differences became apparent. Pigs fed the 20% spray dried whey diet had higher average daily gain and were more feed efficient than pigs fed the 20% roller dried whey diets at the higher lysine levels. In a separate 2 x 3 factorial, evaluating the effect of adding 0 or 20% roller dried whey at varying levels of lysine (.90, 1.05, 1.20%), Pollmann et al. (1983b) discovered that roller dried whey did not improve starter pig performance. The results of these trials emphasize the importance of using a high quality whey when formulating starter diets.

Pollmann et al. (1983b) was also interested in determining the optimum lysine level for 20% dried whey starter diets. One trial found a linear improvement in average daily gain and feed efficiency when the lysine level was increased from .90 to 1.20%. A second 2 x 3 factorial, evaluating two spray dried whey levels (0 or 20%) and three lysine levels (1.2, 1.3 or 1.4), revealed whey additions increased gain by 5.6% with the lysine effect being a quadratic improvement. Pollmann et al. (1983a) analyzed varying lysine levels (.95, 1.05, 1.15, 1.25, 1.35%) in 20% dried whey starter diets. Increasing lysine level to 1.25% improved average daily gain and feed efficiency; however, gain was reduced at 1.35% lysine. Consequently, the researchers concluded that pigs weaned at 3 to 4 weeks of age and fed a corn-soybean meal diet with 20% whey require 1.25% lysine. Fralick and Cline (1983) also compared varying lysine levels (.90, 1.20%) in dried whey diets and concluded that pigs fed supplemental lysine gain faster than those fed a corn-soybean meal basal diet.

Mahan (1984), Fralick and Cline (1983) and Pollmann et al. (1983a,b) demonstrated that with the appropriate lysine level and whey source, dried whey additions will improve average daily gain and feed efficiency. These data cast some doubt on earlier trials that found no response to dried whey when low lysine levels or an unspecified whey source was used.

In a 2 x 2 factorial, Meade et al. (1965) analyzed dried whey (0, 10%) and fish meal (0, 3%) additions to 3-week old starter pig diets. Neither component improved average daily gain or feed efficiency over the corn-soybean meal control. However, the calculated lysine levels (.84 to .96) were considerably lower than suggested by Pollmann et al. (1983a), and the whey drying method was not specified. Hall and Hendrick (1971) explained that the harsher roller drying was still very popular during the mid 1960's when this trial was conducted.

Wahlstrom et al. (1974) also found that 10% low lactose dried whey had no effect on average daily gain, average daily feed intake, or feed efficiency when added with or without 5% sugar or .5% salt to a 10% oats, corn-soybean meal starter diet. The low lactose whey quality may be questioned as it contained 14.1% ash. Robinson (1986) explained that low lactose whey is formed by simply removing a portion of the lactose. The process concentrates the desirable protein and amino acids; however, unless demineralized, the undesirable ash and salt content are also concentrated to extremely high levels. The lysine levels used in the trial were also slightly low at .9 to 1.0%.

Dried whey additions have also proven beneficial in some experiments with unspecified whey quality or questionable lysine levels. Miller et al. (1971) discovered the addition of 7.5% dried whey improved average daily gain and feed efficiency of pigs fed a 16% protein negative control diet. The 7.5% dried whey diet also provided equal performance and less expensive gains than the 19% protein, positive control, complex diet. Newman (1985) determined that pigs fed complex diets containing 15% dried whey gained faster and were more feed efficient than pigs fed simple corn-soybean meal or barley-soybean meal diets. The complex diets also contained 10% oat groats and 3% lard; thus, dried whey may not be responsible for the entire increase in performance.

Graham et al. (1981) compared a 20% protein, corn-soybean meal, 10% rolled oats diet to diets containing 25% delactosed whey, 51% lactose or 15% skim milk. Pigs fed the 25% delactosed whey diet had higher average daily gain than pigs fed the 15% skim milk or control diets. Feed efficiency and feed intake differences were not significant, although the numerically highest average daily feed intake occurred when pigs were fed the 25% delactosed whey diet. Pope and Allee (1982) also found delactosed whey to be beneficial to starter pig performance. Delactosed whey from two different sources and dried whey were compared to a 1.2% lysine, milo-soybean meal diet. Three-week old pigs fed the 20% dried whey diet or the 20% delactosed whey diets were heavier two and five weeks postweaning than pigs fed the basal diet. Clarkson and Allee (1982) supplemented delactosed whey for 20% dried whey on a protein basis rather than by equal weight and found no difference in pig performance. However, pigs fed either whey diet had higher average daily gains at two and five weeks postweaning than pigs fed the 1.2% lysine, milo-soybean meal control diet.

In a 2 x 2 factorial, Cera and Mahan (1985) evaluated corn oil (0, 6%) and dried whey (0, 25%) additions to starter pig diets. The main effects of the 25% dried whey diets revealed higher average daily gains during each of the 4 weeks postweaning and improved feed utilization during the first 3 weeks. The addition of 6% corn oil to diets containing dried whey did not effect performance; however, a constant calorie-lysine ratio was not maintained. Stahly et al. (1982) combined two lysine (1.10, 1.18%), two whey (0, 10%) and two lard (0, 6%) levels to form eight dietary treatments to analyze the effects of calorie-lysine ratio, spray-dried whey, and fat on starter pig performance. The addition of 10% spray-dried whey improved daily gain by 7%, feed efficiency by 3%, and survival by 1% during the 4-week postweaning period. Average daily feed intake and average daily gain were depressed by the addition of fat,regardless of the presence of whey in the diet, unless a constant calorie-lysine ratio was maintained. The dietary inclusion of fat in the corn-soy-whey diets enhanced daily gain and feed efficiency when a constant calorie-lysine ratio was maintained. The authors concluded that the presence of spray-dried whey in the diet enhances the ability of weanling pigs to utilize dietary fat. In concurrence, Cera and Mahan (1985) reported that dried whey additions resulted in an improvement in apparent fat digestibility. Van Wormer and Pollmann (1985) also found the addition of 4% choice white grease improved the feed efficiency of pigs fed 20% spray-dried whey diets.

Thus, it can be concluded that high quality, spray-dried, edible grade whey is beneficial to starter pig performance when other dietary nutrients, particularly lysine, are adequate. However, the mode of action deriving the improvement in performance is still unclear. Among limited research investigating the mode of action, Owsley et al. (1986a) discovered a 20% dried whey diet was higher in dry matter and energy digestibility than a corn-soybean meal basal diet for pigs weaned at 28 days of age. Owsley et al. (1986b) also found that pigs fed the 20% dried whey diet had higher total intestinal trypsin, chymotrypsin and amylase activity than pigs fed the 1.2% lysine control; however, no differences were found when enzyme activity was calculated as units per kilogram of body weight or units per gram of pancreas. The authors theorized that the increase in feed intake caused by dried whey additions to the diet immediately after weaning will increase pancreas weight and the amount of pancreatic enzymes synthesized and secreted, thus improving pig performance. Graham et al. (1981) also found pigs fed a 25% dried whey diet had the highest amylase and protease enzyme activity in the pancreas and small and large intestines. The authors also felt that enzyme activities appeared to be influenced by the higher feed consumption and gains for the pigs fed the dried whey diet. Total lactase activity in the small intestine mucosa and both the small and large intestine contents was also higher when dried whey was included in the diet. Lindemann et al. (1986), who also examined the effect of dried whey on digestive enzyme levels, found that pigs fed a diet containing 20% dried whey tended to have larger pancreases and greater pancreatic and gastric enzyme activity per gram of pancreas for all pancreatic enzymes. It was concluded that the pig has sufficient pancreatic and gastric enzyme activity so that performance should not be limited; however, diet digestibility and subsequent pig performance may be more directly related to the extent of release of these enzymes into the intestines. The data suggests that the presence of dried whey in the diet will increase the amount of enzymes presence in the intestinal tract resulting in improved digestibility and performance. Cera et al. (1987) also investigated the dried whey mode of action by studying small intestinal growth and jejunal morphology directly after weaning. Weaning resulted in a 3-fold reduction in villus height by 3 days postweaning; however, addition of 25% dried whey to the basal diet had no influence on the villus height reduction.

Although the mode of action of dried whey is still controversial, most researchers agree that early weaned pig performance will improve when a high quality dried whey is included in the diet. However, the optimum inclusion level to be used is also debatable. Becker et al. (1957) conducted the first work analyzing whey level in starter diets. The dried whey levels used in the first trial were 0, 30 and 60%. The second trial analyzed 0, 10, 20 and 30% dried whey additions. Although dried whey additions did not improve pig performance over a simple corn-soybean meal diet, the dried whey quality was questionable as a roller dried product was used. Orr et al. (1972) conducted two feeding trials and one nitrogen balance trial to investigate the optimum whey level. A 19% protein diet containing 10% skim milk and 10% oat groats served as the positive control with a 16% protein, corn-soybean meal grower ration serving as the negative control. Dried whey (5, 10, 15, or 20%) replaced corn in the negative control diet. In the first feeding trial, pigs fed the 15 or 20% dried whey diets gained as rapidly as pigs fed the positive control. In the second feeding trial, increasing dried whey level resulted in a linear improvement in average daily gain. In the nitrogen balance study, nitrogen retention improved as whey level increased from 0 to 15%.

Clarkson and Allee (1982) added spray-dried whey at the rate of 10, 20 or 30% to a milo-soybean meal diet with lysine level remaining constant at 1.2%. Pigs fed the 20% dried whey diet gained faster at two and five weeks postweaning than pigs fed the control. Ten percent dried whey did not improve performance over the control, and 30%

dried whey did not have an advantage over 20% dried whey. Therefore, 20% was concluded to be the optimum inclusion level. Fralick and Cline (1983) found similar results when comparing 0, 15 and 30% dried whey in a corn-soybean meal starter diet. Pigs fed the diet containing 15% dried whey gained faster than those fed the control and no particular advantage was found at the 30% dried whey level.

When evaluating barley particle size and spray dried whey level (0, 10, or 20%), Goodband and Hines (1987) found average daily gain and average daily feed intake increased linearly as whey level increased. Using the same whey levels, Thaler et al. (1986) also found a linear increase in average daily gain, average daily feed intake and feed efficiency. Thaler et al. (1986) conducted a second experiment to determine the optimum whey level (0, 5, 10, 15 or 20%) when copper sulfate was present in the diet. Results indicate that copper sulfate may enhance the dried whey effect on starter pig performance as the 5% dried whey addition produced the same response as the 20% dried whey addition when copper sulfate was present in both diets. Edmonds and Baker (1984) also reported an interaction for copper sulfate and dried whey. The inclusion of 25% dried whey or 250 ppm copper in starter diets improved average daily gain and feed efficiency as compared to the corn-soybean meal control. An additive effect was found as pigs fed diets containing copper sulfate and dried whey gained faster than pigs fed diets containing the additives separately.

Mahan et al. (1981) evaluated the optimum inclusion level of dried whey in diets for pigs weaned at 14 days of age. The whey levels evaluated were 0, 15, 20, 25, 30 and 35%. Average daily gain and average daily feed intake were improved linearly as whey level increased. The results indicate that the optimum inclusion level for dried whey may be higher than 20% for pigs weaned earlier than three weeks of age.

The appropriate weaning age and feeding length for optimum whey utilization has also been subject to question. Pollmann et al. (1983b) weaned pigs at 2, 3, 4 or 5 weeks and fed a 1.3% lysine, milo-soybean meal diet with or without 20% dried whey to determine the weaning age effect. Pigs weaned at all ages fed the 20% whey diet weighed more at 8 weeks than those fed the diet without whey. Pigs weaned at 3 to 5 weeks performed similarly and were heavier at eight weeks than those weaned at two weeks. The data suggests that pigs weaned earlier than three weeks may require higher nutrient levels than those provided in this trial. Pope and Allee (1982) evaluated the length of time a 20% dried whey diet should be fed to pigs weaned at three weeks. The dried whey diet was fed for 1, 2, 3, 4 or 5 weeks postweaning. Pigs fed the 20% whey diet for two weeks performed similarly to pigs fed the whey diet for five weeks. Feeding dried whey for only two weeks also markedly reduced the cost of gain. Martino and Mahan (1983) also examined whey feeding length by feeding a 25% dried whey diet for 1, 2, or 3 weeks postweaning. Pigs consuming the dried whey diet had higher growth rates and feed intakes with longer access to the dried whey diet. The improvement in gain and feed intake was also enhanced to a greater extent with lighter weaning weight pigs (4.54 kg). In a nitrogen balance study, the lighter weight pigs also had greater relative nitrogen retention than pigs with a heavier weaning weight. They suggested feeding a dried whey diet for 2 to 3 weeks postweaning for pigs weighing less than 4.54 kg and only for one week for heavier pigs.

In addition to dried whey and delactosed whey, demineralized whey and whey protein concentrate are additional whey based products available to the swine industry. The inclusion of demineralized whey in starter pig diets has not been investigated. However, Robinson (1986) explained that removing the minerals in the demineralized whey production process elevates the lactose and protein content. Thus, the expected feeding value for demineralized whey would be equal or superior to a high quality dried whey. Cinq-Mars et al. (1986) did examine the effect of whey protein concentrate on early weaned pig performance. Pigs fed diets containing 16.2 or 33.7% whey protein concentrate gained faster and were more feed efficient than pigs fed diets without whey protein concentrate. No performance differences were found between whey protein concentrate levels. The results indicate a level of whey protein concentrate of 16.2% is adequate to improve starter pig performance.

The effect of dried skim milk-dried whey combinations on starter pig performance has also been investigated. Danielson et al. (1960) found that pigs weaned at 16 days had the highest average daily gain when fed a diet containing 30% skim milk and 10% dried whey. The other milk product combinations used were 40%-0%, 20%-20%, 10%-30%, and 0%-40%; skim milk and dried whey, respectively. Pigs fed all milk product combinations showed superior performance to those fed the corn-soybean control diet without milk product. The optimum dried skim milk-dried whey ratio can't be determined from this trial as the whey was roller dried. Results from this trial, Martino and Mahan (1983), and Pollmann et al. (1983b) indicate light weight pigs or pigs weaned earlier than three weeks may need higher milk product inclusion levels than 20% to obtain peak performance. Nelssen (1986) reported that pigs fed a high nutrient density diet containing 20% dried whey and 20% skim milk gained faster and were more feed efficient than pigs fed a 20% dried whey diet or a 1.25% lysine, corn-soybean meal diet. Based on these results, a three phase starter program was recommended for early weaned pigs to optimize performance and minimize production costs. Phase one involves feeding the high nutrient density diet until pigs reached 7.0 kg body weight. From 7.0 to 11.5 kg, a 1.25% lysine, corn-soybean meal diet containing dried whey is fed. The last phase calls for a 1.10% lysine, grain-soybean meal diet to be fed from 11.5 to 23 kg.

DRIED SKIM MILK

Research conducted with dried skim milk has taken a different direction than dried whey research. Instead of concentrating on determining the optimum inclusion level, feeding length, or possible lysine level interaction, most researchers have simply used skim milk in complex diets or as a means of comparing milk protein with other protein sources. Dried skim milk is an excellent protein source as it contains 33.5% protein and 2.4% lysine (NRC, 1979).

The main difference between the composition of whey and skim milk is that skim milk contains a large casein portion in addition to the whey fractions (lactose, lactalbumin and minerals); (Robinson, 1986). The addition of casein allows skim milk to have the higher protein and amino acid levels while lowering the percentages of mineral and ash. Dried skim milk also encounters fewer processing steps and, thus, varies less in composition and quality than whey (Lampert, 1975). Processing effects on quality must still be considered as heat can denature the whey proteins and insolubilize the casein (Robinson, 1986).

When feeding a complex diet containing dried skim milk, several researchers have shown an improvement in performance of pigs weaned at three weeks. However, it is difficult to credit skim milk with the entire response as other nutrients were also added to form the complex diet. A corn-soybean meal diet was used as the simple diet in the following experiments. Meade et al. (1969b) found pigs fed complex diets containing 10% dried skim milk, 10% sucrose and 3% fish meal had higher average daily gain and average daily feed intake than pigs fed the simple diet. Meade et al. (1969a) fed a similar complex diet containing 5% skim milk, 5% sucrose and 3% fish meal; however, no response was found. The complex diet used by Bayley and Carlson (1970) contained 15% skim milk, 25% wheat, 5% oat groats and 5% fish meal. Pigs fed the complex diet gained faster than pigs fed the simple diet. Himmelberg et al. (1985) conducted five trials with 30% dried skim milk, 10% sugar, 5% dried fish solubles and 1% dried brewers yeast in the complex diet. The optimum postweaning time for changing pigs from a complex to a simple diet was also explored. The complex diet improved average daily gain, average daily feed intake and feed efficiency in all trials. Average daily gain also increased linearly as day of change from the complex to the simple diet increased from 5 to 20 days postweaning. The effect was more pronounced for lighter weight pigs. Similar to the results of the dried whey research, these results indicate lighter weight pigs may require diets containing high levels of milk products to optimize performance.

Okai et al. (1976) also investigated the effect of diet complexity on starter pig performance. Pigs were allotted to dietary treatment at 10 days of age and were weaned at three weeks. Simple, semi-complex or complex diets were fed during the prestarter and postweaning phases. The simple diet was a wheat-barley-soybean meal diet. The semi-complex diet additionally contained 25% oat groats, 6.4% herring meal and 10% skim milk. The complex diet was semi-purified and contained dextrose, sucrose, corn starch, soybean meal, 11% herring meal, 20% dried skim milk, 15% dried whey and 3% vermiculite. Creep feed intake was extremely low for all diets and no differences were found in average daily gain or feed efficiency in the preweaning phase. In the postweaning period, an increase in diet complexity led to a corresponding increase in feed intake and weight gain. The results indicate young pigs utilized the semi-complex and complex diets extremely well. It is difficult to credit skim milk with the entire improvement in performance found in any of these trials because the diets contained a variety of other ingredients. Further complicating the results, lysine level increased linearly with diet complexity in most trials.

A few researchers have explored the addition of dried skim milk to starter diets without other ingredients confounding the results. Kornegay et al. (1974) and Wahlstrom et al. (1974) compared a corn-soybean meal diet with a 10% dried skim milk diet with or without 5% sugar. No performance differences due to dietary treatment were found. The calculated lysine levels (0.9 to 1.0%) in both trials were lower than those recommended by Pollmann et al. (1983a) for the three-week old pig. Meade et al. (1965) added 10% dried skim milk to a corn-soybean meal diet containing 20% rolled oats and 10% sucrose. Pigs fed the 10% dried skim milk diet tended to gain faster and were more feed efficient than pigs fed the control. It was suggested that pigs fed the diet containing skim milk may have digested dry matter and protein more efficiently than pigs fed the control. Seve (1984) also found an improvement in average daily gain when 10 or 15% dried skim milk was added to the basal diet. Higher protein quality and digestibility was again attributed as the reason for the improvement in performance. Owsley et al. (1986a) examined the nutrient digestibility of 1.15% lysine, corn-soybean meal diets with or without the addition of 20% dried skim milk. Compared to the control, the addition of dried skim milk to the diet increased nitrogen, energy, and dry matter digestibility. Graham et al. (1981) further investigated the digestibility of diets containing skim milk by analyzing digestive enzyme activity and performance of two-week old weaned pigs. Pigs fed the 15% skim milk diet tended to gain faster and be more feed efficient than pigs fed the 10% rolled oats, corn-soybean meal diet. Dietary treatment had no effect on total amylase or protease activity in the pancreas, small and large intestine contents, or in the small intestine mucosa; however, total lactase activity in the small intestinal mucosa and the small and large intestine contents was higher when dried skim milk was provided in the diet. The high lactase activity would suggest that the lactose fraction of skim milk may be responsible for a large portion of the improvement in performance.

Giesting et al. (1985) conducted three trials to determine whether the major protein (casein) or carbohydrate (lactose) fraction of skim milk is responsible for the beneficial performance found when skim milk is fed to the young pig. Casein, soy protein concentrate or isolated soy protein were added along with lactose or corn starch to the basal diet to simulate the protein and carbohydrate fractions provided by a 25% dried skim milk diet. A negative control, corn-soybean meal diet and a positive control, corn-soybean meal, 25% skim milk diet were also fed. Pigs fed the positive control diet had higher average daily gains and average daily feed intake than pigs fed the negative control. Diets containing lactose or casein also supported higher gains and feed intake than the negative control, but the corresponding values were lower than those listed for pigs fed the positive control. Pigs fed the diet containing both lactose and casein performed similarly to pigs fed the positive control, indicating an additive effect to the protein and carbohydrate sources. From this trial, it appears that casein and lactose are equally important in explaining the beneficial response found when feeding dried skim milk to the young pig.

As explained earlier, the majority of the research has used skim milk as a means of comparing alternative protein sources. Fish meal, peanut meal, full-fat soybeans, soybean meal and isolated soy protein have been compared to skim milk as protein sources. The same general results were found in most trials with skim milk being the superior protein for the young pig.

deMoura and Fowler (1983) found pigs gained faster when equal parts of fish meal and skim milk were used as the protein source as compared to full-fat soybeans and soybean meal. Lucas et al. (1959) also combined fish meal and skim milk as a protein source. No improvement in performance was found when skim milk was added to the diet as compared to when fish meal was the only protein source. However, the skim milk was roller dried and, thus, a portion of the protein may have been denatured. Average daily gain and feed efficiency were also poor for all treatments.

Bayley and Holmes (1972) fed semi-purified diets to pigs weaned at ten days of age. The protein sources analyzed were dried skim milk, soy protein flour, fish protein concentrate and a fish protein concentrate-dried whey combination. Pigs fed the diet containing dried skim milk gained faster than pigs fed diets containing the other protein sources. Partridge (1981) demonstrated that pigs fed diets containing dried skim milk as the only protein source gained faster during the starter phase than pigs fed diets containing a combination of skim milk and soybean meal. The pigs consuming the high skim milk diet during the starter phase also increased their weight advantage by the completion of the grower period.

Investigating the mode of action of dried skim milk, Newport (1979) used half or total replacement of dried skim milk with a combination of dried whey and fish protein concentrate as the protein supplement in liquid diets for pigs weaned at two days of age. Protein digestion was also studied in pigs sacrificed at six days of age. A 26-day growth trial was also conducted. Average daily gain was slightly improved when half of the dried skim milk was replaced. Total replacement of skim milk reduced gain and the gain to feed ratio. Increasing the proportion of fish protein reduced apparent digestibility, nitrogen retention, total pepsin activity in the stomach, and trypsin and chymotrypsin activity in the small intestine. Trypsin and chymotrypsin activity in the pancreas were not affected by the source of dietary protein. It was suggested that total replacement of dried skim milk with fish protein concentrate and dried whey may increase the flow rate of digesta through the small intestine. The author theorized that the increased rate of flow, reduced nitrogen digestibility and reduced amounts of trypsin and chymotrypsin in the digesta could reduce the efficiency of protein digestion and adversely affect performance. However, using 35-day old pigs, Asche et al. (1987) found digesta flowed faster when skim milk was the only protein source as compared to soybean meal and corn gluten meal. However, skim milk protein was digested and absorbed more rapidly than the other proteins.

Combs et al. (1963) compared dried skim milk, soybean meal and fish meal as protein sources for the young pig. Pigs fed the diet containing dried skim milk gained faster, consumed more feed and were more feed efficient than pigs fed diets containing the other protein sources. Digestibility information was also collected when pigs were 3 to 4, 5 to 6 and 7 to 8 weeks of age. Including dried skim milk as the protein source improved dry matter, nitrogen and energy digestibility during the periods when pigs were 3 to 4 and 5 to 6 weeks old. Dietary treatment did not affect digestibility during the last time period. Hays et al. (1959) was also interested in the effect of protein source on growth and diet digestibility as the pig increases in age. Soybean meal and spray dried skim milk were the protein sources evaluated in this 35-day growth trial. Digestibility determinations were also made at two and five weeks of age. Pigs fed diets containing skim milk gained faster and were more feed efficient than pigs fed diets containing soybean meal. The skim milk diet also improved dry matter digestibility, nitrogen digestibility and apparent nitrogen retention for two and five week old pigs. The digestibility differences between protein sources were less at five weeks as the digestibility of the soybean meal diet improved.

Lecce et al. (1979) determined soy flour can replace a portion of dried skim milk as the protein source for pigs over three weeks of age without adversely affecting performance. However, average daily gain was reduced when soy flour was included as a portion of the protein source for pigs less than three weeks old. Pekas et al. (1964) found pigs gained faster and were more feed efficient from 1 to 28 days of age when skim milk was the only protein source as compared to soybean meal. However, dietary treatment had no effect on four to five week performance. The literature indicates the performance advantage found when feeding dried skim milk as the only protein source diminishes as the pig becomes older. Exactly when the skim milk advantage is lost is still questionable.

Wilson and Leibholz (1981a,b,c,d) conducted the most in-depth research investigating milk and soy proteins and their effects on digestion in the pig between 7 and 35 days of age. Diets containing dried skim milk as the protein source were compared to diets containing soybean meal, soybean flour or isolated soy protein in various experiments. The inclusion of dried skim milk in the diet improved average daily gain, feed efficiency, dry matter digestibility, nitrogen digestibility, amino acid digestibility and nitrogen retention in all trials, regardless of the soy protein source. Digestibility of the skim milk diets remained similar for pigs at 14 and 35 days of age, while digestibility of the soy protein diets increased with increasing pig age. The author concluded that the reduced performance of young pigs fed soybean protein diets is the result of the lower digestion of amino acids, nitrogen and dry matter prior to the ileum as compared to pigs fed milk protein diets.

CASEIN

The most abundant milk protein is casein. Casein is used principally as an adhesive or binder in paper coating, wood glue, concrete and plastic (Robinson, 1986). In recent years, more attention has been given to the utilization of casein in human nutrition and research trials (Fox, 1983). Casein has been used as a substitute for skim milk by swine researchers interested in comparing milk protein with other protein sources. By using casein instead of skim milk, the researcher may investigate protein source effects, while reducing the possibility of a carbohydrate source interaction.

Galesloot and Tinbergen (1984) suggested casein should be an excellent feed ingredient for nonruminant diets, as it contains high levels of all essential amino acids. However, the actual performance response found in feeding trials has been extremely variable. The reason casein hasn't consistently improved pig performance, is not fully understood. Poor casein quality may be suspected, as Erbersdobler (1983) demonstrated that overheating casein during processing may reduce total digestibility from 95 to 75%. However, Robinson (1986) explained that the processing temperature must be significantly higher than normal to cause protein denaturation since casein is much more stable than whey protein. Webb and Whittier (1970) also explained that the quality and composition of casein doesn't vary as much as the composition of dried whey and skim milk.

When adding 2% casein to the corn-soybean meal, control diet, Miller et al. (1971) found an improvement in rate and efficiency of gain for three-week old pigs. Giesting et al. (1985) also demonstrated a relatively low level of casein in the diet will improve pig performance. As explained in the dried skim milk section, casein was added to a corn-soybean meal diet to simulate the casein fraction provided by a 25% skim milk diet. Pigs fed the diet containing casein had improved average daily gains and feed efficiency as compared to pigs fed the corn-soybean meal negative control; however, the gains of pigs fed the casein diet were still lower than those of pigs fed a 25% dried skim milk, corn-soybean meal diet. These trials indicate that low levels of casein in the diet will improve pig performance.

The results have been less favorable in experiments where casein was the only protein supplement. Walker et al. (1986a) conducted the only research showing an improvement in performance when high levels of casein were compared to other protein sources. Casein, isolated soy protein, ethanol extracted soy protein and soybean meal were the protein sources compared in .91% lysine, corn-based diets for three-week old pigs. Pigs fed the diet containing casein had higher average daily gains than pigs fed the diets containing ethanol extracted soy protein or soybean meal. There was no difference in average daily gain between pigs fed casein or isolated soy protein as the protein source. Pigs fed the casein diet were more feed efficient than pigs fed any of the soy protein diets during the first week on trial; however, treatment differences diminished after the first week. Dry matter, lysine, valine, methionine and proline digestibilities were higher for pigs fed the diet containing casein than for pigs fed any of the soy protein diets. The authors felt the difference in digestibility and possibly in amino acid availability might account for the differences in average daily gain and feed efficiency. In a follow-up study, Walker et al. (1986b) found no differences in apparent nitrogen or essential amino acid availability between diets containing casein, hydrolyzed casein, isolated soy protein or ethanol extracted soy protein as the protein source. However, pigs fed these protein sources had higher apparent nitrogen and essential amino acid availability than pigs fed diets containing soybean meal as the protein source.

Roos et al. (1986a,b) formulated corn-soy protein concentrate and corn-casein diets to evaluate the effect of fumaric acid on starter pig performance. There were no differences in average daily gain, average daily feed intake or feed efficiency due to protein source. Rodriguez and Young (1980) also found no effect on starter pig performance when comparing a casein-buttermilk combination with herring meal as a protein source. In a 2 x 2 factorial, Richard et al. (1983) examined the effect of protein source (casein or isolated soy protein) and fat type (tallow or soybean oil) on starter pig performance and body composition. Protein source had no effect on pig performance, body composition, bone weight or bone calcium. Etheridge et al. (1984) found no differences in performance, digestibility, blood composition or intestinal microflora between pigs fed an oat groats-casein diet and those fed a corn-soybean meal diet. From these trials, it appears that casein does not significantly improve weanling pig performance when it is used as the only protein source in the diet.

The response found when pigs were fed diets containing casein as the only protein source has also been very inconsistent for pigs less than three-weeks old. Pond et al. (1971) fed liquid diets containing 33% casein, isolated soy protein or fish protein concentrate to pigs weaned at two to three days of age. There were no differences in performance between pigs fed casein and fish protein concentrate diets; however, both diets were superior in average daily gain and feed efficiency as compared to diets containing isolated soy protein as the sole protein source. Since the protein sources have different amino acid profiles and were added at the same level, the varying amino acid levels in the diet may have discriminated against isolated soy protein. Mateo and Veum (1980) also compared casein and isolated soy protein as protein sources for 1 to 29 day old pigs. Pigs fed the diet containing casein gained faster and were more feed efficient from 1 to 15 days of age than pigs fed diets containing isolated soy protein. Protein source had no effect on pig performance from 15 to

29 days of age. Digestibility criteria were also analyzed from 11 to 15 days of age. Ether extract, crude protein, energy, ash and dry matter digestibilities were greater for pigs fed diets containing casein than for those fed the diets containing isolated soy protein. Pigs fed a dried skim milk control diet had digestibility values very similar to those fed the casein diet; however, from 1 to 15 days of age, they gained faster and were more feed efficient. The results indicate casein is superior to isolated soy protein, but inferior to skim milk as the sole protein source for the extremely young pig. However, the advantage over isolated soy protein rapidly deteriorates over time. Maner et al. (1962) found the rate of passage for soy protein slows as the pig gets older; whereas, the rate of passage for casein is constant over time. The change in the rate of passage for isolated soy protein may explain the decrease in the advantage for casein as the pig increases in age.

Leibholz (1982) fed dry diets containing skim milk, casein, isolated soy protein, soy protein concentrate, fish meal or soybean meal as protein sources to pigs between 7 and 28 days of age and found results similar to Mateo and Veum (1980). Pigs fed the casein diet had higher average daily gains and were more feed efficient than pigs fed the diets containing the other protein sources except skim milk. Pigs fed the skim milk diet had the highest gains and were the most feed efficient. Diets containing dried skim milk and casein were very similar in digestibility. Pigs fed dried skim milk or casein diets had higher dry matter digestibility, nitrogen digestibility, and nitrogen retention than pigs fed diets containing the other protein sources. Pettigrew et al. (1977) compared a combination of sodium caseinate and dried whey to dried skim milk as a protein source for pigs weaned at 2 to 3 days of age. Pigs fed the dried skim milk diet gained at a faster rate than pigs fed the casein-whey diet. There were no differences in digestibility, empty stomach weight, gut pH or histology of the gastrointestinal tract for pigs fed the different protein sources. From the literature, it is apparent that diets containing casein or skim milk as the sole protein source are equal in digestibility; however, skim milk diets support higher average daily gains. The reason skim milk and casein don't provide equivalent performance is not fully understood.

There is some indication in the literature that a certain ratio of casein to whey proteins must be maintained to optimize performance in the young pig. Newport and Henschel (1984) combined spray dried whey protein concentrate and spray dried skim milk to provide casein:whey protein ratios of 80:20 or 40:60. There were no differences in pig performance due to the casein:whey protein ratio; however, the higher level of whey proteins reduced the concentration of urea nitrogen in the blood and the proportion of urea nitrogen in total urinary nitrogen. Newport and Henschel (1985) also combined spray dried whey protein concentrate and spray dried skim milk to analyze the effects of casein:whey protein ratio on growth, digestion and protein metabolism in neonatal pigs. The casein:whey protein ratios analyzed were 80:20, 60:40, 20:80, or 0:100. A ratio of 60:40 gave maximum growth rate, feed efficiency and nitrogen retention, and the lowest blood urea concentration. From the data, the authors estimated that the optimum casein:whey protein ratio is approximately 50:50, similar to that in sow's milk. Pettigrew et al. (1977) also suggest that for maximum performance young pigs may require a dietary source of intact milk proteins. Since dried whey protein concentrate and dried skim milk are intact milk protein sources, further research may be needed to determine if 50% casein - 50% lactalbumin is the optimum milk protein combination for the young pig.

LACTOSE

Lactose is the carbohydrate fraction of milk. Dried skim milk and dried whey are extremely high in lactose at 50% and 70%, respectively (Robinson, 1986). Since the addition of dried skim milk or dried whey to starter diets improves pig performance, pigs would be expected to respond favorably to lactose additions. Similar to the response found with other milk products, lactose utilization appears to be dependent on the age of the pig.

Aherne et al. (1969) compared lactose, glucose, sucrose and fructose as energy sources for pigs weaned at two, four or seven days. Pigs fed diets containing lactose or glucose as the energy source performed similarly and gained faster and were more feed efficient than pigs fed diets containing sucrose or fructose. Pigs fed sucrose or fructose diets also had higher mortality rates when weaned at two and four days than pigs fed lactose or glucose diets.

The results indicate lactose and glucose are excellent carbohydrate sources for the pig during the first week of life.

Entringer et al. (1975) compared lactose, glucose and corn starch as carbohydrate sources for 20 kg pigs. These older pigs did not respond as favorably to lactose additions to the diet as pigs in the previous trial. Pigs fed the diet containing corn starch had higher nitrogen and dry matter digestibilities as well as improved performance as compared to pigs fed diets containing lactose. From the literature it appears the utilization of lactose by the pig decreases over age, while the utilization of other carbohydrate sources increase with age. This corresponds with the enzymatic system of the pig as lactase, the enzyme capable of breaking down lactose, is high in concentration during the first few weeks of life and decreases over time. Amylase, the enzyme necessary for the digestion of starch, is low in concentration at birth and increases as the pig grows older (Corring et al. 1978). Previous diet and management scheme may also influence the development of the enzymatic system, thus, the exact age when lactase level decreases and amylase concentration increases is not fully understood.

Numerous researchers have investigated the effect of lactose additions to the diet on performance of three to four-week old pigs. Sewell and West (1965) evaluated the effect of lactose on the efficiency of isolated soy protein as a protein source for the young pig, as compared to dried skim milk. In separate diets, two sources of lactose, beta-lactose and dried whey, were added to the isolated soy protein, negative control diet to provide the same amount of lactose as supplied by the 42% dried skim milk, positive control diet. Pigs fed the diets containing lactose gained faster, were more efficient in feed utilization, and had higher nitrogen and ether extract digestibilities than pigs fed the negative control diet. No significant differences in performance were observed between pigs receiving diets containing the various lactose sources.

When adding 13% lactose to a corn-soybean meal diet for three-week old pigs, Clarkson and Allee (1982) found no effect on average daily gain or feed efficiency. Giesting et al. (1985) reported pigs fed diets containing 12.5% lactose had higher average daily gains and average daily feed intake than pigs fed a corn-soybean meal diet. However, pigs fed the lactose diet were lower in average daily gain as compared to pigs fed a 25% skim milk, corn-soybean meal diet. Corbin and McConnell (1986) also found pigs fed a complex diet containing 50% lactose gained faster and were more feed efficient than pigs fed a 20% dried whey, corn-soybean meal diet. The improvement in performance can not be entirely credited to the lactose addition as the complex diet also contained 10% fat and was pelleted.

Turlington et al. (1987) also suggested that lactose will improve nutrient digestibility and slow digesta flow rate as compared to dextrose as carbohydrate sources for 21 to 35 day old pigs. The literature suggests that the addition of lactose to corn-soybean meal starter diets will improve performance of pigs weaned earlier than four weeks of age. The mode of action may be an increase in digestibility due to slower digesta flow and a higher concentration of lactose enzyme or a simple improvement in feed intake.

ISOLATED SOY PROTEIN

As explained in the processing section, various types of soy protein products are produced. Soybean meal is the product most often used in the swine industry; however, soy flour, soy protein concentrate and isolated soy protein are also available (Campbell, 1979).

Soy flour contains approximately 53% protein and 3.3% lysine (Wilding, 1971). Since it is produced by simply removing the fat and hulls from soybeans, soy flour also contains the insoluble and partly indigestible soy carbohydrate fraction (De, 1971). Jones et al. (1977) fed liquid diets to pigs weaned at three weeks of age to compare soy flour and dried skim milk as protein sources. Pigs fed diets containing skim milk were more feed efficient than pigs fed diets containing soy flour; however, protein source had no effect on average daily gain. The data suggests that pigs weaned at three weeks of age can productively utilize soy flour when fed in liquid diets on an hourly feeding schedule. Lecce et al. (1979) used the same hourly feeding schedule to compare soy flour and skim milk as protein sources for pigs weaned at 14 days of age. Daily gain was reduced during the first week on trial for pigs fed soy flour; however, after the pigs reached 21 days of age no differences were found.

Soy protein concentrate commonly contains 65 to 70% protein and 4.2 to 4.4% lysine (Meyer, 1967). The water-soluble nonprotein constituents are removed from soy flour to obtain the more concentrated product (Meyer, 1967). Although the protein level is increased, the insoluble and indigestible soy carbohydrate portion is also concentrated, and thus, the value of soy protein concentrate as a feed ingredient is questionable (De, 1971).

Stahly et al. (1983) compared soy protein concentrate and soybean meal as the protein source for pigs weaned at 28 days of age. Average daily gain, average daily feed intake and feed efficiency were depressed linearly as the level of soy protein concentrate increased in simple, corn-soybean meal diets. However, when 15% dried whey was present in the diets, pigs fed diets containing soy protein concentrate were more feed efficient than pigs fed diets containing soybean meal. Leibholz (1982) found apparent nitrogen and dry matter digestibilities were higher for soy protein concentrate than for soybean meal when fed to 7 to 28 day old pigs. However, since the inclusion of soy protein concentrate in the diet decreased feed intake, pigs fed the soybean meal diet gained faster. Giesting et al. (1985) also found a slight decrease in average daily gain due to lower feed intake for pigs fed diets containing soy protein concentrate. Giesting and Easter (1985) found no differences in average daily gain, feed intake or feed efficiency for pigs fed diets containing soy protein concentrate or soybean meal as the protein source. From the literature, soy protein concentrate appears to be more digestible than soybean meal; however, the reduction in feed intake must be eliminated before soy protein concentrate will improve pig performance.

Isolated soy protein typically contains 92 to 93% protein and 5.5 to 6.0% lysine (Meyer, 1967). The high protein content is achieved by removing the insoluble carbohydrates along with the fat, hulls and soluble carbohydrates from raw soybeans (De, 1971). Since isolated soy protein is the most purified soy protein product, researchers have used it as a standard for comparing plant proteins with other protein sources for the young pig.

The casein section lists numerous trials that have compared isolated soy protein with casein. Diets containing isolated soy protein have had lower digestibilities for dry matter, energy, protein (Mateo and Veum, 1980; Leibholz, 1982) and the essential amino acids (Walker et al., 1986a) than diets containing casein as the sole protein source. Walker et al. (1986b) found no differences in apparent nitrogen or amino acid availability between the protein sources. Casein appears superior to isolated soy protein from these results; however, performance values indicate the response due to protein source is age dependent. Richard et al. (1983) and Walker et al. (1986a) found no difference in average daily gain or feed efficiency for three-week old pigs fed isolated soy protein or casein as the protein source. Pond et al. (1971) and Leibholz (1982) found pigs weaned earlier than three weeks gained faster and were more feed efficient when fed diets containing casein as compared to isolated soy protein. Maner et al. (1961) and Mateo and Veum (1980) demonstrated that the digestibility of diets containing isolated soy protein increases as the pig matures while the digestibility of diets containing casein is constant over age. The increased utilization of isolated soy protein may be due to the maturation of the digestive and enzymatic systems (Corring et al., 1978) or a slowing of the rate of passage of soy proteins (Maner et al., 1962).

Although the literature indicates casein and isolated soy protein provide comparable performance when fed to pigs over three weeks of age, it should not be assumed that soy and milk proteins are equivalent for pigs of this age. Wilson and Leibholz (1981a,b,c,d) demonstrated that skim milk, an intact milk protein source, is superior to isolated soy protein. Pigs fed diets containing skim milk gained faster, were more feed efficient and had higher digestibilities of dry matter, nitrogen, energy and essential amino acids. Giesting et al. (1985) also found the inclusion of dried skim milk in the diet improved average daily gain and feed efficiency as compared to isolated soy protein for pigs weaned at four weeks of age.

Limited research is available comparing isolated soy protein with other soy protein sources. Wilson and Leibholz (1981a,b,c,d) and Leibholz (1982) compared isolated soy protein and soybean meal as protein sources for pigs between 7 and 35 days of age. Pigs fed diets containing isolated soy protein had higher digestibilities for dry matter, nitrogen and the essential amino acids than the pigs fed diets containing soybean meal. Although diet digestibility was higher, due to a reduction in feed intake, pigs fed isolated soy protein diets had lower average daily gains than pigs fed soybean meal diets. Walker et al. (1986a,b) also found dry matter, nitrogen and essential amino acid digestibilities were higher for diets containing isolated soy protein than diets containing soybean meal when fed to pigs weaned at three weeks of age. Feed intake was not depressed for these older pigs, and thus, isolated soy protein tended to improve average daily gain and feed efficiency. Giesting et al. (1985) also found the inclusion of isolated soy protein as a portion of the protein source improved feed efficiency as compared to using soybean meal as the sole protein source. The literature indicates isolated soy protein, similar to soy protein concentrate, is more digestible than soybean meal; however, the reduction in feed intake must be overcome before an improvement will be seen in pig performance.

EFFECT OF PROTEIN AND (OR) CARBOHYDRATE FRACTIONS OF DRIED WHEY ON PERFORMANCE AND NUTRIENT DIGESTIBILITY OF WEANLING PIGS

Summary

One hundred and eighty 3-wk old pigs (initial weight 4.8 kg) were utilized in a 35 d growth trial to determine the effects of the carbohydrate and (or) protein fraction of dried whey on pig performance. In addition, 30 3-wk old pigs (initial weight 4.9 kg) were used in two digestion trials to study the effects of the whey fraction on nutrient digestibility. Dietary treatments included a corn-soybean meal control (CON), control + 20% dried whey (WHE), control + 14% lactose (CHO), control + 2.1% lactalbumin (PRO), control + 14% lactose + 2.1% lactalbumin (CHO + PRO), and control + 8.4% whey protein concentrate (WPC). Diets were pelleted and balanced on an isolysine basis. Lactose and lactalbumin were added at the same levels as provided by a 20% dried whey diet. Pigs fed diets containing milk products exhibited superior average daily gain; feed efficiency; and apparent dry matter, energy and nitrogen digestibility ($P<.05$) compared to pigs fed the control diet. These results indicate that both the carbohydrate (lactose) and protein (lactalbumin) fractions of dried whey are important in explaining the beneficial response to dried whey elicited by the weanling pig.

(Key Words: Weanling Pigs, Dried Whey, Lactose, Lactalbumin, Whey Protein Concentrate.)

Introduction

Several researchers have shown that the inclusion of dried whey in the starter diet will improve performances of pigs weaned at 3 to 4 wk of age (Miller et al., 1971; Graham et al., 1981; Cera and Mahan, 1985: Goodband and Hines, 1987). Additional research with dried whey has investigated the optimum inclusion level (Mahan et al., 1981; Clarkson and Allee, 1982; Fralick and Cline, 1983), appropriate weaning age and feeding length (Pope and Allee, 1982; Pollmann et al., 1983b), and possible interaction with fat (Stahly et al., 1982; Van Wormer and Pollmann, 1985) or copper sulfate (Thaler et al., 1986). However, few researchers have examined the mode of action of dried whey that derives the beneficial growth response.

Owsley et al. (1986a) discovered a diet containing 20% dried whey was higher in dry matter and energy digestibility than a corn-soybean meal diet for pigs weaned at 28 d. Graham et al. (1981), Lindemann et al. (1986) and Owsley et al. (1986b) also reported that pigs fed diet containing dried whey had higher total intestinal chymotrypsin, amylase, protease and lactase activity than pigs fed a corn-soybean meal diet. The effects of the individual carbohydrate and protein fractions of dried whey on starter pig performance and nutrient digestibility have not been determined.

Results from Giesting et al. (1985) indicate the carbohydrate and protein fractions of skim milk have an additive effect on the performance of starter pigs; however, such research has not been done with dried whey. Therefore, the objective of these studies was to determine whether the protein (lactalbumin) or carbohydrate (lactose) fraction of dried whey provides the beneficial growth response in the young pig.

Experimental Procedures

Composition of the dietary treatments used in the three trials is shown in table 1. Dried whey was assumed to contain 72% lactose and 10.5% lactalbumin. Therefore, the 20% dried whey diet (WHE) would contain 14.4% lactose and 2.1% lactalbumin. These assumptions were used to formulate the CHO, PRO and CHO + PRO diets. A diet containing whey protein concentrate was also evaluated in the growth trial to further explore the practical application of the whey fractions. This diet was also formulated to contain 2.1% lactalbumin. All diets were pelleted and contained 1.3% lysine, .8% calcium, and .7% phosphorus.

Pigs were not allowed access to creep feed during the lactation period. During this period, pigs were housed in a total confinement, environmentally controlled, farrowing facility.

Growth Trial

One hundred and eighty weanling pigs (21 ± 3 d) were allotted by litter, sex and weight to the six dietary treatments. Average initial weight was 4.8 kg, with a range of 2.4 to 7.0 kg. Five replications per treatment were used with six pigs/pen. Pigs were housed in an environmentally controlled nursery in pens (1.2 m x 1.5 m) with woven wire floors and a Y-flush gutter, with one nipple waterer and one four hole self-feeder per pen. Feed and water were offered ad libitum. Temperature and air flow were adjusted to maintain optimum comfort for the pigs.

The study was conducted for 5 wk. Criteria measured were average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G). Feeders were checked twice daily and individual pig weights were collected at the end of each 7 d period.

Digestion Trials

In each of two trials, 15 pigs (average initial weight 4.9 kg) weaned at 16-18 d were randomly allotted by litter to dietary treatment. Pigs were housed in individual 37 cm x 45 cm x 45 cm metal cages in an environmentally controlled feeding room maintained between 29 and 32 C. Pigs were fed twice daily and water was offered ad libitum. Pigs were brought to maximum feed intake during a 5 d adjustment period, with feces being collected for the next 5 d. Pigs were then reallotted by litter in a crossover design to a different dietary treatment. This was followed by a second 5 d adjustment and 5 d collection period.

Feces were collected and frozen daily throughout each collection period. At the end of each period, the feces were dried in a forced air oven at 38 C until equilibrated to a constant weight. Feces, along with diet samples, were ground in a Thomas-Wylie experimental grinder equipped with a 1 mm screen. All samples were chemically analyzed for nitrogen and dry matter according to AOAC (1975) methods. Gross energy content was determined by adiabetic bomb calorimetry. Apparent digestibility coefficients were calculated for dry matter, nitrogen and energy.

Statistical Analysis

The data were analyzed using the General Linear Models procedure of the Statistical Analysis System (SAS, 1979). Data from the digestion trials was analyzed for each period and trial; however, since no trial by trial, trial by period, or period by period interactions were found data was pooled for the final analysis. Pen was considered the experimental unit for the growth trial. Preplanned orthogonal contrasts were used to separate treatment means in the digestion and growth trials. The orthogonal comparisons made were CON vs all other treatments, WHE vs the three treatments containing whey fractions (CHO, PRO, and CHO + PRO), the combination (CHO + PRO) vs the individual fractions (CHO, PRO), and the individual fractions against each other (CHO vs PRO).

Results and Discussion

The dried whey and whey protein concentrate chemical analysis is shown in Table 2. The high lactose, low ash and low salt levels indicate that a high quality demineralized whey was used, as Lampert (1975) reported that edible grade dried whey typically contains 72% lactose, 8% ash and 3% salt. The excellent quality dried whey may have influenced the performance and digestibility of pigs fed the WHE diet. Mahan (1984) demonstrated that pigs fed diets containing an edible grade dried whey with a low ash level had higher ADG and ADFI than pigs fed a feed grade dried whey with a high ash content.

The effect of dried whey fractions on weanling pig performance is shown in Table 3. Pigs fed diets containing milk products had improved ($P<.05$) ADG and F/G at 2 and 5 wk postweaning, as compared to those fed the control. Miller et al. (1981), Cera and Mahan (1985), Stahley et al. (1986), and Thaler et al. (1986) also found that ADG and F/G were improved when dried whey was incorporated in starter pig diets. Graham et al. (1981), Clarkson and Allee (1982), and Goodband and Hines (1987) also reported pigs fed diets containing dried whey gained faster than pigs fed corn-soybean meal diets without dried whey; however, there were no differences in F/G. Cinq-Mars et al. (1986) also reported an improvement in ADG and F/G when whey protein concentrate was added to starter pig diets.

Pigs fed the PRO diet also tended to be more feed efficient ($P<.07$) than pigs fed the CHO diet after 5 wk. No differences were found in ADFI at 2 and 5 wk. In addition, no differences in ADG at 2 and 5 wk or F/G at 2 wk were found between the lactose (CHO) and lactalbumin (PRO) diets. Lactose additions to starter pig diets have previously been shown to improve pig performance (Sewell and West, 1965; Giesting et al., 1985). Although lactalbumin additions to swine diets have not previously been evaluated, these positive results were expected since lactalbumin has an excellent amino acid profile, a digestibility of 99%, biological value of 94% and protein efficiency ratio of 3.2 (Robinson,1986). However, no additive effect was found when the lactose and lactalbumin were added together in the

CHO + PRO diet.

Table 4 shows the effect of dried whey fractions on apparent digestibility. Pigs fed diets containing milk products had higher (P<.05) apparent dry matter, nitrogen, and energy digestibility than pigs fed the control. As was the case in the growth trial, there were no differences between the diets containing the dried whey fractions for any of the criteria measured. Owsley et al. (1986a) also reported an increase in dry matter and energy digestibility with the addition of 20% dried whey to a corn-soybean meal diet. Wilson and Leibholz (1981b,c) and Leibholz (1982) found similar improvements in digestibility when skim milk was used as the milk product. Lactose has also previously been shown to improve nitrogen and dry matter digestibility (Sewell and West, 1965).

The results from these trials provide further evidence that milk products improve performance and nutrient digestibility in 3-wk old pigs. It appears that both the carbohydrate (lactose) and protein (lactalbumin) fractions of dried whey are important in explaining the dried whey response; however, when both fractions were present in the diet, no additive effects were found.

Table 1. Diet Composition, %[a]

Ingredients	Dietary Treatments[b]					
	CON	WHE	CHO	PRO	CHO + PRO	WPC
Corn	55.14	41.53	39.30	60.28	44.48	53.68
Soybean meal	38.07	32.25	39.43	30.68	32.00	31.23
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00
Dried whey	---	20.00	---	---	---	---
Lactose	---	---	14.40	---	14.40	---
Lactalbumin	---	---	---	2.10	2.10	---
Whey protein concentrate	---	---	---	---	---	8.34
Dicalcium phosphate	1.49	1.14	1.66	1.60	1.77	1.49
Limestone	.85	.63	.76	.89	.80	.81
Salt	.50	.50	.50	.50	.50	.50
Trace mineral mix[c]	.10	.10	.10	.10	.10	.10
Vitamin mix[d]	.25	.25	.25	.25	.25	.25
L-Lysine HCL	.10	.10	.10	.10	.10	.10
Selenium mix[e]	.15	.15	.15	.15	.15	.15
Antibiotic mix[f]	.25	.25	.25	.25	.25	.25
Copper sulfate[g]	.10	.10	.10	.10	.10	.10

[a]Diets were calculated to contain 1.3% lysine, .8% calcium, and .7% phosphorus.

[b]CON = control, WHE = control + 20% dried whey, CHO = control + 14.4% lactose, PRO = control + 2.1% lactalbumin, CHO + PRO = control + 14.4% lactose + 2.1% lactalbumin, WPC = control + 8.34% whey protein concentrate.

[c]Percentage composition was Fe, 10; Zn, 10; Mn, 10; Cu, 1; I, .3; Co, .1.

[d]Composition per kg premix: vitamin A, 1,762,080 IU; vitamin D_3, 132,156 IU; vitamin E, 8,810 IU; riboflavin, 1,982 mg; menadione, 683 mg; pantothenic acid, 6,793 mg; niacin, 11,013 mg; choline chloride, 203,080 mg; vitamin B_{12}, 9.7 mg.

[e]Premix provided complete diet with .3 ppm supplemental selenium.

[f]Antibiotic contains 44 g chlortetracycline, 44 g sulfamethazine and 22 g penicillin per kg.

[g]Premix supplied complete diet with 250 ppm supplemented copper.

Table 2. Analyzed Ingredient Composition, %.

Ingredient	Demineralized Dried Whey	Whey Protein Concentrate
Protein	13.24	36.64
Lysine	.94	3.63
Lactose	80.50	50.20
Ash	1.24	6.08
Salt	.05	1.84

Table 3. Effect of Dried Whey Fractions on Weanling Pig Performance.

	Dietary Treatment[a]					
	CON	WHE	CHO	PRO	CHO + PRO	WPC
Week 0 to 2						
Daily gain,g[b]	229	280	289	283	263	262
Daily feed,g	287	329	335	312	294	306
Feed/gain[b]	1.24	1.17	1.15	1.10	1.11	1.17
Week 0 to 5						
Daily gain,g[b]	369	423	405	408	411	404
Daily feed,g	565	619	605	582	592	581
Feed/gain[bc]	1.52	1.46	1.49	1.42	1.44	1.44

[a]CON = control, WHE = control + 20% dried whey, CHO = control + 14.4% lactose, PRO = control + 2.1% lactalbumin, CHO + PRO = control + 14.4% lactose + 2.1% lactalbumin, WPC = control + 8.34% whey protein concentrate.

[b]Contrast, CON vs others ($P<.05$).

[c]Contrast, PRO vs CHO ($P<.07$).

Table 4. Effect of Dried Whey Fractions On Apparent Digestibility.

	Dietary Treatment[a]				
	CON	WHE	CHO	PRO	CHO + PRO
Apparent digestibility (%)					
Dry matter[b]	86.8	88.7	88.1	87.9	88.5
Nitrogen[b]	83.2	85.2	84.2	85.3	85.8
Energy[b]	86.3	88.3	88.7	87.7	88.1

[a]CON = control, WHE = control + 20% dried whey, CHO = control + 14.4% lactose, PRO = control + 2.1% lactalbumin, CHO + PRO = control + 14.4% lactose + 2.1% lactalbumin, WPC = control + 8.34% whey protein concentrate.
[b]Contrast, CON vs others (P<.05).

EFFECT OF LACTOSE LEVEL AND PROTEIN SOURCE ON STARTER PIG PERFORMANCE

Summary

A total of 390 weanling pigs (21 ± 3 d) were used in two 2 x 3 factorial experiments to evaluate the effect of lactose level (0%, 12.5%, 25%) and protein source (isolated soy protein, casein) on starter pig performance. In addition, a corn-soybean meal negative control diet (0% lactose) was also evaluated in trial 2. All pigs received the experimental diet for the first two wk and were fed a 20% dried whey, corn-soybean meal diet for the last three wk of the five wk trial. No interaction (P>.05) occurred between lactose level and protein source in either trial. The only treatment difference found in trial 1 was that pigs fed the 25% lactose, isolated soy protein diet were less (P<.05) feed efficient (F/G) after two wk than pigs fed the other diets. In trial 2, pigs fed the diets containing isolated soy protein had higher (P<.05) average daily gain (ADG) and average daily feed intake (ADFI) after two wk than pigs fed the casein diets. In addition, pigs fed the soybean meal diet had improved (P<.01) ADG, ADFI, and F/G after two wk as compared to pigs fed the isolated soy protein or casein diets. The performance advantages were eliminated during the last three wk of the trials when all pigs consumed the 20% dried whey diet. These results indicate that starter pig performance will not be maximized when casein or isolated soy protein are used as the only protein source in the diet. Furthermore, the addition of lactose resulted in no

beneficial effects when casein or isolated soy protein served as the only protein source.

(Key Words: Weanling Pigs, Lactose, Casein, Isolated Soy Protein)

Introduction

Performance of young pigs weaned earlier than 28 days of age is usually improved when starter diets contain protein from milk sources rather than protein from soybean meal (Hays et al., 1959; Combs et al., 1963; Walker et al., 1986), soy flour (Bayley and Holmes, 1972; Lecce et al., 1979), soy protein concentrate (Giesting and Easter, 1985), or isolated soy protein (Wilson and Leibholz, 1981a; Leibholz, 1982). Nutrient digestibility is also improved when pigs are fed diets containing skim milk (Wilson and Leibholz, 1981a,b,c,d) or casein, the major milk protein, (Leibholz, 1982; Walker et al., 1986a,b) rather than soybean meal or isolated soy protein as the only protein source.

The addition of lactose to corn-soybean meal diets has also been shown to improve starter pig performance (Giesting et al., 1985; Corbin and McConnell, 1986) and diet digestibility (Sewell and West, 1965). Turlington et al. (1987) also suggested that the addition of lactose to corn-casein or corn-soybean meal diets will improve diet digestibility by slowing the digesta flow rate for pigs between 21 and 35 d of age. The relative response to lactose was greater for pigs fed corn-soybean meal diets than for pigs fed corn-casein diets. Whether an interaction between lactose level and protein source may effect starter pig performance has not been reported.

These studies were conducted to determine the effect of lactose additions to starter pig diets when either isolated soy protein or casein is utilized as the protein source. Pig performance was measured from 21 to 35 d of age. Subsequent performance was also analyzed from 35 to 56 d of age when all pigs received the same diet.

Experimental Procedures

Two 5-wk growth trials were conducted to evaluate the effects of lactose level and protein source on starter pig performance. One hundred and eighty weanling pigs averaging 6.1 kg (5.0 to 7.0 kg) were used in trial 1. In trial 2, 210 weanling pigs averaging 5.5 kg (4.6 to 6.4 kg) were utilized. In both trials, pigs were weaned at 21 ± 3 d and allotted by litter, sex and weight to the dietary treatments. Prior to weaning, pigs were housed in a total confinement, environmentally controlled, farrowing facility and were not allowed access to creep feed. At weaning, pigs were moved to an environmentally controlled nursery equipped with 1.2 m x 1.5 m pens with woven wire floors and a Y-flush gutter, with one nipple waterer and one four hole self-feeder per pen. Feed and water were offered ad libitum. Temperature and airflow were adjusted to maintain optimum comfort for the pigs. Feeders were checked twice daily and individual pig weights were collected at the end of each week. Criteria measured were average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G).

A two-phase starter program was used to evaluate the dietary treatments. Composition of the diets fed during the first two weeks is shown in table 1. A 2 x 3 factorial consisting of two protein sources (isolated soy protein or casein) and three lactose levels (0, 12.5 or 25%) was used in both trials. Lactose replaced corn starch on an equal weight basis. Trial 2 also contained a 25% corn starch, corn-soybean meal, control diet. All diets were pelleted and contained 1.4% lysine, .8% calcium, and .7% phosphorus.

At the end of the second week, feeders were weighed and emptied and the feed was replaced by a corn-soybean meal diet containing 20% edible grade, spray dried whey. The composition of this diet is shown in table 2. The diet was formulated to contain 1.25% lysine, .8% calcium, and .7% phosphorus. All pigs received this diet for the last three weeks of the trial.

The data were analyzed using the General Linear Models procedure of the Statistical Analysis System (SAS, 1979). Pen was considered the experimental unit for both trials. Since trial 2 contained one additional treatment, the trials were analyzed separately. Preplanned orthogonal contrasts were used to separate treatment means, to compare protein and carbohydrate source main effects, and to check for quadratic or linear effects due to lactose level.

Results

The effect of lactose level and protein source on starter pig performance for trial 1 is shown in table 3. Although there were no carbohydrate and protein source interactions (P>.05), the interaction means were reported. No differences were found in ADG or ADFI at two or five wk. Pigs fed the 25% lactose, isolated soy protein diet were less (P<.05) feed efficient after two wk than pigs fed the other diets. However, this difference was eliminated by the end of the trial.

The effect of lactose level and protein source on starter pig performance for trial 2 is shown in table 4. Although there were again no carbohydrate by protein source interactions (P>.05), the interaction means were reported. Analysis of the main effects revealed that pigs fed diets containing isolated soy protein as the only protein source had higher (P<.05) ADG and ADFI at two wk than pigs fed the casein diets. Increasing the lactose level in the diet had no effect on starter pig performance. Pigs fed the soybean meal diet had improved (P<.01) ADG, ADFI and F/G after two wk as compared to pigs fed the diets containing isolated soy protein or casein as the protein source. Pigs fed the soybean meal diet for the first two wk had also consumed more (P<.05) feed at the end of the five wk period than pigs fed the other diets; however, the differences in ADG and F/G were eliminated during the last three wk of the trial when all pigs consumed the 20% dried whey diet.

Discussion

There were differences in the performance of trial 1 compared to trial 2. In trial 2, pellet quality was poor with an excessive amount of fines present. Thus, a large amount of sorting and feed wastage occurred with the casein and isolated soy protein diets. The feed wastage may have distorted the ADFI and F/G values. The amount of fines present may have also lowered actual feed consumption and reduced ADG.

Although the performance tended to be lower in the trial 2, similar general trends can be seen in both trials. Performance was not improved when pigs were fed diets containing casein as compared to pigs fed diets containing isolated soy protein as the sole protein source. Richard et al. (1983), Etheridge et al. (1984) and Walker et al. (1986) reported similar results as no performance differences were found when casein or isolated soy protein was used as the only protein source in diets for pigs weaned at three to four wk of age. The response appears to be age dependent as pigs weaned earlier than three wk of age consistently gained faster and were more feed efficient when fed diets containing casein as compared to isolated soy protein (Pond et al., 1971; Leibholz, 1982; Mateo and Veum, 1984). Maner et al. (1962) found the rate of passage for soy protein slows as the pig gets older; whereas, the rate of passage for casein is constant over time. The change in the rate of passage for isolated soy protein may explain the decrease in the advantage for casein as the pig increases in age.

The literature suggests that diets containing casein or skim milk as the only protein source are similar in dry matter digestibility, nitrogen digestibility and nitrogen retention; however, the diets containing dried skim milk consistently support higher ADG (Pettigrew et al., 1977; Leibholz, 1982). The reason skim milk and casein do not provide equivalent performance is not fully understood. Pettigrew et al. (1977) suggested that for maximum performance young pigs may require a dietary source of intact milk proteins. There is also some indication from the literature that a certain ratio of casein to whey proteins must be maintained to optimize performance in the young pig. Newport and Henschel (1984, 1985) combined spray dried skim milk and spray dried whey protein concentrate to determine that 50:50 was the optimum casein:whey protein ratio. Since dried whey protein concentrate and dried skim milk are intact milk protein sources, further research may be needed to determine if 50% casein-50% lactalbumin is the optimum milk protein combination for the young pig.

The results of the second trial indicate that soybean meal is superior to isolated soy protein and casein when used as the only protein source for pigs between 21 and 35 d. When comparing the same protein sources for pigs weaned at three wk of age, Walker et al. (1986a) found different results. They reported that pigs fed diets containing isolated soy protein or casein gained faster than pigs fed diets containing soybean meal; however, simple corn-protein source diets with lower nutrient levels and energy density were used. When feeding diets containing isolated soy protein, Wilson and Leibholz (1981a,b,c,d) and Leibholz (1982) discovered that maintaining feed intake may be a problem. They found that pigs fed diets containing isolated soy protein had higher digestibilities for dry matter, nitrogen and the essential amino acids than pigs fed diets containing soybean meal; however, due to a reduction in feed intake, ADG was lower for pigs fed the diet containing isolated soy protein.

The lactose results may have been influenced by the protein sources used in this trial. Several researchers have shown that the addition of lactose to the diet will increase ADG for pigs weaned at three to four wk of age (Sewell and West, 1965; Aherne et al., 1969; Giesting et al., 1985; Corbin and McConnell, 1986). Further research using intact protein sources, such as soybean meal and dried skim milk, may be needed to determine whether lactose level and protein source interact to effect starter pig performance.

Table 1. Diet Composition (%), Week 0 to 2.[a]

Protein Source	ISP[b]			CASEIN			SBM[c]
Lactose level, %	0	12.5	25	0	12.5	25	0
Corn	42.86	42.86	42.86	44.57	44.57	44.57	22.37
ISP	17.29	17.29	17.29	---	---	---	---
Casein	---	---	---	15.93	15.93	15.93	---
Soybean meal	---	---	---	---	---	---	38.39
Lactose	0	12.5	25	0	12.5	25	0
Hydrolyzed corn starch	25	12.5	0	25	12.5	0	25
Soybean oil	10	10	10	10	10	10	10
Dicalcium phosphate	2.35	2.35	2.35	2.36	2.36	2.36	2.13
Limestone	.65	.65	.65	.46	.46	.46	.36
Salt	.50	.50	.50	.50	.50	.50	.50
Trace mineral mix[d]	.10	.10	.10	.10	.10	.10	.10
Vitamin mix[e]	.25	.25	.25	.25	.25	.25	.25
Selenium mix[f]	.15	.15	.15	.15	.15	.15	.15
Antibiotic mix[g]	.25	.25	.25	.25	.25	.25	.25
Copper sulfate[h]	.10	.10	.10	.10	.10	.10	.10
L-Lysine HCL	.20	.20	.20	.20	.20	.20	.20
DL-Methionine	.20	.20	.20	.03	.03	.03	.10
DL-Tryptophan	.05	.05	.05	.05	.05	.05	.05
L-Threonine	.05	.05	.05	.05	.05	.05	.05

[a]Diets were calculated to contain 1.4% lysine, .8% calcium, and .7% phosphorus.
[b]ISP = Isolated soy protein
[c]SBM = Diet containing 48.5% protein soybean meal as the protein source, used only in trial 2.
[d]Composition per kg premix: vitamin A, 1,762,080 IU; vitamin D_3, 132,156 IU; vitamin E, 8,810 IU; riboflavin, 1,982 mg; menadione, 683 mg; pantothenic acid, 6,793 mg; niacin, 11,013 mg; choline chloride, 203,080 mg; vitamin B_{12}, 9.7 mg.
[e]Premix provided complete diet with .3 ppm supplemental selenium.
[f]Antiobiotic contains 44 g chlortetracycline, 44 g sulfamethazine and 22 g penicillin per kg.
[g]Premix provided complete diet with 250 ppm supplemental copper.

Table 2. Diet Composition, week 3 to 5.[a]

Ingredient	%
Corn	42.50
Soybean meal	31.80
Dried whey	20.00
Soybean oil	3.00
Dicalcium phosphate	1.28
Limestone	.47
Trace mineral mix[b]	.10
Vitamin mix[c]	.25
Selenium mix[d]	.15
Antibiotic mix[e]	.25
Copper sulfate[f]	.10
L-Lysine HCL	.10

[a]Diets were calculated to contain 1.25% lysine, .8% calcium, and .7% phosphorus.

[b]Percentage composition was Fe, 10; Zn, 10; Mn, 10; Cu, 1; I, .3; Co, .1.

[c]Composition per kg premix: vitamin A, 1,762,080 IU; vitamin D_3, 132,156 IU; vitamin E, 8,810 IU; riboflavin, 1,982 mg; menadione, 683 mg; pantothenic acid, 6,793 mg; niacin, 11,013 mg; choline chloride, 203,080 mg; vitamin B_{12}, 9.7 mg.

[d]Premix provided complete diet with .3 ppm supplemental selenium.

[e]Antibiotic contains 44 g chlortetracycline, 44 g sulfamethazine and 22 g penicillin per kg.

[f]Premix provided complete diet with 250 ppm supplemental copper.

Table 3. Effect of Lactose Level and Protein Source on Starter Pig Performance (Trial 1).

Protein source	ISP[a]			CASEIN		
Lactose level, %	0	12.5	25	0	12.5	25
<u>Week 0 to 2</u>						
Daily gain, g	183	180	173	194	197	184
Daily feed, g	200	208	253	231	233	224
Feed/gain[b]	1.10	1.16	1.46	1.20	1.18	1.21
<u>Week 0 to 5</u>						
Daily gain, g	393	412	394	434	424	397
Daily feed, g	592	621	611	644	622	593
Feed/gain	1.50	1.47	1.55	1.48	1.47	1.49

[a]ISP = isolated soy protein.
[b]Contrast, 25% lactose - ISP vs other (P<.05).

Table 4. Effect of Lactose Level and Protein Source on Starter Pig Performance (Trial 2).

Protein Source	ISP[a]			CASEIN			SBM[a]
Lactose level, %	0	12.5	25	0	12.5	25	0
<u>Week 0 to 2</u>							
Daily gain, g[bc]	132	139	138	111	110	112	251
Daily feed, g[bc]	254	263	259	236	207	223	300
Feed/gain[c]	1.94	1.90	1.90	2.02	1.90	2.00	1.14
<u>Week 0 to 5</u>							
Daily gain, g	386	373	359	395	372	381	396
Daily feed, g[d]	598	596	559	606	572	565	632
Feed/gain	1.55	1.60	1.56	1.54	1.54	1.48	1.61

[a]ISP = isolated soy protein, SBM = soybean meal.
[b]Contrast, ISP vs Casein (P<.05).
[c]Contrast, SBM vs others (P<.01).
[d]Contrast, SBM vs others (P<.05).

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THE EFFECTS OF THE CARBOHYDRATE AND PROTEIN FRACTIONS OF MILK PRODUCTS ON STARTER PIG PERFORMANCE

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Three growth trials and two digestion trials were conducted to determine the effects of the carbohydrate and protein fractions of milk products on starter pig performance and diet digestibility.

In the first study, 180 3-wk old pigs (initial weight 4.8 kg) were utilized in a 35 d growth trial to determine the effects of the carbohydrate and (or) protein fraction of dried whey on pig performance. In addition, 30 3-wk old pigs (initial weight 4.9 kg) were used in two digestion trials to study the effects of the whey fraction on nutrient digestibility. Dietary treatments included a corn-soybean meal control (CON), control + 20% dried whey (WHE), control + 14% lactose (CHO), control + 2.1% lactalbumin (PRO), control + 14% lactose + 2.1% lactalbumin (CHO + PRO), and control + 8.4% whey protein concentrate (WPC). Diets were pelleted and balanced on an isolysine basis. Lactose and lactalbumin were added at the same levels as provided by a 20% dried whey diet. Pigs fed diets containing milk products exhibited superior average daily gain; feed efficiency; and apparent dry matter, energy and nitrogen digestibility ($P<.05$) compared to pigs fed the control diet. These results indicate that both the carbohydrate (lactose) and protein (lactalbumin) fractions of dried whey are important in explaining the beneficial response to dried whey elicited by the weanling pig.

In the second study, a total of 390 weanling pigs (21 ± 3 d) were used in two 2 x 3 factorial experiments to evaluate the effect of lactose level (0%, 12.5%, 25%) and protein source (isolated soy

protein or casein) on starter pig performance. An additional 0% lactose, corn-soybean meal control treatment was also evaluated in trial 2. All pigs received the experimental diet for the first two weeks and were fed a 20% dried whey, corn-soybean meal diet for the last three weeks on trial. No interaction ($P>.05$) occurred between lactose level and protein source in either trial. The only treatment difference found in trial 1 was that pigs fed the 25% lactose, isolated soy protein diet were less ($P<.05$) feed efficient (F/G) at two weeks than pigs fed the other diets. In trial 2, pigs fed the diets containing isolated soy protein had higher ($P<.05$) average daily gain (ADG) and average daily feed intake (ADFI) at two weeks than pigs fed the casein diets. In addition, pigs fed the soybean meal diet had improved ($P<.01$) ADG, ADFI, and F/G at two weeks as compared to pigs fed the isolated soy protein or casein diets. The performance advantages were eliminated during the last three weeks of the trials when all pigs consumed the 20% dried whey diet. These results indicate that starter pig performance will not be maximized when casein or isolated soy protein are used as the only protein source in the diet. Furthermore, the addition of lactose resulted in no beneficial effects when casein or isolated soy protein served as the only protein source.