Effects of Spray-Dried Porcine Plasma (SDPP) Administered as an Oral Gavage on Indicators of Health, Welfare, and Performance in Pigs Transported After Weaning

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ASTRACT

Transportation of swine is an emerging welfare issue, especially for piglets weaned and then immediately transported. Weaned pigs fed starter diets containing SDPP display improved growth performance. The objective of this study was to determine effects of pre-weaning SDPP on indicators of health, welfare, and performance in transported weaned pigs. Pigs were assigned to treatments: I. SDPP + transport, II. Water + transport, III. SDPP + no transport, or IV. Water + no transport. Pigs received their gavage twice daily for 5 d prior to weaning. Pigs were weaned and either transported or moved directly to the wean-to-finish barn. Rectal temperatures and blood samples were obtained at weaning and after relocation. Body weight was determined on d 1, at weaning, after relocation, and at weekly intervals for 5 wk thereafter. Blood chemistry profiles and serum cortisol concentrations were also determined. Rectal temperature and potassium increased and calcium decreased after groups I and II were transported. Glucose was lowest in group II. Total protein was greater in group I compared to group III. Albumin was greatest in group I compared to all other groups. Sodium was greatest in group II compared to all other groups. Anion gap was greatest in group II compared to group IV. Cortisol, phosphorus, gamma-glutamyltransferase, and chloride, were greater in groups I and II after transportation. In summary, transportation impacted several physiological indicators of health and well-being in weaned pigs, and providing SDPP prior to weaning prevented transportation-induced changes in sodium, glucose, and anion gap levels.

DEDICATION

In memory of

Russell J. Crawford

4/25/69 to 5/28/11

This thesis is dedicated to Mr. Russell J. Crawford. Russell worked at Virginia Tech's Tidewater Agricultural Research and Extension Center in Suffolk, VA as an Agricultural Supervisor, which was his professional title. I had the honor of being able to meet and work with Russ during the summer of 2010 (May to August). Russ was in charge of taking care of the pigs at the research station. Russ was an incredible person who did everything. He not only fed the pigs and took care of them; he loved them with all his heart. He was great at working with the boars and training them to mount a dummy sow in order to collect their semen. He was a pro at heat checking gilts and sows as well as breeding them by AI and also naturally. Russ also fixed everything that ever needed fixing at the barn. Russ was a great teacher and taught me everything to ever possibly know about pigs and working with them. Russell also helped out tremendously with my thesis project, and always came up with great ideas. If it wasn't for him, we wouldn't have included many things in my project. When I was having a hard time finding pink coveralls, Russ is the one who thought that I should buy white ones and then dye them pink, I'm so glad he thought of that so now I have my pink coveralls, thank you again Russell. Russ was great at always thinking outside of the box. He always listened and gave great advice. He was also really good at making me feel better when things weren't going the way I planned with my project and he always said that everything would work out fine, which it always did. Russell was also a great friend outside of work. My hog gals, Beth Alexis and Samantha Gregory, and I always had a blast hanging out with Russ and his wife, Becky, after the work day was over or over the weekends. All of us enjoyed going out to dinner, the movies, and eating lots of ice cream together. Russ always knew of all the great restaurants to eat at and gave us great recommendations of places that we had to try during our summer in Suffolk and the Tidewater area. When my project ended, Russell let me keep my favorite pig from my project, a barrow from treatment group II, 38-2, who I named Gabriel, at the barn and took great care of him for me when I had to head back to Blacksburg for classes. Russ was great with kids too as he would take Gabe and his buddy, who Russ had many nicknames for, to Farm Days to teach third grade students about pigs and the swine industry. Russell was always such a delight to be around and loved to laugh and tell funny stories. My hog gals, Russ, Becky, and I all went to see the movie *Despicable Me*, and Russ fell in love with this movie, and was always quoting his favorite lines from it for the rest of our time at the barn over the summer. My hog gals and I always said that Russ was like Gru, from the movie, and the three of us were like the little girls that Gru adopts in the movie, and we liked to sometimes refer to him as Gru and his hog gals. Following is a quote from the movie that occurred when Gru was reading the girls the book that he wrote for them: "One big unicorn, strong and free, thought he was happy as he could be. Then three little kittens came around and turned his whole life upside down. They made him laugh, they made him cry. He never should have said goodbye. And now he knows he can never part from those three little kittens that changed his heart." Even though Russell had to say goodbye to his hog gals, we will never part as we will always remember him in our hearts.

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CHAPTER I.

INTRODUCTION

The transportation of swine is an emerging welfare issue. This is at least partly due to the heightened concern and awareness of consumers in regard to how their food is produced (Warriss, 1998). Welfare of swine can be negatively affected by poor conditions during transport and these conditions can ultimately influence carcass and meat quality, as well as the value of the final product (Warriss, 1998; NPB, 2008).

Swine may be transported several times during their life (NPB, 2008). With the advent of multi-site production systems, however, transporting pigs at weaning is becoming more common in the U. S. (Sutherland et al., 2010). Weaned pigs are frequently shipped from farrowing units to nursery farms, from which feeder pigs undergo transportation to grow-finish farms, or transported directly from farrowing farms to wean-to-finish farms. The distances that young pigs are transported can vary from short (3 h or less), intermediate (more than 3 h but less than 8 h), or long (more than 8 h), which influences the amount of stress pigs experience. However, research focused on welfare of weaned pigs during transportation is limited. Transportation affects the health and well-being of pigs, particularly in young pigs already experiencing weaning stress. The individual stresses of transport and weaning have been shown to influence the physiology, performance, behavior, and immune response of pigs (McGlone et al., 1993; Hay et al., 2001; Kantiz et al., 2002; Sutherland et al., 2009ab; Sutherland et al., 2010). When weaning coincides with transport, the stressors are additive, which heightens the negative effects on performance during the post-weaning phase (Lewis and Berry, 2004).

One substance that has been shown to improve the health and performance of pigs during the post-weaning period is spray dried porcine plasma (SDPP). Inclusion of SDPP is common in piglet starter diets because this protein source stimulates feed intake, increases feed efficiency, improves growth rate, and reduces scours (Coffey and Cromwell, 2001; van Dijk et al., 2001; Campbell et al., 2010). In this thesis research project, we examined the effects of SDPP, administered as an oral gavage prior to weaning and transportation, on health, well-being, and growth performance in pigs during the post-weaning phase. We hypothesized that consumption of SDPP during the suckling phase would enhance welfare and growth performance of pigs exposed to the stresses of weaning and transportation.

CHAPTER II.

REVIEW OF LITERATURE

Introduction

Transportation is inherently stressful to swine and is an emerging welfare issue, due at least in part to increased concern and awareness of consumers in regards to how their food is produced (Warriss, 1998). Although the number of pigs and hogs that die during transport is low (approximately 1%), welfare during transit is still a major economic concern for pork producers (Sutherland et al., 2009c). Indeed, poor conditions during transport can ultimately influence carcass and meat quality, as well as the value of the final product (Warriss, 1998; NPB 2008).

Swine may be transported several times throughout the production cycle (NPB, 2008), the most researched time being when finished hogs are shipped to the processing plant. Weaned pigs are frequently shipped from farrowing units to nursery farms, from which feeder pigs undergo transportation to grow-finish farms, or are transported directly from farrowing farms to wean-to-finish farms. Transportation affects the health and welfare of pigs, particularly young pigs already experiencing the stress of weaning. The individual stresses of transport and weaning have been shown to influence the physiology, performance, behavior, and immune response of pigs (McGlone et al., 1993; Hay et al., 2001; Kantiz et al., 2002; Sutherland et al., 2009ab; Sutherland et al., 2010). When weaning coincides with transport, the stressors are additive, which heightens the negative effects on performance during the post-weaning phase (Lewis and Berry, 2004). Research is needed to thoroughly characterize the impact of transportation on weaned pig welfare and to develop technologies to mitigate possible stressors.

Changes in the structure of the Virginia and U. S. swine industries

Hog and pig operations are defined as any farm that has at least one hog or pig on hand on December 1st (USDA, 2010). According to census data, the United States had a total of 75,422 operations with hogs and pigs in 2007 (USDA, 2009). This represents a significant decrease from 1997, when there were 124,889 swine farms. During this same period (1997 to 2007) total U. S. swine inventory remained relatively constant at 60 to 70 million head. Thus, average size of swine farms has increased. Of the over 206 million head sold in the U. S. in 2007, over 87 % were from farms marketing in excess of 5,000 animals annually.

The swine industry has evolved from numerous small, family-owned farms raising hogs to be sold to local butchers or very small, family-operated processing plants. At this time, the pork industry was organized as a horizontal network of producers and packers (Kyriazakis and Whittemore, 2006). Within each segment of the production system entities competed with each other, and there was little coordination and communication within and among segments (Kyriazakis and Whittemore, 2006). Over the past two decades, companies within each segment formed vertical networks, with contracts between producers and processors (Kyriazakis and Whittemore, 2006). This led the swine industry to grow into a much more organized industry with vertically integrated companies such as Smithfield Foods, Inc., Premium Standard Farms, and Seaboard capturing the economies of scale (Greenwood, 2007).

As the swine industry evolved into a vertically integrated industry, production systems changed from primarily one-site production to multi-site production. An example of one-site production is a farrow-to-finish farm, meaning that once sows farrow, their pigs remain on the same site until they reach market weight (Harris, 2000). In multi-site production, swine of different age and weight categories are located on separate farm sites and locations (Harris, 2000; NPB, 2003). Multi-site production system began in the U.S. in 1988 on a newly constructed 2000-sow operation where the three main stages of swine production were placed on three separate sites. This was the first network of farms ever constructed specifically for the separation of recently weaned pigs from the adult swine population (Harris, 2000). Within a typical multi-site system, the breeding-gestation complex is in an isolated location. Farrowing may be at the breeding-gestation site, or there may be a separate farrowing or farrowing-nursery site. Weaned pigs are sent to off-site nurseries and then to grow-finish farms. Wean-to-finish farms are also commonly used to grow the pigs to market weight (NPB, 2003).

Advantages and disadvantages of multi-site versus one-site production systems

One advantage that multi-site systems offer is having workers that are specialized in the specific production and management skills required on each site (Harris, 2000; Kyriazakis and Whittemore, 2006). The biggest advantage that a multi-site production system offers, however, is disease prevention and control (NPB, 2003). Disease among pigs is often spread vertically from sows to their suckling pigs, from weaned pigs to suckling pigs, or from growing hogs to weaned pigs. Having separate sites for each age group helps minimize disease transfer (Harris, 2000; Kyriazakis and Whittemore, 2006). Moving pigs by age groups in an all-in/all-out flow reduces the economic impact of an infectious disease (Harris, 2000). When diseases from sows are prevented from infecting pigs by removal from sows, weanlings will perform better, by being able to efficiently gain more weight and produce leaner carcasses, which will then lead to a more profitable product (Harris, 2000).

The different sites within a multi-site system are spaced far enough apart to help prevent diseases from being transferred by birds, pests, and aerosol infections (Kyriazakis and Whittemore, 2006). However, multi-site production systems require transportation of pigs between sites, which is a major disadvantage (NPB, 2003; Kyriazakis and Whittemore, 2006). Depending on age and size, swine have different needs immediately before and during transportation. For example, weanling pigs transported from farrowing units to off-site nursery facilities or straight to wean-to-finish units may require heated trailers and must be given extra time and care to avoid stress and injuries.

Distance between units: short, intermediate, or long (e.g. multi-state production)

There is limited information about transport duration and distances to which hogs are exposed when shipped to market (Warriss, 1998). There is also relatively little information in regards to origin of hogs arriving at processing plants as these records are generally not collected at state or federal levels. This makes determining the average distance that hogs experience on the journey to federally inspected slaughterhouses extremely difficult (Appleby et al., 2008). However, estimates have been made that more than two-thirds of hogs marketed in the U. S. travel less than 240 km to the plant (Appleby et al., 2008).

The distances that pigs and hogs are transported to other farms or to market are increasing due to changes within the infrastructure of the industry and economic opportunities for long-distance and international trade (Grandin, 2007). The main movement of hogs is into and within the Corn Belt states, mainly Iowa, Illinois, and Indiana, because these states produce abundant amounts of corn, the primary feed ingredient for swine (Shields and Mathews, 2003). The Midwest accounts for 70 % of the total hog movement, and hogs are shipped here from the regions of Appalachia, Northern and Southern Plains, and Canada (Shields and Mathews, 2003). The number of market hogs that cross state lines also increased from 30 million in 1970 to 50 million in 2001 (Shields and Mathews, 2003). Since the 1970's hog production has grown in less traditional states, such as North Carolina, even though these areas have a feed cost disadvantage.

Production has flourished in these areas mainly because of several large integrators who have made contracts and close links with producers, packers, and even consumers (Shields and Mathews, 2003). Transportation of feeder pigs mainly occurs from the Northern Plains and Canada into Minnesota and the other Lake States or from the Southern Plains states into the Northern Plains region (Shields and Mathews, 2003). During the early 1990's the number of young pigs crossing state lines was roughly 5 million which increased to 26.9 million in 2001 (Shields and Mathews, 2003). A report by the Economic Research Service revealed that 3 to 4 million pigs are transported annually from farrowing units in North Carolina to nursery facilities or wean-to-finish units in Iowa (Shields and Mathews, 2003). According to the National Pork Producers Council, it generally takes 20 to 24 h for pigs from North Carolina to reach the Midwest for finishing (Appleby et al., 2008). These hogs are generally processed locally but may be shipped to California or back to North Carolina for harvest (Shields and Mathews, 2003). Shields and Mathews (2003) reported that the distance that hogs are transported from grow-finish units in Iowa to slaughter plants in North Carolina is approximately 2700 km, which can take between 24 to 30 h, depending on how often the transporter has to rest and refuel as well as the traffic conditions during the journey (Appleby et al., 2008). Even though the number of breeding pigs that are shipped is low, these pigs travel considerably longer distances than the younger pigs and hogs (Shields and Mathews 2003; Appleby et al., 2008). The journeys that breeding stock experience are generally over 12 h and can even last a few days as these pigs may need to be transported from isolated high-level bio-security units to farms all over the U.S. and Canada (McGlone, 2008a).

Animal response to stress

Definition of stress

Stress is the reaction to stimuli that disrupt the body's normal physiological homeostasis and frequently results in harmful effects (McGlone et al., 1993; Hicks et al., 1998; Yu et al., 2007). Types of stresses that pigs and hogs experience include psychological stresses including restraint, handling, and transportation as well as physical stresses such as hunger, thirst, fatigue, injury, and temperature extremes (Grandin, 1997). Some physiological indicators of stress include changes in cortisol secretion, changes in body temperature, performance changes, changes in blood chemistry and immunology, and possibly gastrointestinal (GI) barrier dysfunction as described below.

Physiological indicators of stress

Adrenal response

One response to a stressor is activation of the hypothalamic-pituitary-adrenal (HPA) axis (McGlone et al., 1993; Hicks et al., 1998) which causes increased blood levels of catecholamines and corticosteroids. Stress causes an increase in corticotropin-releasing hormone (CRH) secretion from the hypothalamus (Désautés et al., 1999). The CRH travels through the hypothalamo-hypophysial portal blood system and then activates the anterior pituitary causing release of adrenocorticotropin (ACTH) (McGlone et al., 1993; Hicks et al., 1998). The high blood concentration of ACTH causes the adrenal cortex to release glucocorticoids, mainly cortisol, into the blood (McGone et al., 1993; Hicks et al., 1998). Elevated cortisol concentrations in pigs can be caused by stresses such as transportation, social environment, electrical stimulation, heat, as well as feed and water deprivation (McGlone et al., 1993, Hicks et al., 1998).

Stress-induced cortisol secretion was demonstrated in a study by Kanintz et al. (2004) who reported that 3 to 11 d-old piglets that were isolated from their sow and littermates for 2 h daily had an increase in basal cortisol levels compared to control piglets, who remained with their litters. The researchers reported that social isolation is a stressful experience for neonatal pigs and may lead to long-term effects on the activity of the HPA-axis. Also concluded from this experiment is that the social stress experienced by piglets is important for evaluating the possible negative consequences on health and welfare of commercially used pigs (Kanitz et al., 2004).

Body temperature

Pigs are homoeothermic, which means that they are able to maintain a relatively constant body temperature within their thermoneutral zone by balancing heat loss and heat production (Verhagen et al., 1988; Ewing et al., 1999; Grandin, 2007; Velarde and Geers, 2007). Pigs experience heat or cold stress when the environmental temperatures reach temperatures above or below the thermoneutral zone (Ewing et al., 1999; Velarde and Geers, 2007). Cold stress occurs when the amount of heat loss is greater than the amount of heat that is produced, which causes hypothermia and in some cases even death. Signs of hypothermia in pigs include huddling and shivering (Velarde and Geers, 2007). When pigs are unable to dissipate enough heat at high ambient temperatures and humidity then hyperthermia occurs (Velarde and Geers, 2007). The main clinical sign of hyperthermia is panting, as pigs are unable to sweat (Velarde and Geers, 2007; Renaudeau et al., 2010).

Heat stress is a major indication of poor welfare in the swine industry and contributes to a substantial amount of hog deaths (Renaudeau et al., 2010). In a study by Renaudeau et al. (2010) rectal temperature was considered to be the most predicitive measure for evaluating the heat tolerance of the pig because rectal temperature shows how well the pig is able to maintain homeothermy during heat stress. Within 1 h of being exposed to an increase in ambient temperature from 24°C to 26°C, the rectal temperature of the pigs increased by 0.46°C, indicating that even during a short period of elevated ambient temperature, pigs have a difficult time maintaining a constant body temperature (Renaudeau et al., 2010).

De Jong et al. (1998) demonstrated how body temperature can be used as an indicator of stress and investigated the effects of environmental enrichment on some physiological responses, including body temperature, to stressors including restraint and relocation. In this experiment, pigs were housed either in a poor (P) environment, which consisted of standard farrowing pens followed by standard grow-finish pens, or in an enriched (E) environment, which included larger farrowing and grow-finish pens that were bedded with straw. The environmental temperature was kept between 21 to 23°C. At 17 wk of age the E pigs had a lower baseline body temperature than did P pigs, indicating that the E pigs were less stressed than the P pigs as stress can affect the body temperature rhythm as well as the body temperature level (De Jong et al., 1998). The researchers concluded that the provision of larger pens and/or straw has an effect on baseline body temperatures in pigs. When the pigs experienced the stressors of restraint and relocation, however, body temperature increased similarly in both groups, showing that the pigs were stressed regardless of environment (De Jong et al., 1998).

Complete Blood Count (CBC)

Hematology as a diagnostic tool in swine is not commonly used for the following reasons: 1) Pigs do not have a suitably visible vein for venipuncture, which makes blood collection difficult (Sims et al., 1996). However, young pigs can be restrained in a supine position in order to collect blood using jugular venipuncture (Sims et al., 1996; Sutherland et al., 2009b), 2) Blood collection must be performed quickly but with care as hematological values will vary greatly if restraint is prolonged and stressful (Sims et al., 1996), 3) Delays during collection can cause the sample to clot especially if using a needle and syringe (Sims et al., 1996), and 4) Porcine erythrocytes lyse easily, which can cause hemolysis in the samples, especially if the sample is not handled properly (Sims et al., 1996). Although there is a limited amount of data for swine available, brief descriptions of each of the various measurements that compromise a CBC report are provided in Table 2.1.

Various measures included in a CBC report have been shown to change in response to different stressors and Dubreuil et al. (1993) conducted an experiment to determine the effect of an acute stress situation (5-min snare restraint) on different blood parameters in growing pigs. A cannula was surgically inserted into the jugular vein of each pig 5 d prior to sampling. Blood was sampled prior to and during application of the stressor. The pigs being stressed had increases in hematocrit, hemoglobin, and total protein. The stress-induced increase in hematocrit and hemoglobin is likely due to the reverse stress-relaxation of erythrocyte storage in the spleen, liver, veins, and lungs. The pigs that were stressed also had increases in total leukocyte and neutrophil counts (Dubreuil et al., 1993). According to Clemens et al. (1986) the neutrophil to leukocyte ratio is a very dependable indicator of stress in pigs. The leukocyte count remained greater even after 2 h in the stressed animals and was associated with an increase in neutrophils (Dubreuil et al., 1993). The severity of the stress event was indicated by a 3-fold increase in cortisol levels during the stress period compared to the pre-stress period during which pigs were calm, lying down, and/or sleeping (Dubreuil et al., 1993).

Blood chemistry

Blood chemistry profiles can be useful for determining the physiological effects of stress. Brief descriptions of each of the various measurements that are included in a blood chemistry profile are provided in Table 2.2. For example, Barnett et al. (1983) studied the effects of chronic stress on some blood parameters in the pig. These researchers found that pigs that experienced unpleasant handling had increased levels of plasma total protein and glucose and also had decreased levels of plasma urea, all of which indicated that the pigs were experiencing a chronic stress response. As previously mentioned, elevated corticosteroids result from both acute and chronic stress (Baldwin and Stephens, 1973; Aberle et al., 1974; Marple et al., 1974; Hemsworth et al., 1981). A result of elevated corticosteroids is an elevated rate of gluconeogenesis and in cold stressed pigs, elevated levels of plasma glucose (Marple et al., 1972). Thus, the results of Barnett et al. (1983) were not unexpected in pigs experiencing unpleasant handling in that the increased levels of corticosteroids would increase gluconeogenesis, leading to elevated levels of plasma glucose. The elevated corticosteroid levels would also cause protein incorporation to be reduced in tissues and thus elevate levels of total plasma protein (Barnett et al., 1983). Hence the blood parameters investigated may be beneficial along with measurements of corticosteroids in evaluating chronic stress and welfare in the pig (Barnett et al., 1983).

Endotoxin and endotoxemia

Under normal conditions, the GI tract uses active transport and facilitated diffusion to absorb solutes. Tight junctions are also used under certain conditions to passively absorb small molecules (Lambert, 2004). Endotoxins, which are derived from the cell wall of Gram-negative bacteria, are highly toxic, large in size, and are normally prevented along with other macromolecules and toxic substances from exiting the intestinal lumen and entering the blood (Sakurada and Hales, 1998; Lambert, 2004; Prosser et al., 2004). The intestinal lumen is able to prevent these substances from leaving through the use of the GI barrier which is composed of physical factors such as enterocyte membranes and the tight junctions between them, immunologic factors including tissue macrophages, and physiologic factors like mucous secretion (Lambert, 2004). Endotoxemia occurs when endotoxins, such as lipopolysaccharides enter the circulation because of dysfunction of the GI barrier and increased GI tract permeability (Sakurada and Hales, 1998; Lambert, 2004; Prosser et al., 2004).

Causes of endotoxemia include heavy exercise and heat stress (Sakurada and Hales, 1998; Lambert, 2004; Prosser et al., 2004). During endotoxemia, there is a suppression of heat-loss mechanisms, causing an elevated body temperature (Sakurada and Hales, 1998). Endotoxemia also triggers inflammatory cytokines to be released, leading to a systemic inflammatory cascade, multiple organ damage, and septic shock (Sakurada and Hales, 1998; Lambert, 2004).

Prosser et al. (2004) found that dietary supplementation of bovine colostrum or goat milk powder significantly reduced GI permeability caused by heat stress in rats. These researchers hypothesized that a potential mechanism by which these substances had a beneficial effect is related to integrity of the tight junctions within the GI barrier. Bovine colostrum fed to weaned pigs as a dietary supplement was also found to restrict gut structural and microbial changes (Huguet et al., 2006). Campbell et al. (2010) reviewed studies indicating that including spray-dried plasma (SDP) in animal feed lowers intestinal inflammation and helps the GI barrier to function properly in the face of pathogenic challenges including rotavirus in pigs (Corl et al., 2007) and *Staphlyococcus aureus* enterotoxin B (SEB) in rats (Pérez-Bosque et al., 2006).

Growth performance measures

Many individual stressors such as high ambient temperature, restricted floor space allowance, and regrouping have been reported to have negative effects on pig performance (Hyun et al., 1998). But the effects on performance when pigs are subjected to multiple stressors simultaneously, which is commonly seen in commercial swine production, has not been sufficiently investigated (Hyun et al., 1998). Feeder pigs were subjected to one of the eight treatment combinations of ambient temperature (constant thermoneutral [24°C] or high cycling temperature [28 to 34°C], stocking density (0.56 or 0.25 m^2/pig), and social group (static group or regrouped at the start of wk 1 and 3) during a 4-wk study (Hyun et al., 1998). When pigs were subjected to all three stressors simultaneously, ADG was depressed by 31% (Hyun et al., 1998). The researchers also examined the effect of stressor order as well as the number of stressors applied concurrently. Hyun et al. (1998) found that as the number of stressors increased from zero to three, ADG, ADFI, and G:F decreased linearly. The results suggest that multiple simultaneous stressors affect pig growth performance in an additive manner. The data also show that if a stressor can be removed or avoided, it will be beneficial to performance even when unmanageable stressors persist (Hyun et al., 1998).

Stress associated with transportation of swine

There are a plethora of factors associated with transportation that may be stressful to pigs and hogs, including temperature extremes, unfamiliar vibrations and noises, poor trailer design, changes in vehicle speed, long journeys, mixing with unfamiliar pigs, low space allowance, poor ventilation, withdrawal from water and feed, and the loading and unloading processes (NPB, 2008). If the stress is extreme, injury, fatigue, and death may result (Ritter et al., 2008). The stress associated with transportation has been shown to influence behavioral and physiological measures in pigs (Sutherland et al., 2009a), as well as meat and carcass quality.

Types of stressors associated with transportation

Temperature and humidity extremes

Environmental factors that affect the level of stress experienced during transportation include temperature extremes usually occurring during the summer and winter months, the humidity level, and wind speed (Grandin, 2007).

Market hogs may become overheated while being shipped because hogs are incapable of efficient thermoregulation when temperatures are high, especially during the summer (Warriss et al., 2006). Averós et al. (2008) found that the risk of market hog mortality increased with an increase in the average temperature during the drive and that the average temperature was a better predictor of mortality than was season. Fitzgerald et al. (2009) showed that when the calculated temperature-humidity index, which is used to predict stress as a result of the interaction between ambient temperature and relative humidity, reached the maximum of 30, there was a 0.0025% increase in total losses in market hogs. In order to protect swine from heat stress during transport, haulers schedule journeys during the early morning or at night, adjust stocking densities, and provide wet sand or shavings or bedding when the temperature is over 15°C. It is generally recommended that pigs be sprinkled with water prior to departure if the temperature is above 27°C (NPB, 2008). Additionally, transporters are advised to ensure that the pigs are comfortable by checking on them within the first hour of the trip and then every 2 to 3 h thereafter (NPB, 2003).

Freezing temperatures also negatively affect the welfare of swine and newly weaned and nursery pigs are particularly sensitive to extreme cold (NPB, 2008). During cold temperatures overcrowded pigs are unable to use bedding for warmth (NPB, 2008). It is recommended that transporters should protect pigs from cold stress by keeping them dry, closing a portion of the ventilation holes, and providing extra bedding (NPB, 2008).

During transport the temperature inside the vehicle can fluctuate. There has been little research conducted to define the optimum transport temperatures for weaned pigs. It is generally recommended, however, that early weaned pigs (17 ± 1 d of age; 4-7 kg) be transported between 24 and 34°C (Lewis and Berry, 2004). Older piglets aged 23 to 26 d can tolerate temperatures as low as 15°C for 12 h (Lewis and Berry, 2004).

Wind and ventilation

When the weather is hot, the presence of wind through the trailer during transport is beneficial. However, it can be harmful to the welfare of pigs and hogs in cold weather if proper precautions are not taken as frostbite can occur from cold winds (NPB, 2008). Fitzgerald et al. (2009) reported that when the wind speed increased from 0 to 7 m/s there was a decrease of 0.0025% in total losses of hogs during hot weather.

Poor air circulation and unfavorable air composition, in conjunction with temperature extremes can cause even more stress to swine during transport (USDA, 1999). Transport vehicles need to provide enough air to swine in order to suit their breathing requirements and in order to control gas and odor concentrations, the air change throughout the vehicle must also be sufficient. During hot weather, swine have an increase in respiration and need adequate ventilation to compensate for this as well as to disperse body heat that the swine are producing (USDA, 1999).

When the transport vehicle is in motion, ventilation is provided by the forced movement of air arising from the differences in pressure between the outside and inside of the vehicle, but when the vehicle is stationary, ventilation is supplied only by natural transfer (Warriss, 1998).

The space volume above the pigs' head while inside the vehicle can also greatly affect the ventilation (Warriss, 1998). This space volume is dependent on the number of decks on the vehicle because the volume is directly related to the height between the decks, and having more decks on the vehicle will decrease the height between all decks (Warriss, 1998). The height between decks in a triple-deck vehicle is generally only 90 cm. According to Warriss (1998), The Animal Transportation Association manual (1996), recommends that there should be at least 10 cm between the pigs' shoulders and the deck above them for sufficient airflow. Livestock exposed to diesel exhaust fumes during long transport journeys take weeks to recover (USDA, 1999) and livestock trailers that are pulled by tractors should have exhaust stacks that are higher than the roof of the trailer (USDA, 1999).

Vibration and noise

Swine are prone to travel and motion sickness (Bradshaw et al., 1996). Bradshaw and others (1996) showed that during both short and long duration trips, between 25 to 50% of pigs either vomited or showed behavioral symptoms of travel sickness. Increased vibrations during transport resulted in high stress levels (Murray, 2000). Vibrations during a simulated transport caused increases in cortisol and heart rate in pigs (Marchant-Forde, 2009). Vibration magnitudes depend on the suspension type of the transport vehicle, the speed that the vehicle is traveling, road quality (smoothness and straightness), how full the vehicle is, as well as the transporter's skills in driving (Marchant-Forde, 2009). Vehicle axles that are equipped with air ride suspension will provide the smoothest journey (Marchant-Forde, 2009). Pigs have incredibly sensitive ears, causing them to be stressed by even the slightest yell (Murray, 2000).

New social groups

Swine are very territorial animals, which makes the mixing of unfamiliar pigs a stressful event resulting in a higher degree of fighting and possibly death (Murray, 2000; Grandin, 2001). Fighting causes skin damage and decreases dressing percent which negatively affects the carcass yield and will lead to higher incidences of pale, soft, and exudative (PSE) or dark, firm, and dry (DFD) meat (Murray, 2000; Grandin, 2001).

Stocking density and floor space allowance

The stocking density of vehicles is one of the most important aspects of transport affecting welfare and health, as well as meat quality in swine (Ritter et al., 2006; Sutherland et al., 2009a; Sutherland et al., 2010). Higher mortality rates have been associated with greater stocking densities (Warriss, 1998; Sutherland et al., 2010). Very low stocking densities have been associated with severe skin damage due to trampling and/or fighting as hogs might be thrown around during the journey (Sutherland et al., 2010). Ritter et al. (2006) found that increasing floor space allowance from 0.39 m^2 to 0.48 m^2/hog, for hogs weighing 129 kg, reduced deaths during transport by 59%. Transport of market hogs has been shown to increase various physiological measures of stress and fatigue including lactate dehyrogenase and creatine phosphokinase (CPK). Lower levels of lactate dehyrogenase were found in hogs transported at a high stocking density (0.31 m^2/100 kg) compared with medium (0.35 m^2/100 kg) or low (0.39 m^2/100 kg) stocking densities (Kim et al., 2004; Sutherland et al., 2010). Increased CPK levels were seen in hogs with floor space allowances of 0.5 m^2/100 kg or less during transport (Warriss et al., 1998; Sutherland et al., 2010). The CPK results suggest that the hogs were suffering from physical stress since CPK is released from muscle fibers under the influence of intense muscular exertion (Warriss et al., 1998).

Inappropriate floor space allowance during transport can add additional stress to pigs already experiencing the stress of weaning, negatively affecting health, performance, and behavior (Hay et al., 2001; Kanitz et al., 2002; Sutherland et al., 2010). However, there is limited data available in regards to the optimal stocking density for transporting young pigs (Sutherland et al., 2009a). In a study investigating space allowance for weaned pigs, Sutherland et al. (2009a) discovered that the neutrophil to lymphocyte ratio was greater for the most crowded pigs (0.05 m^2/pig) compared to other treatments (0.06 and 0.07 m^2/pig). The most crowded pigs also laid down less than those with more floor space. These results suggest that the minimum stocking density for weaned pigs should be at least 0.06 m^2/pig. However, the stocking density that results in the greatest welfare and the least number of deaths from transport has yet to be determined under U.S. conditions (Ritter et al., 2007; Sutherland et al., 2009a).

Others: journey duration, lights, and smells

Journey duration can also adversely affect pig well-being and pork quality. Market hogs transported for 8, 16, and 24 h lost 2.2, 2.0, and 4.3 % BW, respectively, in a study conducted by Brown et al. (1999). Hogs transported for 24 h also lost 2.6 % hot carcass weight. Plasma albumin and protein concentrations increased concomitantly with increased time spent traveling. This indicated that the hogs were becoming dehydrated during the longer trips, with the most severe dehydration occurring in hogs on the truck for 24 h. After slaughter, ultimate pH in the longissimus dorsi, semimembranosus, and adductor muscles was greater for hogs traveling the longest time. Ultimate pH is used to identify stressed and fatigued pigs. Greater pH values are also associated with an increase incidence of DFD meat. In a study by Averós et al. (2008), the risk of mortality increased with journey duration when hogs were not fasted before the trip. For hogs that were fasted before the trip, the duration had little effect, even when the trip lasted 24 h. The researchers concluded that it can be beneficial to withdraw feed for 12 h before transport.

Bright lights, reflections, flapping objects, drain gates, and dogs should be avoided when loading/unloading or transporting as these may scare or distract swine (Murray, 2000). Covering the ramp with a shade or loading at night may help lower stress level (Murray, 2000). Pigs may be reluctant to move if there are unusual smells present (Murray, 2000).

Physiological changes in response to transportation in swine

The physiological indicators of stress as well as the performance measures that were discussed earlier are examined here in different studies to provide examples as to how transportation affects the health, welfare, and performance in pigs and hogs.

Adrenal

Many factors associated with transportation such as temperature extremes, stocking density, mixing with unfamiliar pigs, as well as withdrawal from water and feed, have been shown to activate the HPA axis and thus increase cortisol secretion. This indicates that health and welfare have been impaired (McGlone et al., 1993; Désautés et al., 1999; Hay et al., 2001; Kanitz et al., 2002; Sutherland et al., 2010).

Sutherland et al. (2009a) found that circulating cortisol increased in weaned pigs, 5 kg BW and 18 d of age, during a 60 min transport during the summer irrespective of the stocking densities examined: 0.05, 0.06, and 0.07 m^2/pig. These researchers suggested that weaned pigs experience stress during the journey regardless of floor space allowance. In another study by Sutherland et al. (2009b), weaned pigs of the same age and weight as in the previous experiment, were transported at the same three stocking densities, but were transported during the winter for 112 min. After transport, weaned pigs had elevated levels of cortisol, again irrespective of floor space allowance. Sutherland et al. (2010) also looked at the effects of the three different stocking densities during 148 min transport in the spring and fall. The weaned pigs, again weighing 5 kg and 18 d of age, had greater concentrations of cortisol after transport in all three stocking densities, again suggesting that weaned pigs experience stress during transport irrespective of space allowance. Cortisol concentrations also increased after a 4 h transport in nursery pigs, which implies that these pigs experienced stress during the journey (McGlone et al., 1993).

Hogs weighing 80 kg were used in an experiment, the objective of which was to determine sensitivity to specific types of journeys, namely the degree of roughness of different road conditions (rough or smooth; the trailer remaining stationary served as the control) (Bradshaw et al., 1996). After transport, hogs traveling the rough roads had higher cortisol levels than hogs that were transported on smooth roads. Hogs in both these conditions also had much greater concentrations of cortisol than the control group. Bradshaw et al. (1996) concluded from these results that hogs are sensitive to road conditions during transportation. During another study, hogs were fitted with jugular catheters 48 h prior to transport (Apple et al., 2005). The hogs in this experiment had increased levels of cortisol after being transported for 3 h. The increase was greatest during the first 30 min of the journey, and remained higher than the control pigs throughout the entire period of transportation (Apple et al., 2005).

Body temperature

Body temperature increased in feeder pigs transported under conditions of sufficient floor space, a consistent air temperature inside the trailer of 20°C, and slots allowing good ventilation (Geers et al., 1994). Plasma concentrations of β-endorphin, an indicator of stress, and minimal heart rate also increased after 2-h transport of pigs. Collectively, these physiological changes are consistent with the concept that pigs experience stress due to transportation (Geers et al., 1994).

Ambient temperatures that early weaned pigs experience during transportation can vary tremendously from their recommended comfort zone that ranges from 26 to 32°C (Lewis and Wamnes, 2004). Pigs weaned at 17 d of age were transported during different seasons (summer, spring, or winter) and at stocking densities of recommended (0.06 m^2/pig), 80% of recommended (0.048 m^2/pig), or twice recommended (0.12 m^2/pig) (Lewis and Wamnes, 2004). During the 24 h transport, ear temperatures were recorded every 6 h as ear temperature is a good indication of how well the pigs can cope with ambient temperatures in the trailer. Ear temperature was significantly affected by both season and floor space allowance. The highest ear temperatures (35°C) occurred during the summer. Ear temperatures of 26.9°C were recorded during spring transport, and winter ear temperatures of 16.5°C were recorded. Higher ear temperatures of 27.6°C were recorded at the greatest stocking density compared to ear temperatures of 26.6°C for the standard density and 26.9°C for the lowest density. Higher ear temperatures at the greatest stocking density indicate that these young pigs were not able to thermoregulate efficiently and have a higher risk of experiencing hyperthermia (Lewis and Wamnes, 2004).

When high environmental temperatures are present there is concern that during transport to the processing plant hogs may not be able to thermoregulate efficiently and as a consequence become overheated (Warriss et al., 2006). In a study by Warriss et al. (2006), market hogs were transported in June on a 3 h drive then held for 1 h at the slaughterhouse before being unloaded. Half of the compartments were naturally ventilated, while the rest of the pens had fan-assisted ventilation. Body temperature was recorded at exsanguination as the temperature of the blood lost, and by using thermal imaging to measure the temperature of the surface of the inner ear. The hogs located in the upper deck had higher temperatures than the hogs on the lower deck, and the hogs located toward the front of the vehicle had higher temperatures than those that were transported toward the back. The direction of the air flow might be the reason why the hogs located in the front of the trailer had higher temperatures. Cooler air enters through the rear of the trailer and becomes warmer and more humid as it travels over the hogs in the back compartments, and once reaching the hogs in the front, the air has a much lesser cooling value (Warriss et al., 2006). As a result, the front hogs do not dissipate heat as effectively and will have a higher body temperature. However, the temperatures of the hogs with fan-assisted ventilation were not lower than the temperature of pigs in compartments with natural ventilation, implying that the fans were not functioning adequately to sufficiently remove heat generated by the hogs (Warriss et al., 2006).

Blood chemistry

The previously referenced studies by Sutherland et al. (2009ab; 2010) demonstrated that blood chemistry values including creatine kinase (CK), aspartate aminotransferase (AST), and blood urea nitrogen (BUN) changed during transport, but were not influenced by space allowance (either 0.05, 0.06, or 0.07 m^2/pig). The slight increases in these values may be a sign of protein and muscle breakdown, leading the authors to suggest that weaned pigs experience a catabolic state during transport (Sutherland et al., 2009ab; Sutherland et al., 2010). During the summer (Sutherland et al., 2009a) and winter (Sutherland et al., 2009b), there were increases in blood concentrations of both total protein and albumin after transportation and the changes were not influenced by stocking density. That both total protein and albumin were increased indicates that mild dehydration occurred in transported pigs (Sutherland et al., 2009ab). Hicks et al. (1998) reported that after a 4-h journey, 4-wk old weaned pigs had increased circulating glucose concentrations compared to pigs that were not transported. Feeder pigs that weighed 20 kg were transported for 2 h (Yu et al., 2007). These researchers reported significantly higher blood concentrations of CK and AST, indicating that transportation may have caused damage to the hearts of the pigs (Yu et al., 2007).

As mentioned earlier, Brown et al. (1999) compared physiological changes in market hogs transported for 8, 16, or 24 h with hogs that were not transported. As the duration of the journey increased, the hogs appeared to become more dehydrated and had elevated plasma levels of total protein and albumin; the most serve dehydration was observed in hogs that were transported for 24 h. Another study by Becker et al. (1989) demonstrated a greater increase in plasma glucose concentrations in fasted hogs transported for 24 or 48 h compared to hogs that were not transported but were fasted for the same length of time. The higher levels of plasma glucose in the transported hogs may be indicative of greater energy demand required for handling and moving transported hogs (Becker et al., 1989). During a 3-h transport of market hogs, blood samples were taken every 30 min (Apple et al., 2005). In this study, transported hogs had greater concentrations of plasma glucose at every sampling time compared to the control hogs (Apple et al., 2005).

Performance

McGlone et al. (1993) demonstrated that pigs transported for 4-h had a BW loss of 5.1% compared to a gain in BW of 0.02% in non-transported controls. A negative correlation was found between plasma cortisol and change in BW during transportation, indicating that the transported pigs that lost more weight had a higher adrenal response to transit (McGlone et al., 1993). Transport is a stressful time for pigs and even healthy individuals can lose up to 5% of their BW during a shipping duration of 4-h (McGlone et al., 1993). A significant weight loss of approximately 5 % also occurred in 28-d old weaned pigs subjected to a 4-h transport (Hicks et al., 1998). The additive stresses of journey duration and high ambient temperature negatively affects the performance of young pigs (Berry and Lewis, 2001). In a study conducted by Berry and Lewis (2001) 17-d old weaned pigs were subjected to transport durations of 0, 6, 12, or 24 h at temperatures of 20, 25, 30, or 35°C. Berry and Lewis (2001) found that as the journey duration and temperature increased, piglets lost significantly more weight during the initial post-weaning phase, with the highest weight losses seen when the duration lasted longer than 12 h at 35°C. From these results, Berry and Lewis (2001) concluded that as the piglets attempted to thermoregulate at a temperature above their comfort zone for long durations, pigs had an increase in water loss, which caused these pigs to lose a greater amount of BW.

After experiencing the stresses of transportation, young pigs are subsequently exposed to changes in housing as well as diet (Verhagen et al., 1988; Lefaucheur et al., 1991). An experiment by del Barrio et al. (1993) investigated changes in energy metabolism during the first 2-wk of the grow-finish phase in feeder pigs that had been transported. The researchers reported that 6 to 9 d is required before the metabolic rate of feeder pigs will reach normal levels (del Barrio et al., 1993). The already mentioned study by Lewis and Wamnes (2004) showed that transportation during the summer caused piglets to take a longer time to regain the BW that was lost during the journey compared to pigs subjected to transport during the winter and spring (Lewis and Wamnes, 2004). The researchers also found that after transport in the summer, pigs displayed poor appetites (Lewis and Wamnes, 2004). These findings are in agreement with the study by Berry and Lewis (2001) in that a combination of high temperature and long durations causes poor performance and production. The study by Brown et al. (1999) is also an example of how transportation has negative effects on performance. Market hogs transported for 8, 16, and 24 h lost 2.2, 2.0, and 4.3 % BW respectively (Brown et al., 1999). Hogs transported for 24 h also lost 2.6 % hot carcass weight.

Management to decrease stress due to transportation of swine

Transportation involves many factors that are stressful to pigs. Handlers and transporters need to make sure that all the procedures involved with transporting swine aid in reducing stress as much as possible. Before loading the truck, transporters should prepare for the journey including determining the loading density and having the proper setup for weather conditions (i.e., ventilation and bedding).

Truck and trailer design and equipment

The two most common trailer designs used in the U. S. are straight-deck and possum (pot) belly. The main difference between these two designs is that there are three decks and more internal ramps in pot-belly compared with straight-deck trailers (USDA, 1999; Ritter et al., 2008). Possum belly trailers may not be well suited for hauling swine because having a great number of ramps may cause additional stress on pigs during loading and unloading as swine are inclined to refuse walking up and down ramps (USDA, 1999; Ritter et al., 2008). In order to avoid this problem ramps with a more gradual slope have been designed in some pot-belly trailers (USDA, 1999). Some transporters prefer straight-deck trailers because there are fewer ramps that the pigs will encounter (USDA, 1999).

Truck and trailer design and construction should be in accordance with appropriate legislation (Grandin, 2007). The outside of the transport vehicle should be light in color (Grandin, 2007). Maintenance and cleaning of trucks and trailers should be performed regularly and the materials used to build them should be easy to clean (USDA, 1999; Grandin, 2001; Grandin, 2007). The cleanliness of trucks will help to prevent diseases from spreading as well as preventing blemishes forming on the skin of transported animals (Grandin, 2001). Trailers should have slip resistance flooring and ramps and covered with appropriate bedding to prevent swine from slipping and falling (USDA, 1999; NPB, 2008). Transporters should also make sure that there are no holes in the flooring or loose planks so as to prevent swine from being injured (USDA, 1999). The internal ramps should operate correctly and extend all the way to the floor (NPB, 2008). The compartments should be inspected by transporters regularly to ensure that there are no obstructions, protruding objects, or other hazards that may cause skin damage and other injuries to the pigs (Grandin, 2007; NPB, 2008). Compartments should be appropriately ventilated depending on the weather conditions and the vents should follow the correct legal guides and regulations (Grandin, 2007). For transport durations that last more than 8 h, drinking nipples should be available in all compartments and contain a signal system that indicates low levels (Grandin, 2007). All transporting vehicle gates and doors should open and close correctly and be able to be secured tightly without having any gaps where swine could possibly get a leg or their head stuck or even worse fall off the truck (NPB, 2008).

Stocking density and floor space allowance

Adequate floor space is imperative because pigs prefer to lie down after standing for an extended period of time (Sutherland et al., 2009a). The floor space available per pig is generally contingent on the number of pigs to be loaded for a trip. The stocking density also depends on the weight of the pigs to be loaded, the trailer design, compartment size, and weather conditions. Swine require the proper amount of floor space during transport in order to prevent overcrowding, which will lead to injuries, fatigue, and possibly death (NPB, 2008). When swine are transported in several small groups, injuries will be reduced (NPB, 2003). However, extremely low stocking densities are not recommended as pigs might be thrown during the journey (NPB, 2003). In order to limit the number of pigs in each compartment, dividers or gates should be in place. The National Pork Board (NPB) has established recommendations for floor space allowances based on the average weigh of the pigs to be loaded during normal weather conditions. These transport floor space recommendations range from pigs of 5.5 kg having 0.198 m^2/pig up to hogs that weight 181.8 kg having 1.95 m^2/hog (NPB, 2008). The complete list of transport floor space recommendations are reported in the NPB's Transport Quality Assurance handbook.

Loading and unloading

During the summer, loading should occur during the cooler time of the day or during the night to help reduce stress (Murray, 2000). Partitions, such as sorting boards, should be used to limit the number of pigs to be loaded at one time and to prevent animals from piling on top of one another while going up or down the ramps (Grandin, 2001). The ramps should be flat with slip resistant floors, solid walls, and sufficient lighting (NPB, 2008). Ramps and chutes should be strong, with no gaps between the sides of the ramp and the truck (NPB, 2008). Ramps should not be steeper than 20 degrees as pigs have a difficult time walking up inclines that are steep (NPB, 2008). Handlers and transporters should make sure to maintain ramps and chutes in good condition and free from obstructions or other sharp, protruding objects that might cause injury to swine (Grandin, 2001; NPB, 2008). Prompt unloading in hot weather is necessary as heat builds up rapidly in a stationary transport vehicle (NPB, 2008). The transporting vehicles and loading ramps should be cleaned between deliveries to prevent contamination amongst the loads. Pigs that appear to be ill, injured, or fatigued should never be loaded (NPB, 2008).

Use of bedding

Proper bedding will assist in an effort to ensure that transport conditions are safe by providing swine with good footing to prevent slipping and falling. Bedding also provides comfort by keeping pigs warm during cold weather as well as preventing swine from overheating in hot weather (USDA, 1999; Sutherland et al., 2009c). Bedding should be kept clean and changed after every load to prevent disease transmission (USDA, 1999).

There are four main bedding types used when transporting swine: sawdust, wood shavings, straw, and sand (USDA, 1999). Sawdust is light, absorbent, and good for using in warm weather, when the ambient temperature is above 16°C, as sawdust does not produce heat and it can be dampened to help keep swine cool (USDA, 1999). Softwoods, like pine, are more absorbent than hardwoods, making these woods a better choice (USDA, 1999). Wood shavings share similar characteristics as sawdust (USDA, 1999). Straw is also very absorbent, light, and is able to produce heat that aids in keeping swine warm during cold weather and prevent frostbite especially in aluminum trailers (USDA, 1999; Grandin, 2001; NPB, 2008). Straw should never be used as bedding for swine during warm weather as it has heat-generating characteristics and is not able to help cool swine (USDA, 1999; Grandin, 2001; NPB, 2008). Another disadvantage of using straw is it causes slippery conditions when it becomes saturated (USDA, 1999). Straw can also be very difficult to clean as this type of bedding will clog drains in the trailer (USDA, 1999). The fourth type of material that is used as bedding for transporting swine is sand. Similar to sawdust and wood chips, sand is absorbent and can be dampened to help keep pigs cool (USDA, 1999; Grandin, 2001; NPB, 2008). The main advantage for using sand instead of the other bedding materials is that even when sand gets wet, this type of bedding will still provide the pigs with good footing (USDA, 1999). Sand can be handy to have available during loading and unloading to cover the floor near the tailgate as bedding is frequently pushed away from this area, causing the floor near the tailgate to become slippery (USDA, 1999). However, some transporters will not use sand as it is extremely abrasive, which can damage trailer floors (USDA, 1999). Sand is also much heavier than the other bedding types (USDA, 1999). Knowing how much bedding to use is based on such factors as the duration of the journey, species, and season (USDA, 1999). Generally, sawdust and wood shavings should be approximately 5 cm deep, straw 8 to 10 cm deep, and sand at least 3 cm deep (USDA, 1999).

Others

Since swine are extremely sensitive to high temperatures, sprinkler systems have been installed in some trailers. The sprinkler system may operate from an on-board water storage tank or an external water source (USDA, 1999). Swine sprinkled at 30-min intervals when the ambient temperature is above 27°C, have been reported to have improvements in their performance (USDA, 1999). However, a large amount of cold water should never be put on overheated swine as this may cause shock, or even death (USDA, 1999). Night loading is easier when the transport vehicle is equipped with interior lights as swine are more willing to move into lighted vehicles (USDA, 1999).

Transport drivers should drive with extreme care and caution. Drivers should also avoid rapid acceleration and sudden stops to prevent the pigs from being thrown off their feet (Grandin, 2001; NPB, 2008). Driving with care can greatly reduce the amount of transport losses (Grandin, 2001).

For journey durations longer than 24 h, swine should have access to water and feed (NPB, 2003). According to Warriss (1998), transporting pigs soon after feeding should be avoided as this can increase the number of transport losses. If hogs are to be slaughtered on the same day as transportation, then feed should be withheld for 6 to 8 h before the hogs are loaded. If the hogs will be processed the day after transport, it is advised to provide the hogs with a light feeding (NPB, 2003).

Spray dried plasma protein

Description

Spray-dried porcine plasma (SDPP) is the most common form of a class of substances referred to as spray-dried animal plasma (SDAP) or as mentioned earlier SDP (van Dijk et al., 2001). Spray-dried porcine plasma is of porcine origin and is a byproduct of processing plants (van Dijk et al., 2001). The SDPP is produced by first adding an anticoagulant, usually sodium citrate, to the blood from harvested pigs (van Dijk et al., 2001). Next, the blood is centrifuged to remove the erythrocytes (van Dijk et al., 2001). The plasma obtained is subsequently spray-dried, which sterilizes the plasma, and it is then ready to be added to animal feeds (van Dijk et al., 2001). Spray-dried porcine plasma is a feed ingredient comprised of an assorted mixture of functional proteins and other biologically important elements independent of their nutritional value (Campbell et al., 2010).

Uses of spray-dried plasma proteins in swine production

Spray-dried porcine plasma is an effective protein source that is commonly included in piglet diets at weaning, especially in Phase I diets. Inclusion of SDPP is linked to increasing feed intake, growth rate, feed efficiency, and reducing scours throughout the weaning phase (Kats et al., 1994; Coffey and Cromwell, 2001; van Dijk et al., 2001; Pierce et al., 2005; Campbell et al., 2010). The beneficial effects of SDPP are found to be more evident in production conditions where there is a high level of exposure to pathogens compared to conditions that have low levels of pathogen exposure (Coffey and Cromwell, 1995; van Dijk et al., 2001; Campbell et al., 2010). Researchers have also discovered that pigs prefer diets containing SDPP over diets that include dried skim milk (Kats et al., 1994). Torrallardona et al. (2003) noted that SDAP may be used as an alternative to feed supplemented with antibiotics because it provides a similar level of protection to that of colistin, an antibiotic of proven efficacy, against an experimental challenge with E. coli KPP in weaned pigs. Further investigations into using SDAP to prevent disease in pigs at weaning are needed because the issue of antimicrobials in animal feeds is being questioned by the FDA and others (Torrallardona et al., 2003).

Effects on performance

van Dijk et al. (2001) reviewed the scientific literature and concluded that dietary SDAP levels at up to 6% increases both ADG and ADFI during the first two wk post-weaning in a dose-dependent fashion. The feed conversion ratio (G:F) was also improved with an inclusion of up to 6% SDAP. The positive effect of SDAP on ADG and ADFI is more evident during the first than second wk after weaning (van Dijk et al., 2001). Piglet performance post-weaning is improved both with SDPP and spray-dried bovine plasma (SDBP); the effects of SDPP on ADG are greater than SDBP (van Dijk et al., 2001).

Mechanisms responsible for effects on performance

Currently there are only theories in regards to the precise mechanism by which SDPP enhances the performance of weaned pigs. Information about SDPP's mode of action could help in determining and developing feedstuffs that are less expensive than SDPP, but have similar properties (van Dijk et al., 2001). The positive effects of SDPP on ADG after weaning could be a consequence of enhancing feed intake directly or indirectly by particular bioactive components (van Dijk et al., 2001). The mode of action might be due to an appetite stimulant in SDPP (Ermer et al., 1994). Components of SDPP are likely to influence systemic or intestinal functions that control growth. The enhanced effects of SDPP might be due to specific immunoglobulin proteins (Pierce et al., 2005). A study assessing the effects of SDPP on performance was conducted by Pierce et al. (2005). These researchers evaluated the effects of SDPP and its various molecular weight fractions (IgG-rich fraction, albumin-rich fraction, and low molecular weight fraction) on the growth performance of pigs weaned at approximately 14 to 21 d of age. The IgG-rich fraction was the only molecular weight fraction to increase ADG and ADFI. The effects of the IgG-rich fraction on ADG and ADFI were similar to those of SDPP during the first wk post-weaning (Pierce et al., 2005). The researchers concluded that pigs benefit from SDPP fed during the first wk after weaning and that the component responsible for enhancing feed intake and growth rate is the IgG-rich fraction (Pierce et al., 2005). Spray-dried porcine plasma and SDBP seem to improve growth performance by improving the pig's immunocompetency, mostly likely by the IgG component (Coffey and Cromwell, 2001). The IgG is able to prevent damage to the gut wall caused by bacteria and viruses, which would result in an improved functioning of the GI barrier (Coffey and Cromwell, 2001). This mode of action of IgG can then futher explain the results in the previously mentioned study by Pierce et al. (2005), that IgG was the only component in the study to improve feed intake and growth rate.

As discussed earlier, SDP has been shown to reduce intestinal inflammation and enhance the function of the GI barrier when animals are exposed to different types of stress (Nofrarías et al., 2006; Pérez-Bosque et al., 2006; Corl et al., 2007; Campbell et al., 2010). This leads to improvements in growth performance. In non-challenged pigs, Nofrarías et al. (2006) found that SDP can alter intestinal immune cells, which implies that there is a reduced activation of the immune system. In the study by Corl et al. (2007) pigs were challenged with rotavirus, which can infect small intestinal enterocytes resulting in damage to the GI barrier and watery diarrhea. The pigs fed SDP had lower incidence of diarrhea and improved intestinal health. These researchers suggested that the improved intestinal health might be an effect of SDP changing the immune activation as a response to infection. The SDP in the earlier mentioned study by Pérez-

Bosque et al. (2006) was reported to regulate the SEB-induced intestinal inflammation and the function of the GI barrier by possibly lowering the pro-inflammatory cytokines accompanied by an increase in anti-inflammatory cytokines.

Conclusion

Proper transport of pigs and understanding conditions that affect welfare are crucial to minimizing negative impacts on pigs and pork quality. Improved management methods of transporting swine, including assuring adequate floor space, maintaining temperatures near the thermoneutral zone, and limiting the trip duration will all help to improve swine welfare. Animal welfare groups and, to a lesser extent, consumers are pressuring the swine industry to ensure the welfare of pigs is a priority during transport and is performed to the highest standards. Therefore it is up to all those involved in the industry including the farmers, handlers, transporters, packers, and scientists to continuously strive to better improve the health and well-being of pigs during transport. In order to fully evaluate pig welfare during transportation, researchers need to use a multidisciplinary approach, as described in the following research project. The objective of the study was to determine the effects of pre-weaning administration of SDPP on numerous welfare characteristics in weaned pigs after transport as well as the effects of changes in well-being on post-weaning performance.

Table 2.1. Complete Blood Count (CBC) report

Item	Description	Reference Intervals	Units
Red blood cell count (RBC)	Levels peak at birth and decrease quickly after colostral intake and if iron injection is not administered. Red blood cells are formed in bone marrow and stored here and in the spleen (Sims et al., 1996). These cells provide some reserve for supplementing the circulatory level to meet stressful conditions that need an increase in RBC volume and oxygen transport. The primary function of RBCs is to deliver oxygen to body cells and to remove and transport carbon dioxide to the lungs for respiratory elimination (Ewing et al., 1999).	5.0 – 8.0	$x10^6/\mu L$
Hemoglobin (HGB)	Levels peak at birth and decrease quickly after colostral intake and if iron injection is not administered (Sims et al., 1996).	10.0 –16.0	g/dL
Hematocrit (HCT)	Hematocrit is a count of RBCs and is altered when animals are transported. If animals encounter stress such as handling or transport, the spleen may release RBCs and a higher cell count may occur. More chronic stressors, however, are likely to cause a reduced cell count (Grandin, 2007).	32.0- 50.0	%
Mean corpuscular volume (MCV)	Highest level seen at birth and weaned pigs generally have the lowest (Sims et al., 1996).	50.0-68.0	fL
Mean corpuscular hemoglobin (MCH)	Lowest values observed in weaned pigs about 5 wk of age (Sims et al., 1996).	11.0-17.0	pg
Mean corpuscular hemoglobin concentration (MCHC)	Values towards the upper limit of the interval are seen in breeding animals (Sims et al., 1996).	30.0-34.0	g/dL
White blood cell count (WBC)	Values outside the normal range may be seen in normal weaned and feeder pigs (Sims et al., 1996).	11.0-22.0	$x10^3/\mu L$
Segmented neutrophils (SEG)	Values above the normal range may be seen in healthy weaned and feeder pigs (Sims et al., 1996). Neutrophils are formed in the bone marrow. Their major function is phagocytosis, in which microorganism and foreign particles are engulfed and destroyed by enzymatic action. Large numbers of neutrophils congregate at infection sites and prompt the central nervous system to increase body temperature at the onset of an infection (Ewing et al., 1999).	3.080-10.340	$x10^3/\mu L$
Lymphocytes (LYMPH)	Normal neutrophil: lymphocyte ratio is less than 1 in pigs older than 7 to 10 d. Lymphocytes are the key cells controlling the immune response (Tuchscherer et al., 1998). Lymphocytes are formed from stem cells in bone marrow & develop as T cells in the thymus or B cells in bone marrow. The primary role of B cells is in antibody formation. The role of T cells is in cytotoxicity and in stimulating other immune cells. Chronic stress may reduce the effectiveness of an animal's immune system by causing the lymphocyte count to be reduced (Ewing et al., 1999).	4.290-13.640	$x10^3/\mu L$
Monocytes (MONO)-	Monocytes have a highly variable normal range, causing difficulty in classifying them. Some reference ranges have much higher values. Monocyte counts are not elevated as a result of stress (Sims et al., 1996). Monocytes are formed in the bone marrow & spleen. Their primary function is to destroy microorganisms and remove damaged cells in the tissue injury area through the process of phagocytosis (Ewing et al., 1999).	0.220-2.200	$x10^3/\mu L$
Eosinophils (EOS)	Numbers are influenced by exposure to parasitic larvae. Stress causes a reduction in the eosinophil count (Sims et al., 1996). Formed in the bone marrow and may be phagocytic. This cell class increases in response to allergies and allergic reactions. Chronic stress may result in low levels, which is a condition called eosinopenia (Ewing et al., 1999).	0.110-2.420	$x10^3/\mu L$
Basophils (BASO)	Basophils are not seen in all samples. The bone marrow is the site of formation of basophils. The cells are involved in allergic responses and produce heparin (anticoagulant), histamine (vasodilator and gastric secretory stimulator), lysozyme (antibacterial enzyme), and brandykinin (vasodilator) (Ewing et al., 1999).	0.000-0.440	$x10^3/\mu L$
Platelets	Values towards the lower end of the range are seen in newborn piglets. The lower limit of the reference interval is higher than those of other domestic species. Stressed animals have increased values (Sims et al., 1996). Formed mainly in bone marrow and the liver and spleen produce some during fetal development.	325.0-715.0	$x10^3/\mu L$

	The primary function of platelets is in the blood clotting process. This function is related to meeting emergencies by conserving blood and in the healing process of damaged tissue by contributing to the stable mass of material at the injury site (Ewing et al., 1999).		
Fibrinogen (FIBR)	Higher upper normal values compared to other species (Sims et al., 1996)	100-500	mg/dL
Plasma protein (PP)	Values below the normal range are seen before consumption of colostrum and also may be found in pigs less than 6 mo of age	6.0-8.0	g/dL
Packed cell volume (PCV)	Values peak at birth, fall quickly after colostral intake and also if iron injection is not administered. Increases in PCV level is a sign of dehydration, fear, and lack of control (Appleby et al., 2008).	32-50	%

Table 2.2. Blood chemistry profile

Item	Description	Reference Intervals	Units
Albumin	Blood levels are an indication of normal liver and kidney function (Wittish and Estienne, 2011). Elevated levels are a sign of dehydration (Appleby et al., 2008). Albumin concentrations usually parallel the total protein concentrations (Sutherland et al., 2009b).	3.2 – 4.4	g/dL
Anion gap	Value represents the difference in levels of cations (sodium and potassium) and anions (chloride and CO_2) in extracellular fluid of blood. Increases are associated with metabolic acidosis and decreases indicate metabolic alkalosis (Wittish and Estienne, 2011).	10 – 25	mEq/L
Aspartate Aminotransferase/ Glutamic-Oxalacetic Transaminase (AST/GOT)	An enzyme present in numerous organs including the liver, muscles, and lungs, that functions in the rapid metabolism of glucose (Wittish and Estienne, 2011). When cells are injured or die or in response to exercise AST/GOT is released into the blood stream. Presence of AST/GOT is a good indicator of muscular activity or tissue damage in pigs (Yu et al., 2007).	12 – 65	μ/L
Bilirubin	If red blood cells (RBC) are damaged or if the liver is inflamed or obstructed, blood bilirubin increases. The RBCs are disposed of in the spleen. Hemoglobin is broken down to heme and amino acids. Heme is turned into unconjugated or *indirect* bilirubin in the spleen. Indirect bilirubin is bound to albumin, sent to the liver and conjugated with glucuronic acid, making it water-soluble. Much of this form goes into the bile and into the small intestine. Some of the conjugated or *direct* bilirubin remains in the large intestine and is metabolized by bacteria in the colon. *Total* bilirubin is the sum of indirect and direct bilirubin (Wittish and Estienne, 2011).	Total, 0.0 – 0.2; Direct 0.0 – 0.1; Indirect, 0.0 – 0.2	mg/dL
Calcium	Stored in the bones and teeth of the pig. However, for proper contraction of muscles, including the heart, *ionized* calcium is needed and this specific form of calcium is not a normal product of the bones and teeth. If blood levels become abnormally low, the body must draw calcium from the bones and teeth (Wittish and Estienne, 2011).	8.9 – 11.6	mg/dL
Carbon Dioxide (CO_2)	Levels are an indication of blood pH and whether kidneys are functioning normally. Vomiting and diarrhea can affect blood CO_2 levels (Wittish and Estienne, 2011).	17 – 26	mEq/dL
Chloride	Chloride promotes normal *osmosis*, the process by which molecules move through the permeable walls surrounding cells. Blood chloride levels decline in pigs dehydrated from vomiting and/or diarrhea (Wittish and Estienne, 2011).	95 – 103	mEq/dL
Creatinine	Creatinine is a measure of energy metabolism and is dependent on the amount of muscle in the body. If the amount of muscle in the body changes so will the amount of creatinine in the blood. Creatinine is normally excreted through the kidneys, so blood values give an indication of how well kidneys are functioning (Wittish and Estienne, 2011).	1.2 – 2.5	mg/dL
Creatine kinase (CK)	Enzyme found in various tissues including the heart, brain, and skeletal muscle. CK is a marker of heart attack, severe muscle breakdown, and acute renal failure. Increase in CK is a sign of physical exertion (Wittish and Estienne, 2011). CK is released into the blood when there is muscle damage, e. g. bruising, and when there is vigorous exercise. It is clear that factors negatively affecting welfare result in CK release (Grandin, 2007; Yu et al., 2007; Appleby et al., 2008).	89 – 866	μ/L
Globulin	A large protein important for immunologic responses (e.g., IgG), globulins have many functions such as, the carrier of some hormones, lipids, metals, and antibodies. When chronic infections or liver disease are present, elevated levels are seen. Low levels are found in individuals with compromised immune systems, poor diets, and liver or kidney disease (Wittish and Estienne, 2011).	1.8 – 3.8	g/dL
Glucose	Feed used by the pig for energy must be converted to glucose, a simple sugar. Elevated glucose levels in the blood can interfere with proper metabolism (Wittish and Estienne, 2011). Decreased level indicates food deprivation (Appleby et al., 2008).	54 – 113	mg/dL
Gamma-glutamyltransferase or gamma-glutamyl	Mainly found in liver cells, this enzyme is involved in the transport of amino acids and peptides into cells as well as glutathione metabolism. Elevated levels may be found in liver disease, bile-duct obstruction, and in some cases, excessive magnesium ingestion. Decreased levels can be found in hypothyroidism,	10 – 52	μ/L

transpeptidase (GGT)	hypothalamic malfunction, and low levels of magnesium (Wittish and Estienne, 2011).		
Magnesium	Abnormal levels of magnesium are seen in conditions that cause excessive excretion of magnesium by the kidneys or impaired absorption in the intestines (Wittish and Estienne, 2011).	1.1 – 1.5	mg/dL
Phosphorus	In concert with calcium, phosphorus is required for bone growth and function. Phosphorous is also required for glucose and fat metabolism (Wittish and Estienne, 2011).	4.6 – 8.6	mg/L
Potassium	Potassium is a very important electrolyte for conduction of nerve impulses, muscle contractions, and cell osmosis. Blood potassium levels decline when pigs become dehydrated from vomiting and/or diarrhea (Wittish and Estienne, 2011).	4.7 – 7.1	mEq/L
Sodium	Sodium is important in cell osmosis and the transmission of nerve impulses. Blood sodium levels decline in dehydrated pigs (Wittish and Estienne, 2011).	140 – 150	mEq/L
Total protein	The total amount of protein in the blood increases when a pig becomes dehydrated and levels are an indication of normal function of various organs in the body (Wittish and Estienne, 2011). Total protein and albumin concentrations are markers for protein homeostasis, and increase with dehydration (Sutherland et al., 2009b).	6.5 – 8.1	g/dL
Urea Nitrogen	Levels in the blood are an indication of how well the kidneys are functioning. Increase in urea level is a sign of food deprivation (Appleby et al., 2008; Wittish and Estienne, 2011). Blood urea nitrogen is a metabolic waste product in the blood generated from the breakdown of protein (Sutherland et al., 2009b).	22 – 27	mg/dL

CHAPTER III.

EFFECT OF SPRAY-DRIED PORCINE PLASMA ADMINISTERED AS AN ORAL GAVAGE ON INDICATORS OF HEALTH, WELFARE, AND PERFORMANCE IN PIGS TRANSPORTED AFTER WEANING

1. Introduction

Production systems that require the transportation of pigs at weaning are increasing throughout the U. S. (Sutherland et al., 2010). Weaned pigs are commonly transported from farrowing units to nursery farms or wean-to-finish units. Transportation affects the welfare and health of swine, particularly in young pigs already experiencing weaning stress. Individually, both transport and weaning have been shown to influence the physiology, performance, behavior, and immune response of pigs (McGlone et al., 1993; Hay et al., 2001; Kantiz et al., 2002; Sutherland et al., 2009ab; Sutherland et al., 2010). When weaning occurs simultaneously with transportation, the stressors are additive, which greatly compromises performance during the post-weaning phase (Lewis and Berry, 2004).

Weaned pigs are frequently fed starter diets containing spray-dried porcine plasma (SDPP) to increase growth rate, feed intake, and feed efficiency as well as to reduce scouring during the post-weaning period (Coffey and Cromwell, 2001; van Dijk et al., 2001; Campbell et al., 2010). Although the precise mechanism by which SDPP improves the growth performance of weaned pigs is unclear, it has been hypothesized that SDPP acts by improving the pig's immunocompetency and enhancing the function of the gastrointestinal (GI) barrier (Coffey and Cromwell, 2001; Campbell et al., 2010). The objective of the experiment reported herein was to determine the effects of SDPP, administered in the form of an oral gavage for 5 d before weaning, on health, well-being, and performance in young pigs after transportation.

2. Materials and Methods

2.1 General

The experiment was conducted at the Virginia Tech-Tidewater Agricultural Research and Extension Center (TAREC) in Suffolk, VA, USA during the months of June and July, 2010. The protocol for the study was approved by the Institutional Animal Care and Use Committee (IACUC) of Virginia Tech.

At 17 ± 1 d of age, 80 Duroc x Yorkshire x Landrace suckling pigs (40 barrows and 40 gilts) from 12 different litters were selected for the study based on gender and average BW. Piglets were randomly assigned to one of four treatments that began at 26 ± 1 d of age: I. SDPP (0.375 g/mL) + transport, II. Water + transport, III. SDPP + no transport, and IV. Water + no transport (n = 10 barrows and 10 gilts per treatment). Each treatment group contained piglets from each litter. Colored ear tags were placed in the left ear of animals for easy identification of the pigs in the different treatment groups.

During the suckling phase, piglets remained with their sow and littermates in standard farrowing crates that measured 2.01 m in length, 1.49 m in width, and 0.56 m in height. All sows were fed on an ad-libitum basis a fortified corn and soybean meal-based lactation diet that met or exceeded the nutrient requirements put forth by NRC (1998). Piglets were not offered creep feed, and water was provided on an ad-libitum basis by nipple waterers in the farrowing crates. Cross-fostering was kept to a minimum.

After relocation to the wean-to-finish barn, pigs were randomly placed into 1 of 5 pens based on gender and treatment group. Thus, each of the 5 pens had 2 gilts and 2 barrows from each of the 4 treatment groups. The wean-to-finish pens measured 3.35 m in length and 3.35 m in width and were situated over a combination solid and slatted concrete floors. Each pen contained a four-hole stainless steel feeder and nipple drinker. During the first 5-wk period in the wean-to-finish unit pigs were allowed ad-libitum access to fortified corn and soybean meal-based diets in a 3-phase feeding program that met or exceeded the requirements for the various nutrients (NRC, 1998). Wean-to-finish diets did not contain SDPP.

2.2 Spray-Dried Porcine Plasma

Beginning at 26 ± 1 d of age pigs received 25 mL of their assigned gavage twice daily (at 0800 and 2000 h) for 5 d prior to weaning. The SDPP (Appetein; American Protein Corp., Inc.; Ankeny, IA) was mixed with water to create a slurry that was administered as an oral gavage. The slurry contained 0.375 g SDPP per 1 mL water, for a total of 9.375 g SDPP per 25 mL water. The dose of SDPP employed was based on the percentage of SDPP included in typical nursery starter diets (5.0%) and average feed consumption of newly weaned pigs (399 g/d) at the TAREC swine research facility (Harper and Estienne, 2002). The drencher used to administer the SDPP was manufactured by Henke Sass Wolf (Tuttlingen, Germany). Pigs in treatment groups II and IV received 25 mL of water using a 25 mL syringe. Gavages were administered slowly to prevent pigs from regurgitating SDPP or water.

2.3 Transportation and Relocation

Prior to loading piglets (groups I and II) on the livestock trailer, pine sawdust bedding was spread over the floor of the trailer and a thermometer was placed inside at pig height to measure the environmental temperature. The temperature inside the trailer was recorded as 35°C prior to transport, 33°C half way through the journey (after driving approximately 2.5 h), and 40°C upon arrival to the wean-to-finish barn.

At 31 ± 1 d of age, the 40 pigs in treatment groups I and II were removed by litter to be weighed, rectal temperatures were recorded, and blood samples were collected. Pigs were then moved as one large group to be loaded into the trailer. Handlers used sorting boards to guide the pigs toward the solid wood loading ramp leading to the trailer. The pigs were loaded into the rear compartment of the livestock trailer (CornPro; Cornelius Manufacturing, Inc.; Elnora, IN) which measured 2.29 m in length and 1.83 m in width, providing a floor space allowance of 0.10 m^2/pig. Pigs were sprinkled with water after all pigs were loaded onto the trailer. Pigs were then transported for 5 h on a round trip on a smooth continuous roadway back to the TAREC swine unit. The transporters stopped after approximately 2.5 h to check on pigs and to record the temperature inside the trailer. After the 5-h journey, pigs were unloaded, weighed, rectal temperatures were determined, and blood samples collected. Pigs were then placed in 1 of the 5 wean-to-finish pens based on gender and treatment group.

Pigs from treatment groups III and IV were removed from their farrowing crates, weighed, rectal temperatures were determined, and blood samples collected. Pigs were then guided by handlers using sorting boards to the wean-to-finish barn. Upon arrival at the wean-to-finish barn, pigs were weighed, rectal temperatures determined, and blood samples collected. Pigs were then placed into 1 of the 5 wean-to-finish pens, based on gender and treatment group. Thus, each of the 5 pens had 2 gilts and 2 barrows from each of the 4 treatment groups.

2.4 Performance and Rectal Temperature

Body weights were recorded at 26 ± 1 d of age (first day of receiving gavages), at weaning (prior to transportation or relocation), immediately after transportation or relocation, and then once weekly for 5 wk.

Rectal temperatures were determined using a standard rectal thermometer (Agri-Pro Enterprises of Iowa, Inc.; Iowa Falls, IA). Rectal temperatures were measured and recorded for each pig prior to weaning and before transportation or relocation, as well as after transportation or relocation but prior to placing in the wean-to-finish pens.

2.5 Blood Collection and Analyses

Blood samples (24 mL) were collected via jugular venipuncture (one inch, 20 gauge needle) after pigs were placed in a supine position on a V-trough. Blood was placed in two collection tubes labeled for use in determining blood chemistry profiles and analysis of cortisol concentrations. Serum was harvested following centrifugation. Samples were subjected to a complete clinical chemistry analysis using an Olympus AU400 clinical chemistry analyzer (Beckman Coulter, Inc.; Brea, CA) in the pathology laboratory of the Virginia-Maryland Regional College of Veterinary Medicine in Blacksburg, VA. Concentrations of glucose, urea nitrogen, creatinine, phosphorus, calcium, magnesium, total protein, albumin, globulin, aspartate aminotransferase/glutamic-oxalacetic transaminase (AST/GOT), gamma-glutamyl transferase (GGT), bilirubin-total, bilirubin-direct, bilirubin-indirect, creatine kinase (CK), sodium, potassium, chloride, carbon dioxide (CO_2), and anion gap were determined.

Serum cortisol concentrations were determined using a radioimmunoassay kit (Coat-A-Count Cortisol; Siemens Healthcare Diagnostics, Los Angeles, CA). This cortisol assay was validated for pig serum by Griffith and Minton (1992). All samples were run in one assay with an intra-assay coefficient of variation of 8.79 % and a sensitivity of 2.0 ng/mL.

2.6 Statistical Analysis

Data were analyzed using the General Linear Models (GLM) procedure of SAS for Windows Version 9.2 (SAS Institute, Inc.; Cary, NC). Serum cortisol concentration, rectal temperature, and the blood chemistry data were subjected to analysis of variance for a 2 x 2 x 2 factorial design using a model that included gavage (SDPP or water), transport (yes or no), time (pre-wean/transport/relocation or post-wean/transport/relocation), and all interactions as possible sources of variation. Body weights and weight gain data were subjected to analysis of variance for a 2 x 2 x 8 factorial design using a model that included gavage (SDPP or water), transport (yes or no), and time (initial, pre-wean/transport/relocation, post-wean/transport/relocation, wk 1, wk 2, wk 3, wk 4, or wk 5), and all interactions as possible sources of variation. Individual means were compared using the P-DIFF and STDERR options of the GLM procedure and were adjusted using the Tukey-Kramer option. Values were considered statistically different at $P < 0.05$. Results are reported as least squares (LS) means.

3. Results

Four pigs (2 barrows and 2 gilts) died during the experiment. One barrow was from treatment group I, 1 barrow and 1 gilt were from treatment group II, and 1 gilt was from treatment group III. The barrow from treatment group I died shortly after obtaining post-transport measurements. The gilt from group III was found dead 5 d after being relocated to the wean-to-finish barn. The barrow from treatment group II was observed to have a swollen, left hock the day after being transported and placed into the wean-to-finish barn, and had to be humanely euthanized 5 d after relocation. The treatment group II gilt was found dead during the second week of being housed in the wean-to-finish barn.

3.1 Growth Performance

Gavage had an effect ($P = 0.0001$) on BW, and pigs that received SDPP (groups I and III) weighed more than pigs that received water (groups II and IV) (Table 3.1). As expected, time also affected ($P < 0.0001$) BW and among treatment groups the greatest BW was recorded 5-wk post weaning (Table 3.1).

For weight gain, there was a trend for an interaction between gavage and transport (P = 0.077). Pigs that received SDPP but were not transported (group III) tended to gain more weight than pigs that received water and were not transported (group IV). There was an effect of time (P < 0.0001) on weight gain. Pigs gained the most weight from the time period when they were weighed after weaning, and thus either after transport or relocation, until they were weighed for the last time 5-wk post weaning (Table 3.2). Gavage affected weight gain (P = 0.029) and pigs that received SDPP (groups I and III) gained more weight than the pigs that received water (groups II and IV) (Table 3.2).

3.2 Rectal Temperature

Gavage, transport, and time interacted (P = 0.019) to affect rectal temperature, with a greater increase seen in pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III), and in pigs that received water and were transported (group II) compared to pigs that received water and were directly relocated to the wean-to-finish barn (group IV) (Figure 3.1).

3.3 Blood Chemistry

There was a three-way interaction of gavage, transport, and time (P = 0.03) for blood calcium concentrations with a significant decrease seen (Figure 3.2) in pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III), and in pigs that received water and were transported (group II) compared to pigs that were not transported and were directly relocated to the wean-to-finish barn (group IV). Gavage, transport, and time also presented a three-way interaction (P = 0.001) for potassium blood levels with a significant increase seen after transportation (Figure 3.3) in pigs that received SDPP (treatment group I) compared to pigs in groups II, III, and IV.

For serum glucose levels there was a two-way interaction of gavage and transport (*P* = 0.01) with the pigs in group treated with SDPP having greater glucose levels after being transported compared to the pigs in treatment group II (Figure 3.4). Gavage and transport also affected (*P* = 0.01) serum levels of total protein. As displayed in Figure 3. 5, pigs that received SDPP and were transported (group I) had a greater total protein blood level compared to pigs that received SDPP but did not undergo transportation (group III). For serum albumin levels there was a two-way interaction of gavage and transport (*P* = 0.01). Treatment group I pigs had a greater blood level of albumin compared to group II, III, and IV pigs (Figure 3.6). Gavage and transport displayed a two-way interaction for serum sodium levels (*P* = 0.03) and pigs that received water and were transported (group II) had a significantly greater sodium level compared to pigs in treatment groups I, III, and IV (Figure 3.7). A two-way interaction of gavage and transport (*P* = 0.04) was also presented for anion gap blood levels with a greater level seen in treatment group II pigs compared to pigs in group IV (Figure 3.8).

For blood levels of phosphorus, transport and time displayed a two-way interaction (*P* = 0.006). There was a significant increase in blood phosphorus levels in transported pigs (groups I and II) compared to pigs in groups III and IV that were relocated to the wean-to-finish barn (Figure 3.9). A two-way interaction of transport and time (*P* = 0.005) was also presented for serum GGT levels. As seen in Figure 3.10, blood levels of GGT were greater after transportation of pigs in treatment groups I and II compared to treatment group III and IV pigs that did not undergo transportation. Transport and time displayed a two-way interaction (*P* = 0.001) for chloride blood levels. Chloride levels significantly increased after pigs in groups I and II were transported compared to pigs (groups III and IV) that were relocated to the wean-to-finish barn (Figure 3.11). There was a tendency for an interaction of transport and time for serum urea nitrogen levels, however there were no significant differences among treatment groups (*P* = 0.06; data not shown).

There were effects (*P* < 0.0001) of time on blood levels of CK, creatinine, anion gap, and AST/GOT, with levels increasing after pigs were either transported or relocated to the wean-to-finish barn. An effect of time (*P* = 0.004) was also seen for indirect and total bilirubin blood levels. Total and indirect bilirubin blood levels were greater after pigs either experienced being relocated to the wean-to-finish barn or underwent a 5 h transport. There was a significant effect of time (*P* = 0.025) on serum total protein levels with an increase seen after pigs were either transported or relocated. There was also an effect (*P* = 0.007) of time on albumin blood levels with albumin levels increasing after pigs were either relocated or transported for 5 h. An effect of time (*P* = 0.0001) was displayed for serum sodium levels; serum sodium levels greatly increased after pigs were transported or relocated to the wean-to-finish barn.

An effect of transport (*P* = 0.01) and an effect of time (*P* = 0.002) were presented for urea nitrogen blood levels. Pigs in groups I and II (transported groups) had greater blood urea nitrogen levels compared to pigs in groups III and IV (non-transported groups). Blood urea nitrogen levels were greater after pigs were transported or relocated. There was an effect of gavage (*P* = 0.04), an effect of transport (*P* = 0.007), and an effect of time (*P* < 0.0001) for blood levels of CO_2. Pigs that received water (treatment groups II and IV) had greater blood levels of CO_2 than the pigs that received SDPP (groups I and III). Pigs that were not transported (groups III and IV) had greater serum CO_2 levels compared to transported pigs (groups I and II). After transportation or relocation, pigs experienced a decrease in CO_2 blood levels. There was an effect of gavage (*P* = 0.022) on serum phosphorus levels. The pigs that received SDPP (groups I and III) had greater blood phosphorus levels compared to pigs that received water (groups II and IV).

3.4 Cortisol

There was a two-way interaction ($P < 0.0001$) between transport and time for serum cortisol concentrations with cortisol concentrations significantly greater in treatment groups I and II after transport compared to pigs in groups III and IV that were relocated to the wean-to-finish barn (Figure 3.12).

4. Discussion

The main objective of this study was to determine the effect of SDPP administered prior to weaning, on various indicators of pig welfare after transportation. Moreover, the 2 x 2 x 2 factorial arrangement of treatments allowed us to compare indicators of welfare after weaning and transportation with indicators of welfare after weaning alone. In modern commercial operations these two events usually occur at the same time.

In previous research, the effects of dietary addition of SDPP on pig health and performance have been demonstrated during the first 2 wk post-weaning. In this study, we looked at the effects of SDPP administered as an oral gavage for 5 d prior to weaning on performance over a 5 wk period after transport and weaning. From our results, the pigs that were administered SDPP (treatment groups I and III) weighed more than the pigs that received water (treatment groups II and IV) which supports our hypothesis that providing SDPP prior to weaning helps improve pig performance post-weaning. The pigs that received SDPP also gained more weight than the pigs that were administered water, which also supports our hypothesis that providing SDPP prior to weaning would assist in enhancing post-weaning growth performance. Further research is needed to determine the optimum dose of SDPP to administer and a commercially feasible method of delivery.

In this experiment, the events of weaning and transportation or relocation occurred on one of the hottest days in July, 2010 with the ambient temperature recorded at 40°C just prior to transportation. Rectal temperature increased in all treatment groups, but the magnitude of increase was greatest for pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III), and for pigs that received water and were transported (group II) compared to pigs that received water and were directly relocated to the wean-to-finish barn (group IV). According to the USDA (1999), poor air circulation, unfavorable air composition, along with temperature extremes can cause stress during transport. In the present study, pigs were not able to thermoregulate efficiently while in the trailer for 5 h, which caused rectal temperature to increase more than in pigs that were not transported. The results from our study indicate that a 5-h transport causes more stress than does just relocation. According to Galyean et al. (1995) and Sporer et al. (2008) rectal temperature is a well known indicator of an inflammatory response to infection in calves transported to the feedlot. The results from our experiment indicate that providing SDPP prior to weaning and transport does not seem to prevent hyperthermia. However since previous researchers, such as Pérez-Bosque et al. (2006) have found that providing SDPP aids in regulating intestinal inflammation as well as regulating the function of the gastrointestinal barrier by possibly lowering the pro-inflammatory cytokines accompanied by an increase in anti-inflammatory cytokines, future investigation is needed to see if this is also true when SDPP is administered prior to weaning and transport since the results from previous studies do not fully support the results from our experiment.

Calcium levels were decreased in both treatment groups I and II after transportation. Ionized calcium, which is a form of calcium that is not stored in bones and teeth, is needed for proper contraction of muscles, and blood levels that are low are an indication that the body is drawing calcium from teeth and bones to aid in properly contracting muscles. A decline in calcium could be a sign of muscles being slightly exerted as a result of the physical stress of transportation. However, previous researchers (Warriss, 1998; Kim et al., 2004; Yu et al., 2007; McGlone, 2008ab; Sutherland et al., 2009ab; Sutherland et al., 2010) reported no changes in blood calcium levels due to transportation in pigs. These researchers, however, reported increases in CK and AST, which are released from muscle fibers into the bloodstream in response to exercise or tissue damage and are good indicators of physical stress and tissue damage in pigs. In our study, AST and CK levels were similar for transported pigs and non-transported pigs and suggest that weaned pigs transported for 5 h show only a mild physical stress response. Providing SDPP did not protect the pigs from having muscles slightly exerted from the physical stress of transport. Previous studies have indicated that abnormal electrolyte and mineral balance including hypocalcaemia occur in transported cattle (Schaefer et al., 1990), which is supported by our results of lower calcium levels in transported pigs.

Blood levels of potassium increased in pigs in treatment group I only. Potassium is an essential electrolyte for transmission of nerve impulses, muscle contractions, and cell osmosis. Blood potassium levels decline when pigs become dehydrated from vomiting or diarrhea. Since the pigs in treatment group I had an increase in potassium levels, perhaps providing SDPP prior to transport helped to keep the pigs from becoming completely dehydrated during a 5 h journey. Pigs that were provided SDPP but were not transported did not have an increase in blood potassium. These pigs were not experiencing the stress of transportation for 5 h and also had access to water before the transported pigs did, which could mask the effects of SDPP on some of the blood chemistry measurements and having access to water earlier could also cause the blood potassium level to remain closer to normal levels.

The serum glucose concentration was lower in pigs in treatment group II (received water and were transported) compared to the pigs within treatment groups I (received SDPP and were transported) and IV (received water and were not transported). Hicks et al. (1998) reported an increase in glucose levels in pigs transported for 4 h and Apple et al. (2005) also found an increase in glucose after hogs were transported for 3 h. A study by Cole et al. (1988) reported elevated serum glucose in relation to journey duration in feeder calves. A high level of glucose is a sign that the metabolism of the pig is not normal and glucose levels can also be increased by stress through catecholamine-mediated glycogenolysis (Warriss et al., 1998). A decreased level of glucose in the blood is an indication of food deprivation (Appleby et al., 2008). In the present study, because the pigs in group I had similar glucose levels to the pigs in group IV, it is possible that providing SDPP prior to weaning and transport helped to maintain glucose levels.

Total protein and albumin concentrations in the blood, which increase with dehydration, are indicators of protein homeostasis (Sutherland et al., 2009a). Albumin concentrations usually parallel total protein concentrations (Sutherland et al., 2009ab). In the present study, there was a interactive effect of gavage and transport for both albumin and total protein levels with the pigs in treatment group I (pigs that received SDPP and were transported) having a greater albumin level compared to all other treatment groups and a greater total protein level compared to pigs within treatment group III (pigs that received SDPP but were not transported). In a study by Sutherland et al. (2009b) total protein and albumin concentrations increased but were within the normal range for weanling pigs and the authors suggest from these findings that pigs may have been experiencing mild dehydration as a result of transport. The SDPP used in our study, Appetein, is mainly composed of proteins, specifically albumin and globulin, so perhaps that could help to explain why the pigs in treatment group I had the highest levels of total protein and albumin. But it is interesting to see that the pigs that received SDPP and were transported (group I) had higher levels than the pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III). Perhaps the additional stress of being transported also caused the pigs in treatment group I to have higher levels of total protein and albumin than the pigs in treatment group III.

Serum concentration of anion gap increased significantly more in treatment group II pigs that were administered water and were transported, compared to the pigs in group IV, pigs that received water but were directly relocated to the wean-to-finish barn. Anion gap level in the blood is a diagnostic concept that represents the difference in levels of cations (potassium and sodium) and anions (chloride and CO_2 in the extracellular fluid of blood) and increases are associated with metabolic acidosis (Parker et al., 2003; Wittish and Estienne, 2011). Our results are in contrast to the results presented by Schaefer et al. (1990), in that the concentration of anion gap decreased after bulls were transported for 6 h. In our study, since the concentration of anion gap only increased in pigs that received water and were transported, perhaps providing SDPP prior to transport and weaning aids in preventing metabolic acidosis.

Concentration of blood sodium significantly increased in treatment group II pigs only. A low blood sodium level is an indication of dehydration in pigs. The fact that this blood chemistry measurement only increased in pigs that were transported and did not receive SDPP suggests that the physiology of the pigs were affected by transportation. Schaefer et al. (1990) also reported higher serum sodium levels after yearling bulls were transported for 6 h, which supports our findings of increased levels of sodium in treatment group II after a 5 h journey. Perhaps providing SDPP prior to transportation helps to keep electrolytes balanced during the journey.

The blood chemistry measurements of chloride, phosphorus, and GGT increased in transported pigs regardless of receiving SDPP or not. Both groups that were transported had increased levels of chloride which indicates that these pigs were not dehydrated, as a decline in chloride levels is a sign of dehydration caused by diarrhea and/or vomiting and Schafer et al. (1990) also reported increases in chloride levels after transporting yearling bulls for 6 h and concluded that these bulls were experiencing a moderate level of stress due to an imbalance in chloride, sodium, and potassium levels. Elevated levels of GGT in the blood are associated with liver disease, bile-duct obstruction, and excessive magnesium ingestion (Wittish and Estienne, 2011). This enzyme is mainly found in liver cells and GGT is involved in the transport of amino acids and peptides and glutathione metabolism (Wittish and Estienne, 2011). Sutherland et al. (2010) also reported higher levels of GGT after transporting weaned pigs for 148 min regardless of the space allowances of 0.05, 0.06, and 0.07 m^2/pig. Phosphorus in the blood, along with calcium, is needed for bone growth and function, and is also required for glucose and fat metabolism (Wittish and Estienne, 2011). The stress of transportation alters the metabolism of pigs as shown by increases in chloride, GGT, and phosphorus blood levels. Providing SDPP prior to transport and weaning does not seem to fully assist in regulating the metabolism of pigs.

Serum cortisol concentrations were significantly increased in both treatment groups I and II after transportation, which implies that weaned pigs experienced stress during the 5 h journey. Concentrations of cortisol have been reported to increase in weaned pigs transported for 60 min in the summer, 112 min in the winter, as well as for 148 min during the fall and spring at stocking densities of 0.05, 0.06, and 0.07 m^2/pig (Sutherland et al., 2009ab; Sutherland et al., 2010). The researchers of these studies concluded that weaned pigs experience stress regardless of space allowance and season. McGlone et al. (1993) also found that after a 4 h journey, nursery pigs had greater levels of cortisol. These studies support our results, and it can be concluded that weaned pigs are experiencing stress during short and intermediate journeys. Providing SDPP prior to weaning and transport did not result in preventing elevated cortisol concentrations in pigs.

5. Conclusion

In summary, transportation impacted physiological indicators of health and welfare in weaned pigs. The changes in certain blood chemistry values, along with an increase in serum cortisol concentration and an increase in rectal temperature after transport indicated that weaned pigs are experiencing stress during a 5 h journey. Providing SDPP prior to weaning, prevented transportation-induced changes in blood levels of glucose, anion gap and sodium, which perhaps helped the pigs to maintain homeostasis and a balance of electrolytes as well as preventing metabolic acidosis during a 5 h journey.

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Table 3.1
The main effects of gavage and time on BW for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning.

Gavage	BW (kg)[4]	*P* – value
SDPP[1]	14.09 ± 0.12[a]	0.0001
Water[2]	13.45 ± 0.12[b]	
Time		
Initial[3]	9.16 ± 0.23[u]	< 0.0001
Pre-wean/transport/relocation	10.51 ± 0.23[v]	
Post-wean/transport/relocation	10.21 ± 0.24[v]	
Wk 1 post-wean	10.67 ± 0.24[v]	
Wk 2 post-wean	12.98 ± 0.24[w]	
Wk 3 post-wean	15.12 ± 0.24[x]	
Wk 4 post-wean	18.34 ± 0.24[y]	
Wk 5 post-wean	23.19 ± 0.24[z]	

[1]SDPP = spray-dried porcine plasma; pigs in treatment groups I and III; n = 20/treatment group.
[2]Water = pigs in treatment groups II and IV; n = 20/treatment group.
[3]Initial = BW prior to start of gavage.
[4]Values are least squares means ± SE.
[a-b]Means within a column for effect of gavage with different superscripts differ ($P = 0.0001$).
[u-z]Means within a column for effect of time with different superscripts differ ($P < 0.0001$).

Table 3.2
The main effects of gavage and time on weight gain for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning.

Gavage	Weight gain (kg)[4]	*P* – value
SDPP[1]	3.55 ± 0.10[a]	0.029
Water[2]	3.24 ± 0.10[b]	
Time		
Initial[3] to Pre-wean/transport/relocation	1.34 ± 0.19[v]	< 0.0001
Pre-wean/transport/relocation to Post-wean/transport/relocation	-0.32 ± 0.19[u]	
Post-wean/transport/relocation to Wk 1	0.46 ± 0.20[u]	
Wk 1 to Wk 2 post-wean	2.30 ± 0.20[w]	
Wk 2 to Wk 3 post-wean	2.18 ± 0.20[vw]	
Wk 3 to Wk 4 post-wean	3.26 ± 0.20[x]	
Wk 4 to Wk 5 post-wean	5.13 ± 0.20[y]	
Post-wean/transport/relocation to Wk 5	12.83 ± 0.20[z]	

[1]SDPP = spray-dried porcine plasma; pigs in treatment groups I and III; n = 20/treatment group.
[2]Water = pigs in treatment groups II and IV; n = 20/treatment group.
[3]Initial = BW prior to start of gavage.
[4]Values are least squares means ± SE.
[a-b]Means within a column for effect of gavage with different superscripts differ ($P = 0.029$).
[u-z]Means within a column for effect of time with different superscripts differ ($P < 0.0001$).

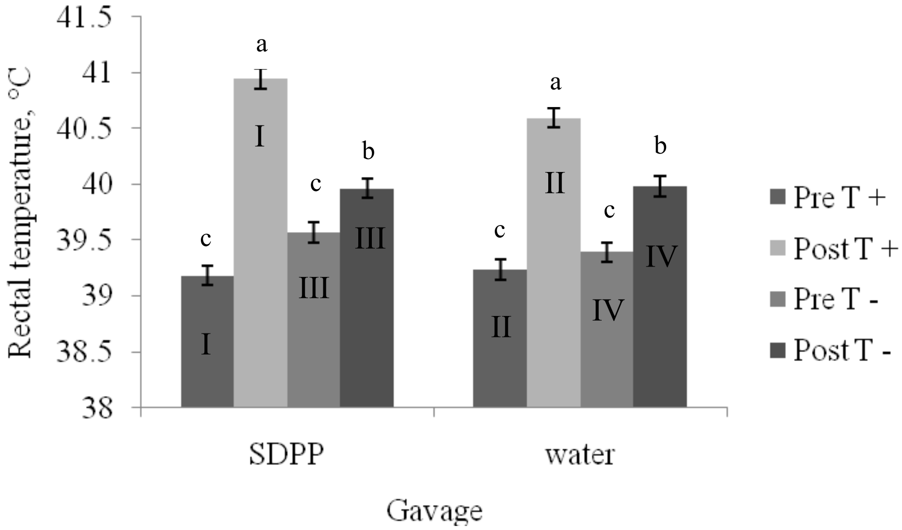

Fig. 3.1. Interactive effects of gavage, transport, and time on rectal temperature for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); Pre T + = pre-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Post T + = post-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Pre T - = pre-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group); Post T - = post-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a three-way interaction (P = 0.019) of gavage, transport, and time. Rectal temperature increased in all treatment groups, but the magnitude of increase was greatest for pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III), and for pigs that received water and were transported (group II) compared to pigs that received water and were directly relocated to the wean-to-finish barn (group IV).

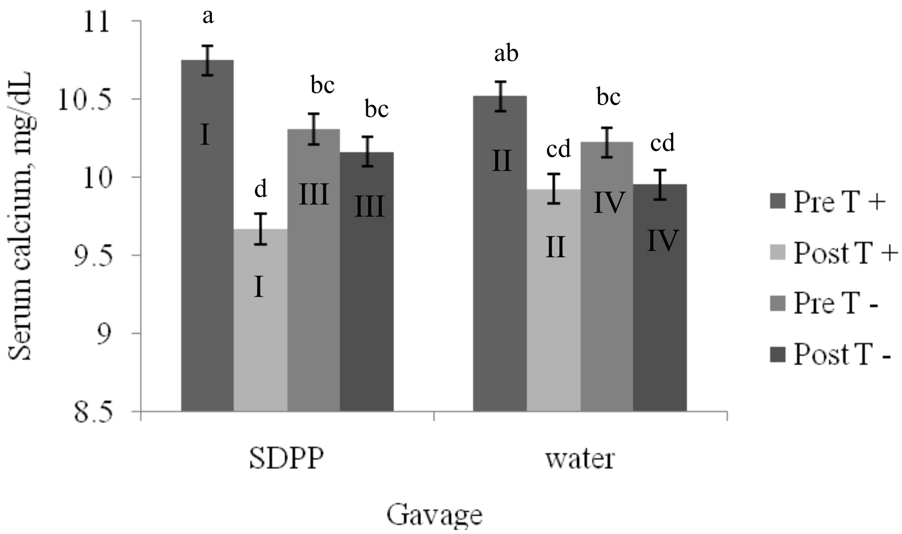

Fig. 3.2. Interactive effects of gavage, transport, and time on serum calcium concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); Pre T + = pre-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Post T + = post-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Pre T - = pre-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group); Post T - = post-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a three-way interaction ($P = 0.025$) of gavage, transport, and time. Serum calcium concentration decreased for pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III), and for pigs that received water and were transported (group II) compared to pigs that were not transported and were directly relocated to the wean-to-finish barn (group IV).

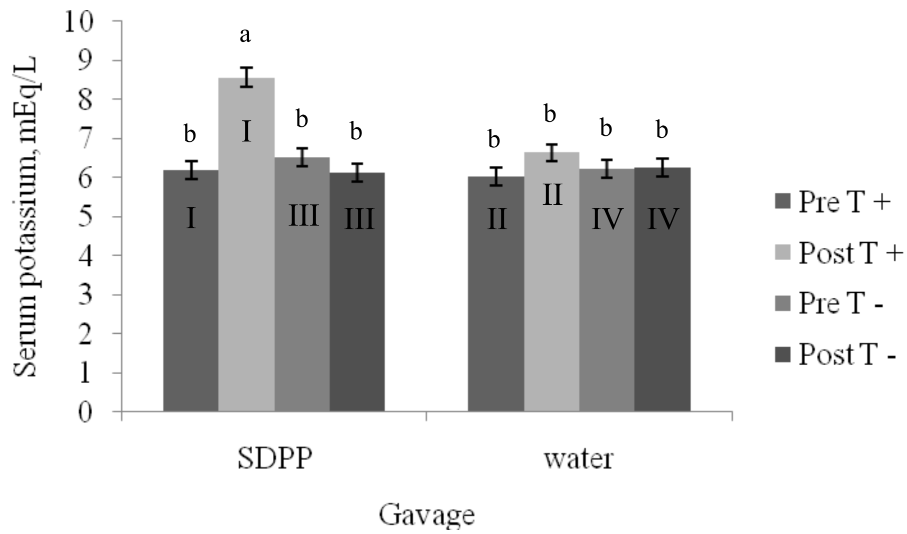

Fig. 3.3. Interactive effects of gavage, transport, and time on serum potassium concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); Pre T + = pre-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Post T + = post-weaning/transport measurement for pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); Pre T - = pre-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group); Post T - = post-weaning/relocation measurement for pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a three-way interaction ($P = 0.001$) of gavage, transport, and time. Concentration of potassium increased after pigs that received SDPP were transported for 5 h (treatment group I) but not after pigs that received water and were transported (group II) or after pigs (groups III and IV) were directly relocated to the wean-to-finish barn.

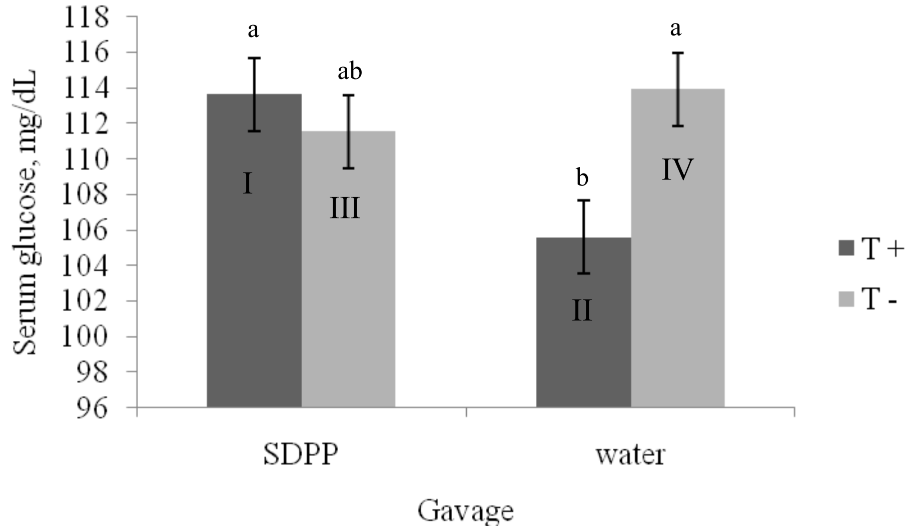

Fig. 3.4. Interactive effect of gavage and transport on serum glucose concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (*P* = 0.012) of gavage and transport. Serum glucose concentration was greater in pigs that received SDPP were transported and compared with pigs that received water and were transported.

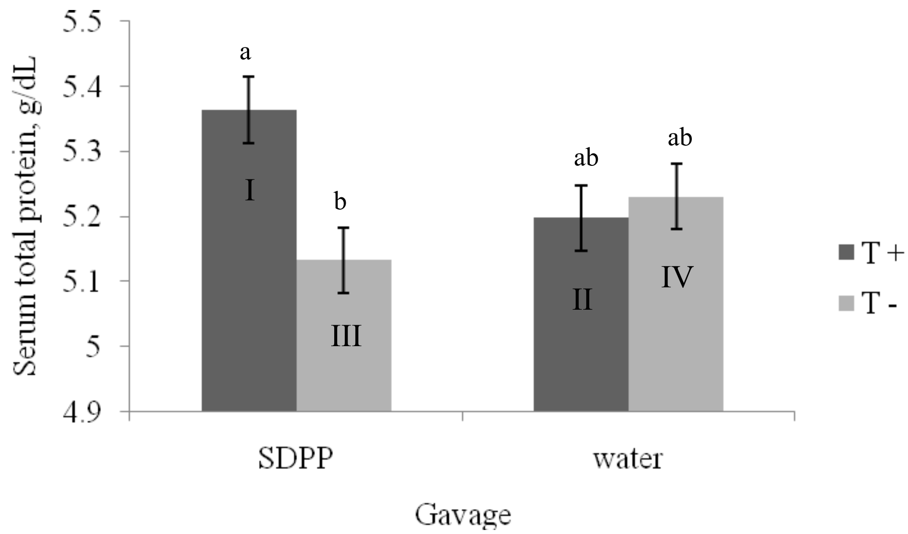

Fig. 3.5. Interactive effect of gavage and transport on serum total protein concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction ($P = 0.010$) of gavage and transport. Serum total protein concentration were greater for pigs that received SDPP and were transported (group I) compared to pigs that received SDPP and were directly relocated to the wean-to-finish barn (group III).

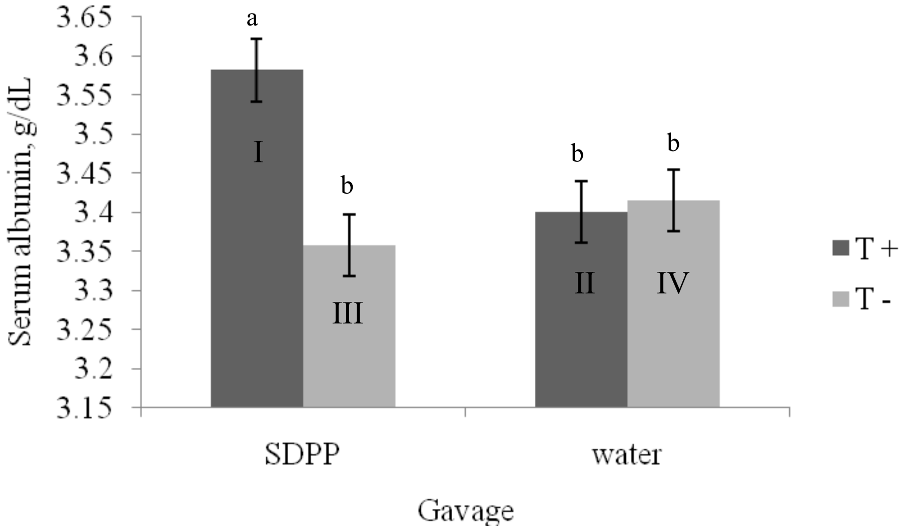

Fig. 3.6. Interactive effect of gavage and transport on serum albumin concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (*P* = 0.003) of gavage and transport. Pigs that received SDPP and were transported (group I) had greater levels of serum albumin compared to pigs that received water and were transported (group II) compared to pigs that received SDPP or water (groups III and IV) and were directly relocated to the wean-to-finish barn.

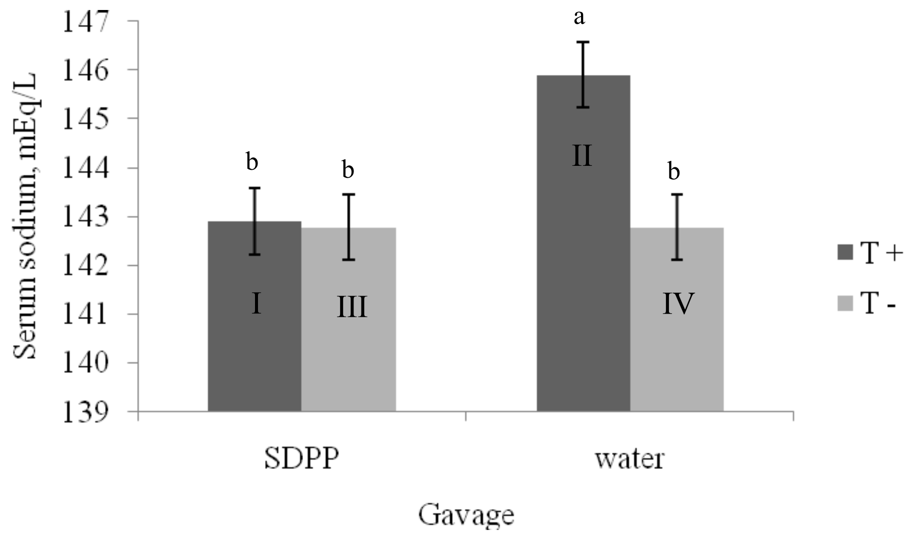

Fig. 3.7. Interactive effect of gavage and transport on serum sodium concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (P = 0.028) of gavage and transport. Serum sodium levels were greater in pigs that received water and were transported (group II) compared to pigs that received SDPP and were transported (group I) and pigs that received SDPP or water and were relocated directly to the wean-to-finish barn (groups III and IV).

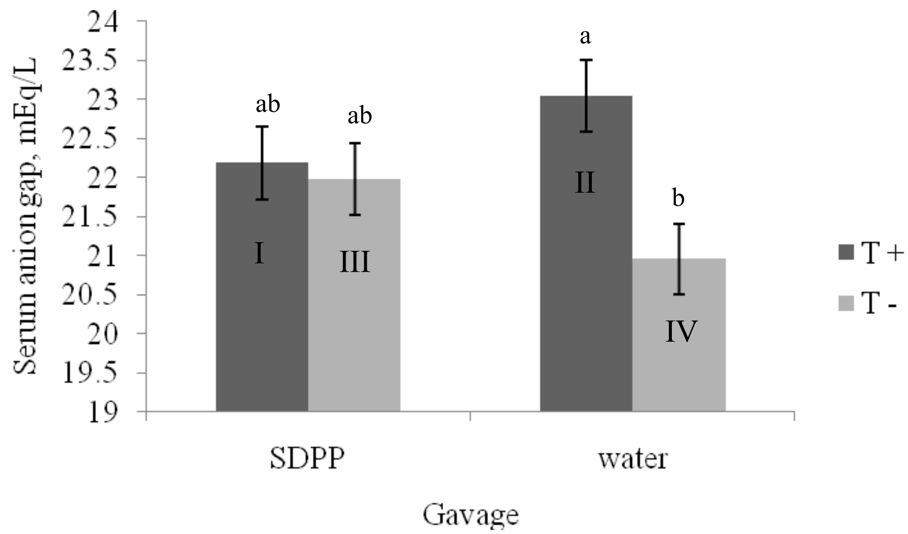

Fig. 3.8. Interactive effect of gavage and transport on serum anion gap concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. SDPP = spray-dried porcine plasma (treatment groups I and III; n = 20/treatment group); water = pigs in treatment groups II and IV (n = 20/treatment group); T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (*P* = 0.040) of gavage and transport. Serum anion gap concentration was greater in pigs that received water and were transported (group II) compared to pigs that received water were relocated directly to the wean-to-finish barn (group IV).

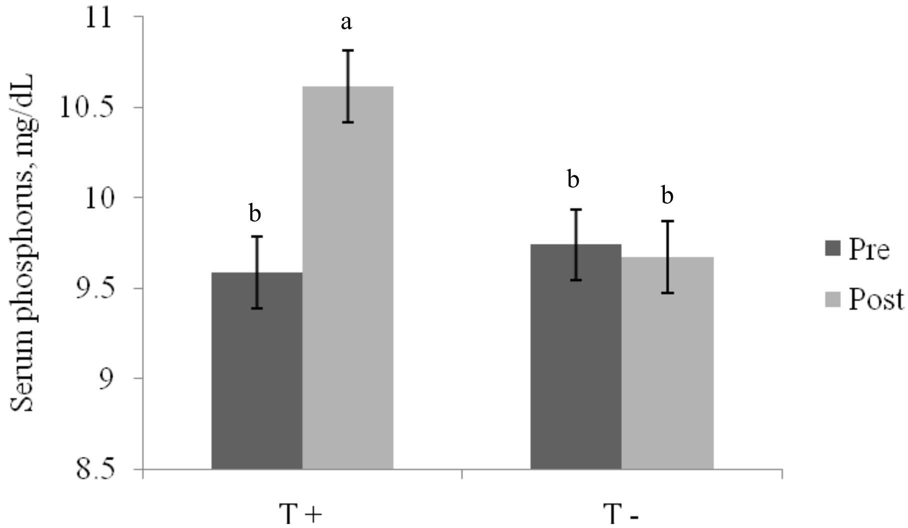

Fig. 3.9. Interactive effect of transport and time on serum phosphorous concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. Pre = pre-weaning/transport/relocation measurement; Post = post-weaning/transport/relocation measurement; T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction ($P = 0.006$) of transport and time. Serum phosphorus levels increased after pigs were transported (groups I and II) but not after pigs were directly relocated to the wean-to-finish barn (groups III and IV).

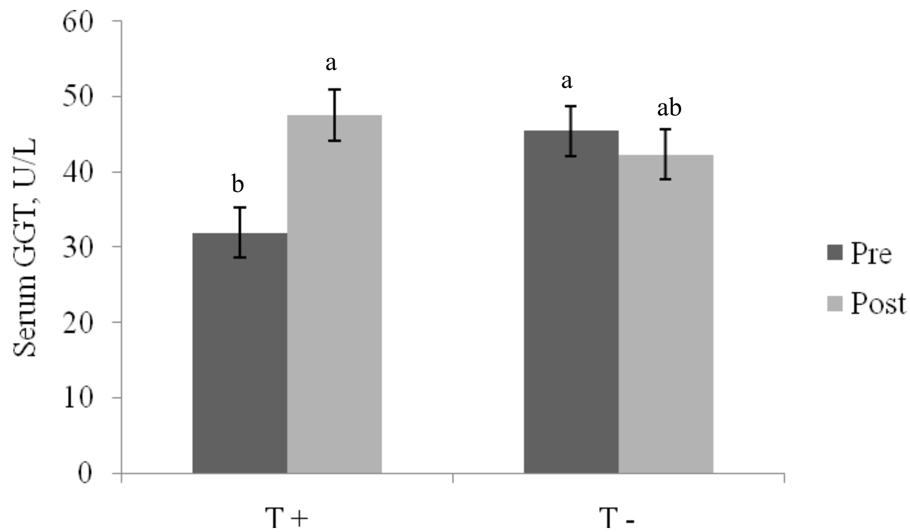

Fig. 3.10. Interactive effect of transport and time on serum gamma-glutamyltransferase transpeptidase (GGT) concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. GGT = gamma-glutamyltransferase transpeptidase; Pre = pre-weaning/transport/relocation measurement; Post = post-weaning/transport/relocation measurement; T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (P = 0.005) of transport and time. Serum GGT concentration increased after pigs were transported (groups I and II) but not after pigs were directly relocated to the wean-to-finish barn (groups III and IV).

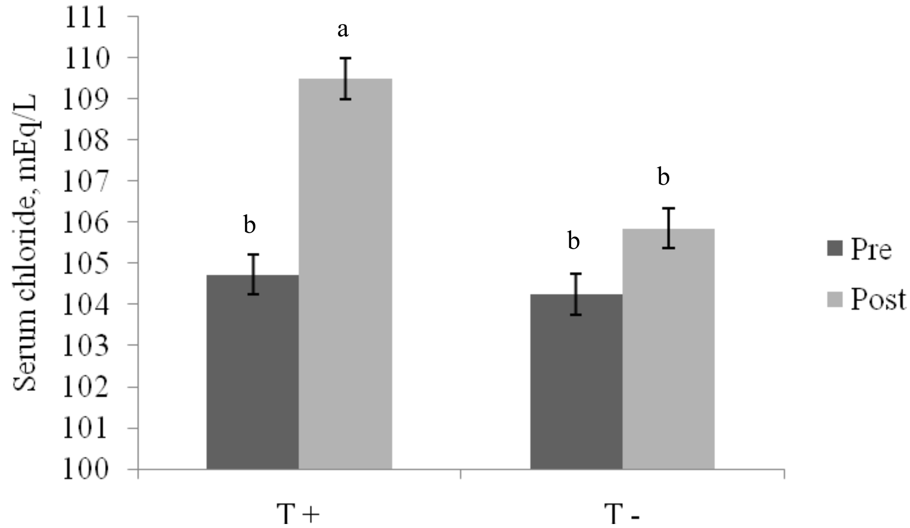

Fig. 3.11. Interactive effect of transport and time on serum chloride concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. Pre = pre-weaning/transport/relocation measurement; Post = post-weaning/transport/relocation measurement; T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction (P = 0.001) of transport and time. Serum chloride concentration increased after pigs were transported (groups I and II) but not after pigs were directly relocated to the wean-to-finish barn (group III and IV).

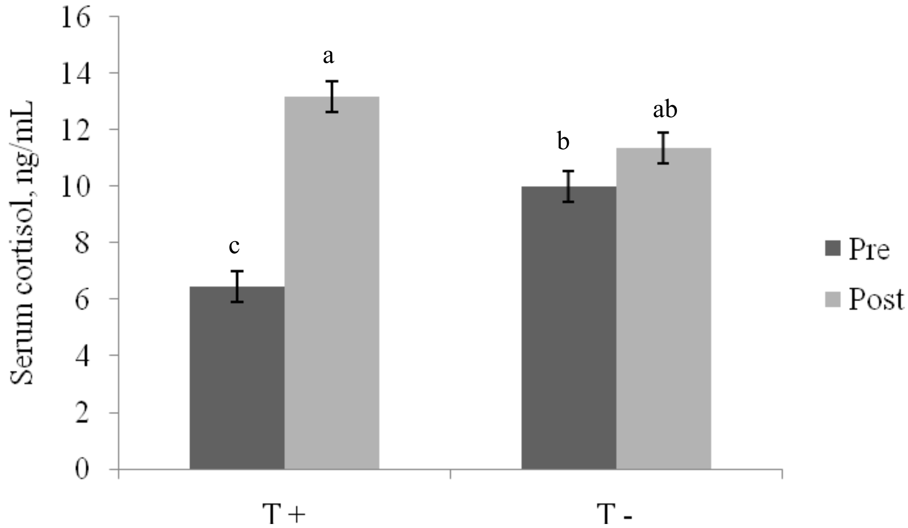

Fig. 3.12. Interactive effect of transport and time on serum cortisol concentration for pigs administered twice daily 25 mL oral gavage of spray-dried porcine plasma (9.375 g/25 mL) or water, and that were transported for 5 h or not transported after weaning. Data are represented as least squares means ± SE and means with different superscripts differ. Pre = pre-weaning/transport/relocation measurement; Post = post-weaning/transport/relocation measurement; T + = pigs transported for 5 h (treatment groups I and II; n = 20/treatment group); T - = pigs relocated to the wean-to-finish barn (treatment groups III and IV; n = 20/treatment group). There was a two-way interaction ($P < 0.0001$) of transport and time. Serum cortisol concentration increased after pigs were transported (groups I and II) but not after pigs were relocated directly to the wean-to-finish barn (groups III and IV).

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