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Effect of Sensory Additives on Sow Lactation Performance, Subsequent Reproductive Performance, and Nursey Pig Performance

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Effect of Sensory Additives on Sow Lactation Performance, Subsequent Reproductive Performance, and Nursey Pig Performance

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Abstract

Maximizing nutrient intake during lactation is vital to sow performance as well as litter performance. The aim of these studies was to evaluate the impact of a sensory additive on sow lactation performance and nursery pig performance. Five groups of sows were farrowed, three during winter (October, December and January) and two during summer months (June, July, August). Sows were weighed, and back fat depth was measured, at 110 d of gestation prior to entering the lactation room, and again at weaning. The sows were blocked by parity, and then allotted by BW at d 110 to Control or 0.075% sensory additive (Luctamax® SowVive, Lucta S.A., Spain). Experimental diets were offered upon entry to the lactation room and fed through weaning. Feed disappearance was recorded every three days. Sows were fed 2.72 kg/day until farrowing, and then allowed to eat *ad libitum* from 24 hours post-farrowing until weaning. A total of 270 piglets were utilized for the nursery trial. Upon weaning, pigs were blocked by bodyweight and then randomly assigned to one of five dietary treatments (Diet A, Diet B, Diet C, PC, and NC). No differences were observed in sow feed intake ($P > 0.4$) in winter months, while an seasonal effect of an increase in feed intake was observed during summer months. In conclusion, in the current study, lactation diets supplemented with a sensory additive improved sow feed intake during summer months, but had no effect in winter months, and improved litter performance and helped maintain sow body condition. Nursery pig performance was slightly enhanced for diets B and C.

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Contents

List of Tables

List of Figures

Introduction

Introduction

Pork production in the United States has consistently increased since the year 2000 (Shahbandeh, 2022). The consistent increase in production could be correlated with an increase in efficiency to production practices by producers, and the ever-increasing population. However, producers must continue to advance in terms of efficiency to continue to meet the increasing demands for pork. Lower voluntary feed intake during the lactation period could result in reduced reproductive performance and compromised milk production, which in turn jeopardizes the nursing litter's performance (Revell et al., 1998). Nutritionally adequate diets are crucial for optimizing sow productivity by allowing for sufficient milk production for piglet survival and growth while still maintaining the sow's consistent reproductive function (Jones and Stahly, 1999). In order to continue to improve efficiency, sows must be able to produce enough milk to sustain their growing litter, and still maintain proper body condition to maximize reproductive performance.

The lactation period only makes up 15 to 20% of a sow's production cycle however it is undoubtably the most metabolically demanding stage within the production cycle. The sow's primary focus during this period must be to sustain milk production enough to support a rapidly growing litter (Tokach et al., 2019). Milk production requires the sow to invest a large segment of her metabolic activity, therefore the sow needs to consume and digest as much feed as possible to sustain viable milk production through the entire lactation process. Nutrient needs of a lactating sow are largely determined by demand for milk production generated by her nursing litter (Jones and Stahly, 1999).

With this in mind it is imperative that the sow is able to consume the maximum amount of nutrition to sustain milk production and not sacrifice reproductive performance. Voluntary feed intake of lactating sows can often be low enough to compromise milk production and subsequent reproduction. In order to prevent severe losses during lactation, producers could feed more during the gestation period so that they begin lactation with appropriate body reserves that enable them to adapt more effectively to the demands of milk production and subsequent reproduction. However, when feed intake in the gestation period begins to increase, voluntary feed intake during the lactation period decreases, and this decrease in intake can be associated with an rapid loss of body fat reserves (Revell et al., 1998). Sows with greater intake during the lactation period typically show reduced losses in backfat, and generally don’t show any negative effects on the weaning to estrus interval. Sows with decreased intake during lactation must tap into reserves within the body to produce enough milk to sustain their litter.

Several factors can limit a sow’s voluntary feed intake and reproductive performance. Physical feed intake capacity is a major limiting factor for growth in the beginning of the growing period regardless of the dietary energy concentration. The pigs’ ability to regulate energy intake is absent in pigs weighing less than 20 kg (Black et al., 1986). Another major limiting factor can be heat stress. Due to their low capacity to sweat, sows are extremely sensitive to higher ambient temperatures. Increased temperature can have negative effects on sow reproduction that include prolonged weaning to service intervals, increased numbers of regular and irregular returns to estrus, reduced litter size, and reduced milk yield (Wegner et al., 2014). The minimization of heat produced that is caused by diminished feed intake is a critical factor to maintaining core body temperature within a safe range for the individual. The diminished feed intake during heat stress is a direct cause of reduced growth rate in heat stressed pigs. (Renaudeau et al., 2013).

Piglets face a large challenge at weaning, during this period they have to make the transition from suckling the sow's milk to the independent selection and ingestion of feed items. Sampling food sources through a trial-and-error process of individual learning can be time-consuming and potentially dangerous if there is potential for toxicity (Oostindjer et al., 2010). The lactation period and early nursery phases play a crucial role in piglets' performance later in life. Birth weight and weaning weight both serve as a significant indicator for pig performance while in the nursery. Pigs that are heavier at weaning can be predicted to exit the nursery with a heavier body weight (de Grau et al., 2005). The change in the pig's environment at weaning such as diet type, waterers, etc imposes a big challenge to the newly weaned pigs, especially when relating this back to voluntary feed intake (Laskoski et al., 2019). It has been demonstrated that piglets with heavier body weights have much greater ability to get the best teats, fully drain and better stimulate the teat, which induces a greater milk flow (Le Dividich et al., 1999).

Throughout the last two decades, a substantial increase in the use of aromatic herbs and essential oils as feed additives in animal nutrition has been observed (Franz et al., 2010). In the swine industry, sensory feed additives are widely utilized in an attempt to improve feed palatability and animal husbandry performance (Windisch et al., 2008; Franz et al., 2010). Sensory additives are substances that change or improve the organoleptic properties (taste, color, odor, feel) of feed. Some characteristics of texture can be felt when the feed/diet is first procured by the mouth, but the majority will be perceived when the feed/diet is broken down by mastication, or while it is being pushed and swished around the oral cavity via the tongue and combined with saliva (Szczesniak, 2002). Among the orosensory qualities of a feedstuff, taste and odor without a doubt play a critical role, because these two senses have evolved in animals to trigger either a preference for compounds that are nutritious or an aversion to compounds that can be toxic (Goff and Klee, 2006).

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Chapter 1: Literature Review

The aim of the Literature Review is to review the effects of the addition of sensory additives on sow intake during the lactation period, and reproductive performance post-lactation. The effects of sensory additives on nursery pig growth performance will also be summarized.

Nutritional Demands During Lactation

Maximizing nutrient intake during the lactation period can in some cases prove to be a challenging task. However, increasing the nutrient uptake of the sow is extremely beneficial to the sow and her litter's performance (Wondra et al., 1995). Nutritionally adequate diets are crucial for maximizing sow productivity by allowing for sufficient milk production for piglet survival and growth while still maintaining the sow's consistent reproductive function (Jones and Stahly, 1999). Although lactation represents only 15to 20% of the productive cycle of a sow, it is undeniably the most metabolically demanding stage of production. The sow's focus during lactation is to sustain milk production for the large and rapid growing litter of piglets but this sometimes cannot be achieved by voluntary feed intake alone (Tokach et al., 2019). Nursing a large litter has negative effects on performance of primiparous sows during the lactation period such as loss of body weight, loss of backfat, and litter weight gain could suffer as well. Post-weaning performance may also be hindered by lengthening the weaning to estrus interval (Eissen et al., 2003). Milk production requires the sow to invest a large segment of her metabolic activity, therefore the sow needs to consume as much feed as possible to sustain viable milk production through the entire lactation process. Nutrient needs of a lactating sow are largely determined by demand for milk production generated by her nursing litter (Jones and Stahly, 1999). The mobilization of body fat and protein reserves appears to be imperative to support milk production in high producing sows, although it is unclear whether body mobilization is an obligatory process in modern sows (Pedersen et al., 2019). During lactation, demand for amino acids can surpass the bioavailable amino acids from diets resulting in maternal protein loss, of which the majority is derived from muscle protein. This can reduce milk nutrient output, which limits litter growth. Sows continue to mobilize maternal body protein throughout the lactation period, indicating the presence of a strong homeorhetic drive for milk production that maintains some level of milk output, but evidently this drive is not sufficient to maintain milk nutrient output up to the biological potential of the sow. The main goal of the nutrition program for lactating sows should be to maximize feed intake to sustain milk production, without excessive mobilization of body reserves (Tokach et al., 2019).

Energy Requirements During Lactation

The entire metabolic energy requirements of sows in the lactation stage of production are highly inconsistent. Milk production has the most substantial influence on variability in the metabolic energy requirements of lactating sows (Gauthier et al., 2019). During the gestation period, enough body reserves must be built to account for the eventual nutritional insufficiency that could occur in the following lactation. However, these reserves should not be in excess to avoid the occurrence of problems during parturition that are common for sows that are too heavy conditioned, or to compromise feed intake after farrowing. During the lactation period, it is often suggested to adapt nutritional supplies to requirements to maximize the production of milk and piglet's growth and minimize reproductive problems of sows after weaning. Consequently, nutritional supplies to sows must be adapted to maintain body reserves in optimal condition all along their productive life and optimize their reproductive performance. On farm, this requires a precise adjustment of the feeding level and the feed composition according to the performance of sows but also to housing conditions, which may affect nutrient utilization and voluntary feed intake. During the lactation period, the sow requires energy and nutrients for maintenance of body weight as well as milk production. Sows can and may become catabolic during lactation and mobilize protein and lipid from body reserves to support milk production (Hansen et al., 2014). In correlation with frequent mobilization of reserves in the body during the lactation period and the progressive acquisition of mature live weight, maternal body weight will increase during the gestation period in conjunction to the weight gain of both the uterus and conceptus. The maternal body weight gain that will be accomplished during the gestation period depends strongly on the body composition and the amount of the body weight that was lost during previous lactation period, and the feeding strategy implemented to acquire the operations goals for live weight and body fatness over sequential parities (Dourmad et al., 2007). Since the lower critical temperature (minimum body temperature that can be tolerated by an organism) during the lactation period is much lower than during pregnancy (about 10 to 15 °C), and ambient temperature in farrowing rooms typically exceeds that limit, it can be generally assumed that sows in lactation do not have specific energy requirements for thermoregulation. Sows that are in the lactation period are only moderately active. Therefore, the related energy expenditure is much lower and much less variable than sows in gestation (Dourmad et al., 2007).

Intake during lactation and the effects on performance

The main focus in sow nutrition is to maximize the intake of nutrients during the lactation period. Accomplishing this goal will show a benefit to the sow and her respective litter's performance (Wondra et al., 1995). Voluntary feed intake of lactating sows is often low enough to compromise milk production and subsequent reproduction. One strategy to compensate for this is to feed sows, and especially gilts, enough feed during the gestation period so that they begin lactation with appropriate body reserves that enable them to adapt more effectively to the demands of milk production and subsequent reproduction. However, when feed intake in the gestation period begins to increase, voluntary feed intake during the lactation period decreases, and this decrease in intake can be associated with the decrease in body fat reserves. In short, the more fat reserves a sow carries at the end of the gestation period the less she will eat during the lactation period (Revell et al., 1998). Promoting feed intake during lactation can play a huge roll in reducing body weight and backfat losses and therefore aid in preventing the negative effects of nursing a large litter. It is therefore typically suggested to increase the daily feed intake by sow during the lactation period. A greater feed intake during the lactation period, either by nutritional or genetic measures, should hence reduce backfat and body weight losses of sows regardless of parity and decrease the probability of an increased weaning to estrus interval, as well as the probability of a lower litter size of the subsequent litter (Eissen et al., 2003). Sows with greater intake during the lactation period typically show reduced losses in backfat, and generally don't show any negative effects on the weaning to estrus interval. Sows with decreased intake during lactation must tap into reserves within the body to produce enough milk to sustain their respective litter. This typically leads to drastic losses of body condition, a prolonged weaning to estrus interval, and reduced litter performance. Nutrient requirements increase during lactation, and milk production is the main reason for this increase. Typically, peak milk production occurs during the third week of the lactation period, therefore it is vital to supply enough nutrients, so the sow can produce enough milk for her nursing litter.

Factors Influencing Feed and Energy Intake

Many threats to modern swine production systems are closely correlated to feed intake, such as introduction of feed at weaning or precise feeding of growing-finishing pigs without abundant supply. Sufficient but not excessive feed intake of pigs is typically correlated with increased growth performance and feed efficiency, as well as more ideal cost over investment (Li and Patience, 2016). Pigs can adjust voluntary feed intake in response to dietary features. In most cases, energy density of a feed becomes the first determining factor of average daily feed intake. As available energy content in the diet is lowered, pigs will try to maintain sustained daily energy intake in the way of consuming more feed, until intake is limited by physical feed intake capacity or other environmental factors come into play (Beaulieu et al., 2009). Physical feed intake capacity is a major limiting factor for growth in the beginning of the growing period regardless of the dietary energy concentration. The pig's ability to regulate energy intake is absent in pigs weighing less than 20 kg (Black et al., 1986). Oresanya et al. (2007) suggests that the pig's ability to adjust feed intake is not capable of fully compensating for the reduction in dietary digestible energy concentration on lower energy diets. When diets that are highly digestible become progressively diluted with ingredients that are lower in energy, such that the concentration of energy is reduced, feed consumption should show an increase at such a rate that digestible energy intake remains approximately constant and performance is unaffected (Beaulieu et al., 2009). However, after a critical point in digestible energy or fiber content, digestible energy intake will be compromised, and performance will be impeded as the dilution continues further. The “critical point” mentioned before can be inferred to reflect physical gut capacity (Black et al., 1986).

Thermal Environment Effects on Performance

As ambient temperature increases, and thermal environment begins to exceed the thermoneutral zone, pigs will exhibit different behavioral changes like changing their posture, which will reduce their contact with other pigs in the same pen (Giles et al., 1998). Voluntary feed intake can be reduced by approximately 40 g for every °C above the thermoneutral zone, and this reduction can be correlated with alterations in feeding behavior like time of eating and the size of the meal (Nyachoti et al., 2004). Newborn piglets face an intense thermal challenge that could be potentially life threatening at birth with temperatures that are typically recommended for farrowing sows. To compensate for the different temperature needs, additional heating is needed to assist newborn piglets in regulating their body temperature. However, additional heating could be a thermal stressor for the sow, especially when inside a farrowing crate where the opportunity for thermoregulatory behavior is limited. Sows will not show a preference for heated pen flooring for a potential farrowing site when given a choice, however piglets will actively search for a heat source soon after birth (Malmkvist et al., 2012). The thermal comfort zones for sows range from 16°C to 22°C for lactating sows and

30°C to 32°C for piglets (Messias de Bragança et al., 1998). When the temperature is above the thermal comfort zone for lactating sows in the farrowing facilities, while these conditions are beneficial to the piglets, they can be severely detrimental to the sow by causing heat stress, which directly affects the sow's production capabilities (Ribeiro et al., 2018).

Heat Stress and Cold Stress Effects on Performance

Due to their low sweating capacity, sows are extremely sensitive to higher ambient temperatures. Increased temperature can have negative effects on sow reproduction that include prolonged weaning to service intervals, increased numbers of regular and irregular returns to estrus, reduced litter size and reduced milk yield (Wegner et al., 2014). Heat stress is a condition where the body is unable to rid itself of excess heat. This causes an increase to the core body temperature, respiration rate, and a rise in heart rate can also be observed in animals that are experiencing heat stress. Generally, heat stress will lead to an increase in water consumption, and reduced feed intake, while in some extreme cases heat stress can be fatal, where heat stress is prolonged, and the core body temperature is not lowered to normal (Zaheer, 2019). A main limiting factor within the swine industry can be the climatic environment, particularly when the ambient temperature begins to exceed the temperature range of the thermal comfort zone. Physiological and metabolic adjustments resulting from the thermoregulatory responses to thermal stress have shown to have negative impacts on pig performance. For pigs with ad libitum access to feed, the minimization of heat produced that is caused by diminished feed intake is a critical factor to maintaining core body temperature within a safe range for the individual. The diminished feed intake during heat stress is a direct cause to reduced growth rate in heat stressed pigs. (Renaudeau et al., 2013). Fertility and prolificacy have been shown to decrease during the warmer summer months. For example, farrowing rate is at its lowest during the summer, and there are fewer pigs born alive to sows bred in the summer than to sows bred in the winter or spring. The correlation between higher temperatures and reproductive performance have been thoroughly studied in Asian and European countries. It has been hypothesized that reduced reproductive performance in summer occurs through a combination of high temperatures, a reduction in GnRH secretion, and impaired ovarian follicle development that compromises corpus lutea functions resulting in low progesterone concentrations (Koketsu et al., 2017). The effects of cold stress on overall performance and voluntary feed intake haven't been widely studied when compared to studies dealing with heat stress. Whenever the ambient temperature drops below the lower critical temperature, pigs must generate more body heat to compensate for heat lost to the environment. During this situation pigs will need to consume more feed in order support extra heat production (Li and Patience, 2016). Pigs that have been exposed to cold stress won't always show an increase in feed intake to sustain the rate of energy deposition that occurs in the body under thermoneutral conditions. if pigs are housed in cold temperatures, the capacity for physical feed intake becomes a more vital factor that will affect feed intake (Close, 2018).

Reproductive performance of Sows

Reproductive traits like litter size, litter weight, and survival rate hold more importance on an economic scale than some other swine traits that can be measured (Yen et al., 1987). Reproductive performance of sows can be measured a multitude of ways, for example number of pigs weaned per sow or number of litters per sow per year. These measurements are dependent on differing factors. The number of pigs weaned relies heavily on the number of pigs born alive, and preweaning mortality. Whereas the number of litters per sow per year is reliant on non-productive days, lactation length, and gestation length. It is critical for producers to maximize the sow herd's reproductive potential during the sows' lifetime to minimize cost of production and become more economically efficient (Koketsu et al., 2017). Proper body condition prior to parturition increases the performance of the sow during lactation and thereafter. According to Maes et al. (2004) there is a positive correlation between weaned pig numbers and the decrease in backfat levels during lactation. This suggests that sows that wean larger litters should show greater backfat losses than sows that wean less pigs. However, this can be variable from herd to herd meaning that it is possible to minimize backfat losses during the lactation period by managing feed intake during the lactation period. Many studies have shown that sows that that loose too much weight during lactation will experience prolonged remating intervals, lower pregnancy rates, and a reduction in embryo survival (Maes et al., 2004). It is critical to maximize voluntary feed intake in lactating sows. Decreased lactation feed intake can be associated with a decrease in average piglet weaning weight, prolonged weaning to cycle interval, reduced farrowing rates, as well as more culled sows due to reproductive failure, and a reduced number of pigs born alive at the ensuing farrowing. This is very likely the case for first parity sows where lower feed intake during the lactation period can be extremely detrimental to reproductive performance post-weaning. However, current increases in the duration of the lactation period and the use of current automatic feeders for sows in lactation can reduce the probability of a decrease in reproductive performance. However, there is another concern that some nurse sows with increased lactation length can lose too much of their body reserves due to high milk yields, and so they may have prolonged weaning to first mating interval and lower farrowing rates (Koketsu et al., 2017). Maintaining appropriate body condition during the lactation period plays a crucial role in the impending reproductive success for the sow. Maximizing voluntary intake during this period should maximize the sow's production potential and shorten their weaning to cycle interval. Sows that have a major drop in intake during the lactation period are more likely to show a decrease in their reproductive performance (Koketsu et al., 1996B).

Factors Affecting Litter Performance

Maximizing litter performance during the nursing phase can play a critical role later during the weaning phase. The early stages of a piglet's life play an extremely important role on performance while nursing the sow. The greater the piglet's birth weight, the greater the potential body weight gain during the lactation period. It has been demonstrated that piglets with heavier body weights have much greater ability to get the best teats, fully drain and better stimulate the teat, which induces a greater milk flow (Le Dividich et al., 1999). Piglets that are born with a body weight that is lighter than average are at a greater risk of preweaning mortality and may show a reduction in growth rates through the duration of that individual's life. Low birthweight piglets account for a greater percentage of preweaning mortality than their contemporaries with average birthweights. During the suckling phase, faster growing piglets typically have a greater body weight than slower growing piglets within the same litter (Zeng et al., 2019). In some studies, it has been suggested that slower growing piglets have the capability of compensating for their lower body weight with increased postnatal growth (Quiniou et al., 2002). One main limitation to piglet performance post-weaning is low weaning weight. Animal growth is regulated by many factors, including pathogen pressure, environment, genetics, and nutrition. Many factors have been correlated with variation in pre-weaning piglet weight. The desire to optimize pig production in all-in all-out production systems has brought about the problem of slow growing pigs causing variations within the herd. It is difficult to achieve all-in all-out production flow when there are substantial variations in pig size mainly caused by variation in growth rate. Variations in growth performance post-weaning should be kept at a minimum to maximize space utilization, especially in all-in all-out management systems (de Grau et al., 2005).

Factors Effecting Nursery Pig Performance

Maximizing pig performance immediately after weaning is critical in improving growth efficiency and productivity through the duration of a pig’s life. The weaning period, however, is typically characterized by a period of lower feed intake that can be correlated with physical, physiological, and behavioral challenges that typically affect growth rates in the period shortly after weaning (Sulabo et al., 1970). One of the largest and most important challenges in swine production is overcoming the initial anorexia of the piglet post-weaning. The use of ingredients that are palatable can help facilitate the initiation of feeding at weaning. There have been several studies to measure the preference for different feed ingredients, and they have found that preference is largely dependent on odor and taste (Solà-Oriol et al., 2007). Birth weight and weaning weight both serve as a significant indicator for pig performance while in the nursery. The weight of a pig at any given point in its life is strongly correlated to that individual's weight at an earlier stage of life. Pigs that are heavier at weaning can be predicted to exit the nursery with a heavier body weight. However, some of the heaviest pigs do not maintain the body wight advantage throughout the nursery phase. This could be because they might not have adapted to solid feed as well or as quickly than the average body weight pigs (de Grau et al., 2005). Piglet weight gains can be highly variable in the first and, more subtly, the second week post-farrowing. During the first week, for example, some piglets will more than double their birth weight, while others will gain only minute amounts. These early gains are virtually uncorrelated with the piglet's birth weight. However, in the latter weeks of lactation piglet's rate of gain becomes more closely related with their body weight during that time (Thompson and Fraser, 1988). Lighter weight pigs that enter the nursery typically have a greater rate of culling or death, and usually are lighter when exiting the nursery phase. Some factors that could contribute to a lighter weight pig's poorer nursery performance and greater risk of mortality are the possibility that the lightweight pigs are potential carriers for disease, are just poor feed converters, and may have lower feed intake than heavier pigs (de Grau et al., 2005). Lower feed consumption in the post-weaning phase and consequent hindered growth can impede performance and have negative effects on the pig's metabolism and health status. The change in the pig's environment at weaning such as diet type, waterers, etc imposes a big challenge to the newly weaned pigs, especially when relating this back to voluntary feed intake (Laskoski et al., 2019).

Sensory Additives

Sensory additives are substances that change or improve the organoleptic properties (taste, color, odor, feel) of feed. The last two decades have seen a substantial increase in the use of aromatic herbs and essential oils as feed additives in animal nutrition (Franz et al., 2010). In the swine industry, sensory feed additives are widely utilized to improve feed palatability and zootechnical performance (Windisch et al., 2008; Franz et al., 2010). Feed intake is an important factor that affects growth performance and can be affected by the feed composition and the palatability of a feed. Pigs in general have an exceptional ability to distinguish that palatability of different feed ingredients (Solà-Oriol et al., 2007). Therefore, a good strategy to try and improve feed intake is to select feed ingredients that are highly palatable or utilize feed additives that can help change the palatability of a feed (Seabolt et al., 2010). The palatability of feed to pigs is affected by the makeup of the feedstuffs that are included in a specific diet (Solà-Oriol, 2008). Among the orosensory qualities of a feedstuff, taste and odor without a doubt play a critical role, because these two senses have evolved in animals to trigger either a preference for compounds that are nutritious or an aversion to compounds that can be toxic (Goff and Klee, 2006). Some characteristics of texture can be felt when the feed/diet is first procured by the mouth, but the majority will be perceived when the feed/diet is broken down by mastication, or while it is being pushed and swished around the oral cavity via the tongue and combined with saliva. The possibility of testing the sensations that are experienced by pigs whilst eating different feeds or feed ingredients is impossible. However, this exact process can be evaluated by utilizing texture testing instruments that are able to quantify specific physical traits of feed, that then can be translated in terms of sensory perception (Szczesniak, 2002). Preference studies are also utilized to determine what ingredients to compare palatability. Particle size can change the texture of a feed and show numerous benefits including an increased average daily feed intake in sows. As particle size is reduced, digestible energy intake, litter body weight, apparent digestibility is increased, while fecal output decreases. However, reducing particle size will show an increase severity of ulceration and keratinization in the esophageal region of the stomach (Wondra et al., 1995).

Sensory Additives Related to Intake

Feed flavors or sensory additives are utilized commonly in young piglet diets to help aid with diet acceptance and increase intake of the diet. Exposure to the flavor prior to weaning could also enhance responses post-weaning when the same flavor is added to the nursery diets; however, evidence of this in piglets is limited (Sulabo et al., 1970). In recent times the use of various plants and their extracts, like essential oils, as feed additives for livestock production has become more popular throughout the world. The impending threat of bans on antibiotics in the livestock industry continues to lead the scientific community to find alternative methods to improve or maintain feed intake and animal performance, such as growth rate and meat production in swine, cattle, and poultry (Clouard et al., 2014. In livestock production, specifically swine production, pigs are often exposed to stressors during sensitive periods in the production cycle which can impact feeding activity. Feeding activity is strongly affected by unfamiliar feeding and environmental conditions. Aromatic herbs are often claimed to improve the palatability of feed by improving the feed flavor, thus increasing voluntary feed intake which will result in improved weight gain and performance (Zeng et al., 2019.

Scope of Research

Maximizing lactation feed intake is critical to optimize sow reproductive performance and improve longevity. Sensory additives have been shown to potentially stimulate sow feed intake by modulating the organoleptic properties of the feed to make it more palatable. However, the results from literature on sow intake response to sensory additives are inconsistent. In addition, most studies were conducted more than 10 years ago. With recent considerable genetic improvement in litter size in swine, it is important to re-evaluate the impact of sensory additives using modern sow genetic lines. Thus, a study to investigate sensory additives and the potential benefits of their supplementation in sow lactation diets is detailed in chapter 2. An experiment was conducted to analyze the effect of the sensory additive SowVive (Lucta, Barcelona, Spain) on sow intake and reproductive performance. The potential benefits of sensory additives to nursey diets will be discussed in more detail in chapter 3. An experiment was conducted to determine the effects of sensory additives on growth performance in nursery pigs.

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Chapter 2: Effect of a sensory additive on sow reproductive performance

Effect of sensory additive and farrowing season on sow reproductive performance

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Abstract:

Maximizing nutrient intake during lactation is vital to sow performance as well as litter performance. The aim of these studies was to evaluate the impact of the sensory additive on sow lactation performance and nursery pig performance. Five groups of sows were farrowed, three during winter (October, December and January) and two during summer months (June, July, August). Sows were weighed, and backfat depth was measured, at 110 d of gestation prior to entering the lactation room, and again at weaning. The sows were blocked by parity, and then allotted by BW at d 110 to Control or 0.075% sensory additive (Luctamax® SowVive, Lucta S.A., Spain). Experimental diets were offered upon entry to the lactation room and fed through weaning. Feed disappearance was recorded every three days. Sows were fed 2.72 kg/ day until farrowing, and then allowed to eat *ad libitum* from 24 hours post-farrowing until weaning. No differences were observed on sows feed intake (*P* > 0.4) in winter months, while an increase in feed intake was observed during summer months in sows offered sensory additive. Feeding sows the sensory additive lowered preweaning mortality by 4.9% (*P* = 0.051) and sows weaned an additional 1.42 piglets (*P* = 0.026) with similar weaning weights (*P* = 0.86) when compared to control. In conclusion, in the current study, lactation diets supplemented with a sensory additive improved sow intake, improved litter performance, and helped maintain sow body condition during summer months, but had no effect in winter months. Nursery performance was unaffected.

Keywords: Sow, sensory additive, litter performance, body condition

Introduction

The lactation period is the most metabolically demanding period of a sow's production cycle, even though lactation only accounts for 15 to 20% of the sow's production cycle. The primary focus of the sow is to sustain enough milk production to maintain body condition and support her growing litter (Tokach et al., 2019). The sow must maintain body condition while producing enough milk to support a large growing litter of piglets. It is critical that the sow's nutritional demands are met during the lactation period. A sow's milk yield can vary drastically and is dependent upon the supply of protein and energy in the diet. Even though a sow can buffer milk production by catabolism of reserves in the body, milk yield still responds to maternal energy during the lactation period. The mobilization of body fat and protein reserves appear to be vital in the support of milk production in high-producing sows, although it isn't clear whether body mobilization is an obligatory process in modern sows (Pedersen et al., 2019). Extensive catabolism in lactation is often linked to poor successive reproductive performance of sows.

Seasonal effects on sow performance have been widely studied in past years (Renaudeau et al. 2013; Wegner et al. 2014; Koketsu et al., 2017). In thermoneutral environments, sow appetite has been observed to be greater than in hotter ambient temperature environments (Ribeiro et al., 2018). Heat stress during warmer seasons can cause a loss in appetite, lower reproductive performance, and reduced farrowing rate (Koketsu et al., 2017). However, inconsistent results, sporadic data with modern genetic sows, and lack of information on seasonal effects on the response to sensory additives suggest more research is required. Studies involving sensory additive being fed to lactating sows have been very limited (Clouard and Val-Laillet, 2014). In the current study, we used 111 sows farrowing in two farrowing seasons to develop a better understanding of the impact of sensory additive feeding during lactation on reproductive performance.

Materials and Methods

A total of 111 sows (53 for Control; 58 for SowVive) from three lactation groups were used to evaluate the effect of SowVive on reproductive performance. Two groups of sows were followed through a subsequent cycle to investigate the seasonal impact on SowVive. The five groups (3 winter, 2 summer) of breeding age gilts and sows (~42 breeding females in each group) were utilized in this study in order to evaluate whether feeding Luctastrom SowVive (Lucta, Barcelona, Spain)improves sow reproductive efficiency and/or litter performance. Sows and gilts were housed in a gestation barn in stalls once pregnancy was confirmed via ultrasound. All sows and gilts were weighed, blocked by weight and parity, and then allotted randomly to one of two dietary treatments once they were moved into farrowing crates. All sows and gilts were fed a common gestation diet up to the point where they were moved into farrowing crates and at this point, they began the lactation treatments.

Gestation

All gilts and sows were fed approximately 2.26 kg/day once daily until d 110 when the lactation diet was provided at 2.72 kg/day for the remainder of the gestation period. This was fed according to standard practices considering the environment and body condition of the gilts and sows. Note that it is a common practice to attempt to feed to a common body condition score based on the Herd Manger's daily observations. A record system has been established starting on March 26, 2012 in an attempt to quantify the number of sow days that sows had received an increase or a decrease in feed intake and the amount of the increase or decrease (Dorumad, et, al., 2007) Feed offered sows identified to need more feed was increased by 0.227 or 0.454 kg of feed/day and feed offered sows identified as needing less feed was decreased by 0.227 or 0.454 kg of feed/day. Data were summarized to indicate, by treatment, the number of sow days those sows received either a 0.227 or 0.454 kg of feed/day increase or decrease in feed offered. Gilts and sows were weighed at approximately 110 days of gestation when they were moved into farrowing crates. Gilts and sows were stratified by body weight and parity to one of two dietary treatments. Experimental lactation treatment diets were offered upon the gilts and sows entry into the farrowing crates, and this was continued until weaning.

Lactation

Gilts and sows were fed experimental lactation diets starting at the time they were moved to the farrowing facility and the amount fed remained approximately 2.72 kg, fed in two equal meals daily, until parturition. Within 24 hours of parturition, gilts and sows were offered feed at least two times daily and feed was fed to appetite. Feed intake was recorded and averaged daily. Feed intake was calculated on days 2, 4, 6, 8, 10, 12 post-partum and intake from all sows was recorded again at weaning.

Treatments

Gestation:

A common gestation diet (Table 2) was initiated immediately following the breeding period and continued through day 110 of gestation. Diets were fed in the meal form.

Lactation:

The lactation diet (Table 1) was provided starting at d 110 of gestation at 2.72 kg per day until farrowing, then ad libitum starting at 24 h post-partum. Diets were fed in the meal form. Treatment 1 was a Control: moderate complex diet, while Treatment 2 was Treatment. 1 + Luctarom SowViveat at 0.68 kg/909 kg.

Data Collected:

Gilts and sows were weighed at d 110 of gestation, 48 h post-farrowing, and again at weaning. Backfat depth was measured at d 110 of gestation and again at weaning. Number and litter weight of pigs at birth (total and live) and at weaning (not later than a 21-d average) was recorded. Pigs were weighed individually (intra litter CV was determined). Total litter weight was collected at 24 h, and 48 h post-partum to determine the colostrum yield and again on d 14 and weaning to determine the piglets weight gain during lactation. Total number of pigs and weight were recorded before and after cross fostering). Cross fostering was kept to a minimum and was done on a within-treatment basis (weights were recorded again to calculate litter performance if cross fostering occurred after initial birth weights were recorded). In addition, number and weights of stillbirths and mummified pigs were recorded.

Breeding records and weights for all sows and gilts allotted to this trial (including sows not farrowing) were recorded for conception rate calculation. Sows were fed a minimum of 2 times daily and had ad libitum access to feed throughout lactation. Feed wastage and feed disappearance were recorded and summed at the end of lactation. Lactation feed intake was determined and recorded for each sow. All weaned sows were heat checked at least once a day with intact boars and the number of days to first estrus following weaning determined. Feed samples will be collected at the beginning of each breed group's initiation of study.

Data analysis:

Data were analyzed using PROC MIXED of SAS. Fixed effects were treatment, season, the treatment by season interaction, and replicate, and parity served as a covariate. Individual sows/gilts were the experimental unit. Conception rate, rebreding rate, and farrowing rate were analyzed by Chi-square. The F-protected LSD procedure was used to compare treatment means.

Results

A total of 111 sows (53 for Control; 58 for SowVive) from three lactation groups were used to evaluate the effect of SowVive on reproductive performance. Two groups of sows were followed through a subsequent cycle to investigate the seasonal impact on SowVive.

Initial BW of sows were 259 kg and 263 kg (P = 0.35) for control and SowVive and BW were 242.6 and 245.22 kg (P = 0.37) at the end of lactation (Table 2). Backfat thickness change during lactation was not affected by SowviVe treatment (-0.68 vs -1.13 P = 0.68, Table 2), and weaning-to- estrus interval was similar between the two treatments (4.91 vs 4.96 P = 0.508, Table 3). Whereas Sows fed SowVive had greater feed intake on d 19 to 21 (Figure 1, P = 0.05), the differences in total lactation feed intake (139.2 vs 133.6 kg; P = 0.13) and total ADFI (5.45 vs 5.24 kg/d; P = 0.13) were not significant. This observation on appetite's stimulation during lactation allow sows fed SowVive diets to wean off relative larger litter (10.83 vs 10.36 piglets; P = 0.28, Table = 3) and still maintain similar body condition at weaning when compared to sows fed control diets. In addition, sows fed SowVive had 3.03 kg heavier weaning litter weights than sows fed control diets, and average piglet's BW at weaning was similar between two dietary treatments (5.57 vs 5.56; P= 0.933).

Farrowing season had great impacts on reproductive performance (Table 4 and 5). Sows that farrowed in winter lost less BW post-farrowing than sows that farrowed in summer (Table 4, -1.02 vs -8.35 kg, P = 0.0382).

As for intake, winter farrowing sows had greater intake on d 7 to 9 (P < 0.01), d 13 to 15 (P = 0.04), d 16 to 18 (P = 0.08), and d 19 to 21 (P = 0.05), which leads to 22.71 and 23.56 kg greater intake on d 6 to 27 (P < 0.01) and total intake (P < 0.01) than summer farrowing sows, respectively. Although it is not statistically significant, the greater intake observed in winter farrowing group resulted in numerically greater weaning weight (248.65 vs 239.15 kg P = 0.17) and more sow backfat deposit (2.23 vs -4.04 mm P = 0.35) than its summer counterparts. Furthermore, farrowing season did not seem to affect the offspring performance traits measured (Table 5). Numerically lower preweaning mortality (18.59 vs 20.99 % P = 0.34), greater weaning litter weight (60.53 vs 57.86 kg P = 0.69), greater litter weight gain (46.96 vs 44.2 kg P = 0.544) was observed in winter than summer farrowing group. For categorical variables, piglets birth weight of less than 0.907 kg (Chi square, P = 0.0547; Table 8) was lowered in sows fed SowVive than those sows fed the control diet. This response was only observed in the winter farrowing group but not in the summer farrowing group (P = 0.856).

Note that the intake stimulation from SowVive appears to only occur when sows experience heat stress during summer. Sows fed SowVive increased intake on d 0 to 6, d 10 to 12 and d 13 to 15 by 0.45 kg [Figure 3 (a), SowVive by season P = 0.05], 2.37 kg [Figure 3 (c), Sowvive by season P = 0.08] and 2.21 kg [Figure 3 (d), SowVive by season P = 0.065], respectively compared to sows fed the control diet during summer, but not in winter where intake was already high (Figure 4, Table 6). Sows fed both control and SowVive diets increased total feed consumption from hot temperature to cooler temperature. The observation on seasonal impact reduces the magnitude of intake difference in sows fed control diets when compared to SowVive (8.44 kg different during summer while 2.87 kg during winter).

Discussion

The results demonstrated that supplementing sow diets with SowVive during the lactation period slightly increased total feed intake, as well as ADFI from days 19 to 21. Previous studies have shown that heat stress can lower feed intake which in turn can reduce productivity, as well as reduce reproductive performance in sow herds. Fertility and prolificacy have been known decrease in the summer months. Koketsu et al. (2017) found that farrowing rates are the lowest in the summer, and there are fewer pigs born alive in summer litters in the hotter summer months. Wegner et al. (2014) suggests that due to their low sweating capacity sows are more susceptible to hotter ambient temperatures, and that this can cause various negative effects on sow performance, namely reducing voluntary feed intake.

Milk production requires the sow to invest a large segment of her metabolic activity, therefore the sow needs to consume as much feed as possible to sustain viable milk production through the entire lactation process. The lactation period only makes up 15 to 20% of a sow's production cycle, however it undoubtably is the most metabolically demanding stage within the production cycle. Tokach et al. (2019) suggests that the sow's primary focus during this period must be to sustain milk production enough to support a rapidly growing litter. This coincides with our findings as we saw an increase in feed intake throughout the duration of the lactation period. We can assume this response during lactation is the sows attempt to nourish her litter. To know the exact nutrient requirements of lactating sows is challenging due to requirements relying on milk yield and feed intake which can vary drastically between individuals. Although there have been recent efforts by Gauthier et al. (2019) to create dynamic models of nutrient use as well as individual requirements for lactating sows, more research needs to be conducted to attain more accurate models.

Changing the taste, smell, or texture of feed has been widely studied throughout the field (Wondra et al. 1995; Goff and Klee, 2006; Windisch et al. 2008; Franz et al. 2010). Wondra et al. (1995) found that by changing the particle size of the feed they were able to observe improved intake and reduced fecal output. Unfortunately, the potential gut health risks with smaller feed particle sizes such as ulcers were also observed which may negate the potential benefits of reducing feed particle size. Various aromatic herbs, and essential oils have been utilized in feed substantially in the past thirty years. Franz et al. 2010 indicated that some aromatic plants and compounds can improve digestion and performance, as well as improve characteristics of feed such as palatability, and aroma. This evidence supports the concept of supplementation of sensory additives in sow lactation diets can improve total voluntary feed intake during the lactation period.

Seasonal effects on sow performance have been widely studied in past years (Renaudeau et al. 2013; Wegner et al. 2014; Koketsu et al., 2017). When ambient temperature rises, sow intake tends to decrease. Reduced intake during the lactation period can often be associated with lower average weaning weight, longer weaning to estrus intervals, an increased number of culled sows, as well as reduced subsequent farrowing rates (Koketsu et al. 2017). In the summer months we observed a reduction in overall total intake when compared to the winter farrowing months, this reduction is likely due to a limited intake due to heat stress. When looking specifically at the summer trials we observed an increased average daily feed intake during the lactation period in sows fed the sensory additive SowVive, however there was no difference in feed intake during the winter farrowings. We believe that in the winter trials we were not able to see a difference because the sows may have reached their stomach capacity in the cooler temperatures and were eating the maximum amount of feed they could consume (Revell et. al., 1998).

Conclusion

Supplementation of the sensory additive SowVive to sow lactation diets fed ad libitum can help stimulate voluntary feed intake for lactating sows in the summer months.

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Appendix

Table 1. Lactation diet composition (as-fed).

	Control	SowVive
Ingredients		
Corn, Yellow Dent	48.205	48.13
Soybean meal, 48%	26.5	26.5
Corn DDGS, >6 and <9% Oil	20	20
Fat	1	1
Monocalcium phosphate	1.25	1.25
Limestone	1.325	1.325
Sodium chloride	0.5	0.5
L-Lysine	0.4	0.4
DL-Methionine	0.0275	0.0275
L-Threonine	0.115	0.115
L-Tryptophan	0.02	0.02
Trace Mineral Premix (NB-8534)	0.15	0.15
Vitamin Premix (NB-6508)	0.25	0.25
Lucta_antioxident	0.0075	0.0075
Luctarom (SowVive)	0	0.075
Sow Add Pack (NB-6442)	0.25	0.25
Total	100	100
Calculate		
ME (kcal/kg)	3295	3293
CP (%)	22.68	22.67
SID Lysine (%)	1.21	1.21
Total P (%)	0.70	0.70
Available P (%)	0.40	0.40
Ca (%)	0.85	0.85
Analyzed		
GE (kcal/kg)	4138.0	4142.0
NDF, %	24.7	23.4
ADF, %	6.2	5.9

The vitamin premix provided the following per kg of complete diet: 397.5 mg of Ca as $CaCO_3$, 11,022.9 IU of vitamin A, 1,377.9 IU of vitamin D_3, 44.09 IU of vitamin E, 0.0386 mg vitamin B_{12}, 4.41 mg of menadione, 8.27 mg of riboflavin, 27.56 mg of D-pantothenic acid, and 49.6 mg of niacin.

The mineral premix provided the following per kg of complete diet: 84 mg of Ca as $CaCO_3$, 165 mg of Fe as $FeSO_4$, 165 mg of Zn as $ZnSO_4$, 39.6 mg of Mn as $MnSO_4$, 16.5 mg of Cu as $CuSO_4$, 0.3 mg of I as CaI_2, and 0.3 mg of Se as Na_2SeO_3.

Table 2 Common Gestation Diet Composition (as fed)

	Gilts/Sows	
Ingredients	kg	%
Corn, Yellow Dent	535.86	59.07
Soybean meal, 48%, high protein,	54.43	6
Corn DDGS, >6 and <9% Oil	272.16	30
Fat (Darling, Yellow Grease)	9.07	1
Calcium phosphate (monocalcium)	7.26	0.8
Limestone, 2012 NRC	15.65	1.725
Sodium chloride	4.08	0.450
Copper Sulfate	0.00	0.00
L-Lysine	1.99	0.220
DL-Methionine	0.00	0.00
L-Threonine	0.34	0.038
L-Tryptophan	0.04	0.005
Trace Mineral Premix (NB-8534)	1.36	0.150
Vitamin Premix (NB-6508)	2.26	0.250
Ronozyme P CT	0.14	0.015
Ethoxipuin (Quinguard)	0.27	0.03
Sow Add Pack (NB-6442)	2.26	0.25
Total	907.18	100.0

Table 3. Effect of SowVive supplementation on sow performance (LSmeans)

	Treatment			P - Value	
	Control	SowVive	SEM	Parity	Trt
	n=53	n=58			
d 110 BW, kg	259.07	262.73	5.96	0.1334	0.346
Farrowing BW, kg	250.48	252.42	2.75	0.001	0.465
Farrowing loss, kg	-5.66	-3.71	2.75	0.001	0.465
Lactation loss, kg	-7.82	-7.27	2.71	0.066	0.8213
Backfat at weaning, mm	14.75	14.43	0.86	0.0481	0.688
Backfat Change during lactation, mm	-1.13	-0.68	3.48	0.088	0.6834
Wean wt, kg	242.58	245.22	4.18	<0.0001	0.368
Feed Intake 1 to 3	7.20	7.35	0.57	0.5208	0.3268
ADFI 1 to 3, kg	2.60	2.68	0.11	0.5312	0.2427
Feed Intake 4 to 6, kg	7.45	7.39	0.78	0.4271	0.8076
ADFI 4 to 6, kg	2.48	2.46	0.26	0.4271	0.8076
Feed Intake 7 to 9, kg	12.19	12.03	0.82	<0.0001	0.8195
ADFI 7 to 9, kg	4.04	4.02	0.26	<0.0001	0.9306
Feed intake 10 to 12, kg	14.14	15.18	0.96	0.0257	0.1716
ADFI 10 to 12, kg	4.71	5.06	0.32	0.0257	0.1716
Feed Intake 13 to 15, kg	16.30	17.26	0.72	<0.0001	0.1538
ADFI 13 to 15, kg	5.43	5.75	0.24	<0.0001	0.1538
Feed Intake 16 to 18, kg	20.63	21.64	2.33	0.0168	0.187
ADFI 16 to 18, kg	6.88	7.21	0.78	0.0168	0.187
Feed Intake 19 to 21, kg	18.40	20.20	0.98	<0.0001	0.0077
ADFI 19 to 21, kg	6.13	6.73	0.33	<0.0001	0.0077
Feed Intake 22 to 24, kg	21.18	21.34	1.23	0.1344	0.8292
ADFI 22 to 24, kg	7.06	7.11	0.41	0.1344	0.8292
Feed Intake 25 to 27, kg	17.51	17.94	1.44	0.0842	0.6303
ADFI 25 to 27, kg	7.99	8.25	0.77	0.0705	0.5466
Total FI	133.57	139.22	4.05	<0.0001	0.1327
Total ADFI	5.22	5.45	0.18	<0.0001	0.1323
Feed Intake 0 to 6	14.52	14.76	1.10	0.1137	0.5303
ADFI 0 to 6 , kg	2.52	2.58	0.15	0.1071	0.3956
Feed Intake 6 to 27	118.80	124.21	3.49	<0.0001	0.1373
ADFI 6 to 27 , kg	6.01	6.27	0.21	<0.0001	0.1439

A total of 111 sows were selected and assigned to treatments: control or SowVive on d 110 of gestation.

Data were analyzed using Mixed procedure of SAS (Cary, NC) as randomize complete block design with farrowing group as random effect and treatment as fix effect.

Probability value ≤ 0.05 was considered significant different while Probability value > 0.05 but ≤ 0.1 was defined as tendency different.

Table 4. Effect of SowVive supplementation on offspring performance (LSmeans)

	Treatment			P - Value	
	Control	SowVive	SEM	Parity	Trt
	n=53	n=58			
Total born, num	16.65	16.82	0.62	0.0607	0.7977
Total born wt, kg	18.75	18.83	1.17	0.0041	0.9259
Born alive, num	13.01	13.46	0.61	0.0236	0.4106
Born alive wt, kg	15.76	16.26	1.06	0.0015	0.5598
Average born alive wt, kg	1.20	1.20	0.06	0.0463	0.9953
Stillborn, num	3.58	3.28	0.39	0.0002	0.4542
Stillborn, %	0.19	0.16	0.02	0.0119	0.2742
Stillborn wt, kg	2.94	2.53	0.46	0.1036	0.3197
Mummy, num	0.35	0.38	0.08	0.0079	0.724
Mummy wt, kg	0.03	0.03	0.01	0.5575	0.9356
Cross foster, n	0.03	0.03	0.13	0.4347	0.9881
Cross foster wt, kg	0.06	0.06	0.24	0.4347	0.9881
Total dead	2.67	2.72	0.36	0.2871	0.8893
24 h, n	11.79	12.08	0.61	0.0162	0.5764
24 h litter wt, kg	16.20	16.85	1.03	0.0009	0.4632
Avg 24 h wt, kg	1.35	1.38	0.06	0.0886	0.6541
48 h, n	11.41	11.74	0.50	0.0073	0.5144
48 h litter wt, kg	17.53	18.13	1.03	0.0003	0.5103
Avg 48 h wt, kg	1.52	1.53	0.06	0.0484	0.9519
14 d, n	10.51	10.82	0.54	0.0011	0.5078
14 d litter wt, kg	39.90	41.18	2.26	0.0002	0.5204
Avg 14 d wt, kg	3.74	3.77	0.12	0.1053	0.8225
Weaned pigs, num	10.36	10.83	0.60	0.0001	0.2811
Weaning litter wt, kg	57.68	60.71	3.96	<0.0001	0.2611
Litter wt gain, kg	44.38	46.78	2.83	<0.0001	0.2541
Average wean wt, kg	5.57	5.56	0.16	0.2445	0.9331
Piglets ADG, kg	0.22	0.22	0.01	0.4122	0.9882
CV birth wt	24.66	23.16	1.71	0.1447	0.2364
CV wean wt	24.72	24.42	1.70	0.0905	0.8417
Wean to estrus, d	4.91	4.96	0.18	0.5815	0.559

A total of 111 sows were selected and assigned to treatments: control or SowVive on d 110 of gestation.
Data were analyzed using Mixed procedure of SAS (Cary, NC) as randomize complete block design with farrowing group as random effect and treatment as fix effect.

Table 5. Effect of farrowing season on sow performance (LSmeans).

	Season[1]			P – Value
	Summer	Winter	SEM	season
	n=51	n=60		
d 110 BW, kg	265.03	256.76	7.55	0.4158
Farrowing BW, kg	247.79	255.12	2.96	0.0382
Farrowing loss, kg	-8.35	-1.02	2.96	0.0382
Lactation loss, kg	-8.96	-6.13	3.07	0.4559
wnp2	14.25	14.94	0.91	0.4878
P2 Change	-4.04	2.23	4.77	0.3511
Wean wt, kg	239.15	248.65	5.19	0.17
Feed Intake 1 to 3	6.68	7.87	0.79	0.2847
ADFI 1 to 3, kg	2.67	2.62	0.14	0.7933
Feed Intake 4 to 6, kg	7.62	7.21	1.06	0.7825
ADFI 4 to 6, kg	2.54	2.40	0.35	0.7825
Feed Intake 7 to 9, kg	10.54	13.68	0.93	0.0075
ADFI 7 to 9, kg	3.49	4.56	0.30	0.0041
Feed intake 10 to 12, kg	14.53	14.79	1.14	0.8566
ADFI 10 to 12, kg	4.84	4.93	0.38	0.8566
Feed Intake 13 to 15, kg	15.77	17.79	0.79	0.0363
ADFI 13 to 15, kg	5.26	5.93	0.26	0.0363
Feed Intake 16 to 18, kg	17.09	25.18	3.20	0.0747
ADFI 16 to 18, kg	5.70	8.39	1.07	0.0747
Feed Intake 19 to 21, kg	17.68	20.92	1.23	0.0511
ADFI 19 to 21, kg	5.89	6.97	0.41	0.0511
Feed Intake 22 to 24, kg	19.78	22.73	1.59	0.1755
ADFI 22 to 24, kg	6.59	7.58	0.53	0.1755
Feed Intake 25 to 27, kg	16.97	18.48	1.84	0.5462
ADFI 25 to 27, kg	6.98	9.26	1.00	0.0986
Total FI	124.57	148.22	4.49	<0.0001
Total ADFI	4.83	5.84	0.21	0.0002
Feed Intake 0 to 6	14.19	15.09	1.51	0.6717
ADFI 0 to 6 , kg	2.58	2.52	0.20	0.8015
Feed Intake 6 to 27	110.15	132.86	3.56	<0.0001
ADFI 6 to 27 , kg	5.50	6.79	0.24	<0.0001

Table 6. Effect of farrowing season on offspring performance (Lsmeans).

	Season[1]			P – Value
	Summer	Winter	SEM	season
	n=51	n=60		
Total born, n	16.32	17.14	0.63	0.2379
total born wt, kg	18.95	18.64	1.44	0.8696
Born alive, n	13.22	13.25	0.69	0.9678
Bron alive wt, kg	16.54	15.48	1.26	0.5106
average born alive wt, kg	1.24	1.17	0.08	0.4265
Stillborn, n	3.01	3.86	0.41	0.0654
Stillborn %	0.15	0.20	0.02	0.0637
Stillborn wt, kg	2.38	3.09	0.51	0.2458
mummy	0.41	0.33	0.09	0.3549
mummy wt, kg	0.04	0.03	0.01	0.6422
Cross Foster, n	0.08	-0.01	0.13	0.5475
Cross Foster wt, kg	0.14	-0.02	0.24	0.5475
net	13.27	13.23	0.72	0.9638
net wt, kg	16.67	15.45	1.26	0.4563
Adjnetwt, kg	13.86	13.47	1.21	0.8022
Total dead	2.88	2.51	0.37	0.3505
Preweaning mortality, n	20.99	18.59	2.28	0.3401
24H, n	11.60	12.27	0.71	0.4543
24H litter wt, kg	17.00	16.05	1.19	0.5278
Avg 24H wt, kg	1.44	1.29	0.07	0.0945
48H, n	11.24	11.91	0.52	0.2614
48H litter wt, kg	18.22	17.44	1.17	0.5924
Avg 48H wt, kg	1.60	1.45	0.07	0.0631
14D, n	10.30	11.02	0.62	0.3522
14D litter wt, kg	40.73	40.34	2.58	0.9026
Avg 14D wt, kg	3.90	3.61	0.13	0.0703
Weaned pigs, n	10.41	10.78	0.74	0.6996
Weaning litter wt, kg	57.86	60.53	4.98	0.6885
Litter wt gain, kg	44.20	46.96	3.46	0.5442
Average wean wt, kg	5.57	5.56	0.16	0.9709
Piglets ADG, kg	0.22	0.22	0.01	0.7047
CV birth wt	24.27	23.54	2.08	0.7904
CV wean wt	23.76	25.37	1.95	0.5075
Wean to estrus, d	4.87	5.00	0.24	0.6764

Probability value ≤ 0.05 was considered significant different while Probability value > 0.05 but ≤ 0.1 was defined as tendency different.

Table 7. Sow treatment by farrowing season interaction on sow performance (Lsmeans)

	Summer		Winter			P - Value
	Control	SowVive	Control	SowVivie	SEM	Trt*season[1]
	n=26	n=26	n=27	n=32		
d 110 BW, kg	265.20	264.86	252.94	260.59	8.03	0.3041
Farrowing BW, kg	246.91	248.67	254.05	256.18	3.51	0.9456
Farrowing loss, kg	-9.23	-7.47	-2.08	0.04	3.51	0.9456
Lactation loss, kg	-9.62	-8.29	-6.01	-6.25	3.51	0.7471
wnp2	14.46	14.04	15.04	14.83	1.06	0.8903
P2 Change	-4.02	-4.05	1.77	2.69	4.84	0.6639
Wean wt, kg	237.51	240.79	247.66	249.64	5.58	0.824
Total FI	120.35	128.79	146.79	149.66	5.21	0.4589
Total ADFI	4.66	4.99	5.78	5.90	0.23	0.4928
Feed Intake 0 to 6	13.55^{a}	14.83^{b}	15.49	14.69	1.53	0.0065
ADFI 0 to 6 , kg	2.46^{a}	2.71^{b}	2.58	2.45	0.21	0.0063
Feed Intake 6 to 27	106.55	113.74	131.05	134.68	4.38	0.6249
ADFI 6 to 27 , kg	5.33	5.66	6.68	6.89	0.27	0.728

a.b.c Means within a row without a common superscript differ significantly at P <0.05
x.y.z. Means within a row without a common superscript tended to be differ at 0.10 > P > 0.05. Data were analyzed using Mixed procedure of SAS (Cary, NC) as randomize complete block design with farrowing group as random effect while season, treatment and its interaction as fix effects. Probability value ≤ 0.05 was considered significant different while Probability value > 0.05 but ≤ 0.1 was defined as tendency different.

Table 8. Sow treatment by farrowing season interaction on sow performance (LSmeans)

	Summer		Winter			P - Value
	Control	SowVivie	Control	SowVive	SEM	Trt*season[1]
	n=26	n=26	n=27	n=32		
Total born, n	16.56	16.08	16.74	17.55	0.78	0.3193
total born wt, kg	18.86	19.04	18.65	18.63	1.56	0.9063
Born alive, n	13.05	13.38	12.97	13.53	0.79	0.8242
Born alive wt, kg	16.03	17.05	15.49	15.46	1.39	0.5359
average born alive wt, kg	1.22	1.27	1.19	1.14	0.08	0.3121
Stillborn, n	3.42	2.60	3.75	3.97	0.50	0.1971
Stillborn %	0.18	0.13	0.20	0.20	0.03	0.2044
Stillborn wt, kg	2.80	1.96	3.09	3.10	0.59	0.3137
mummy	0.47	0.35	0.24	0.41	0.11	0.0939
mummy wt, kg	0.05	0.02	0.02	0.04	0.02	0.077
Total dead	2.89	2.88	2.45	2.56	0.45	0.8739
Preweaning mortality, n	20.63	21.35	18.37	18.82	2.81	0.9556
Weaned pigs, n	10.24	10.58	10.47	11.09	0.80	0.75
Weaning litter wt, kg	55.63	60.09	59.74	61.32	5.32	0.5884
Litter wt gain, kg	42.36	46.03	46.41	47.52	3.76	0.5369
Average wean wt, kg	5.46	5.69	5.69	5.44	0.20	0.1451
Piglets ADG, kg	0.21	0.22	0.23	0.22	0.01	0.1599
CV birth wt	25.79	22.76	23.53	23.56	2.27	0.2274
CV wean wt	24.10	23.42	25.33	25.41	2.21	0.7983
Wean to estrus, d	4.83	4.91	4.99	5.02	0.24	0.7702

a.b.c Means within a row without a common superscript differ significantly at $P < 0.05$

x.y.z. Means within a row without a common superscript tended to be differ at $0.10 > P > 0.05$

Table 9. Effect of SowVive supplementation on reproductive performance (Chi square)

	summer		P - Value	Winter		P - Value
	Control	SowVive		Control	SowVive	
Birth weight less than .907 kg	0.1509	0.1461	0.8561	0.2795	0.2215	0.0547
Wean BW less than 3.17 kg	0.0588	0.0584	0.9832	0.0604	0.0771	0.3943
Wean BW less than 3.64 kg	0.0817	0.0928	0.6312	0.094	0.1131	0.4167
Deadloss	0.1729	0.1777	0.8657	0.1836	0.1656	0.4974

A total of 111 sows were selected and assigned to treatments: control or SowVive on d 110 of gestation.
Category data were analyzed using Chi-square test of frequency procedure of SAS (Cary, NC) with treatment as fix effects. Probability value ≤ 0.05 was considered significant

Table 10. Effect of SowVive supplementation on reproductive performance (Chi square)

	Treatment		
	Control	SowVive	Trt
Birth weight less than 2 lbs	28.37%	21.75%	0.026
Wean BW less than 7 lbs	5.99%	7.60%	0.405
Wean BW less than 8 lbs	8.80%	11.29%	0.284
Dead loss	18.62%	15.92%	0.3

A total of 61 sows were selected and assigned to treatments: control or SowVive on d 110 of gestation. These three groups of sows were farrowed in October, December and January.

Data were analyzed using Mixed procedure of SAS (Cary, NC) as randomize complete block design with farrowing group as random effect while treatment was treated as fix effects. Probability value ≤ 0.05 was considered significant different while Probability value > 0.05 but ≤ 0.1 was defined as tendency different.

Figure 1. Effect of SowVive on d 19 to 21 feed intake and average daily feed intake (P < 0.01)

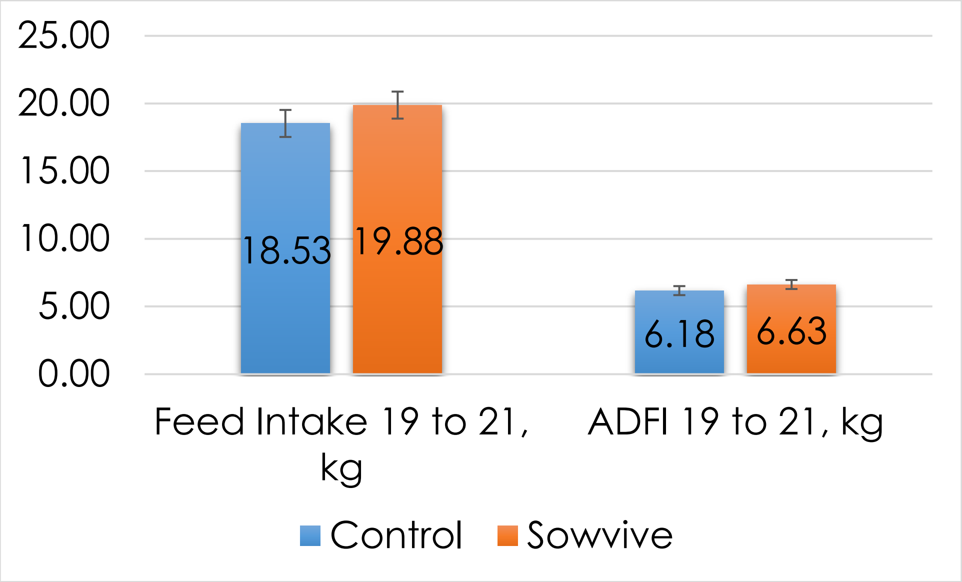


Figure 2. SowVive by season interaction effect on (a) d 0-6, (b) d 4-6, (c) d10-12 and (d) d 13-15 feed intake (P < 0.01, P = 0.037, P = 0.08, and P = 0.065, respectively)

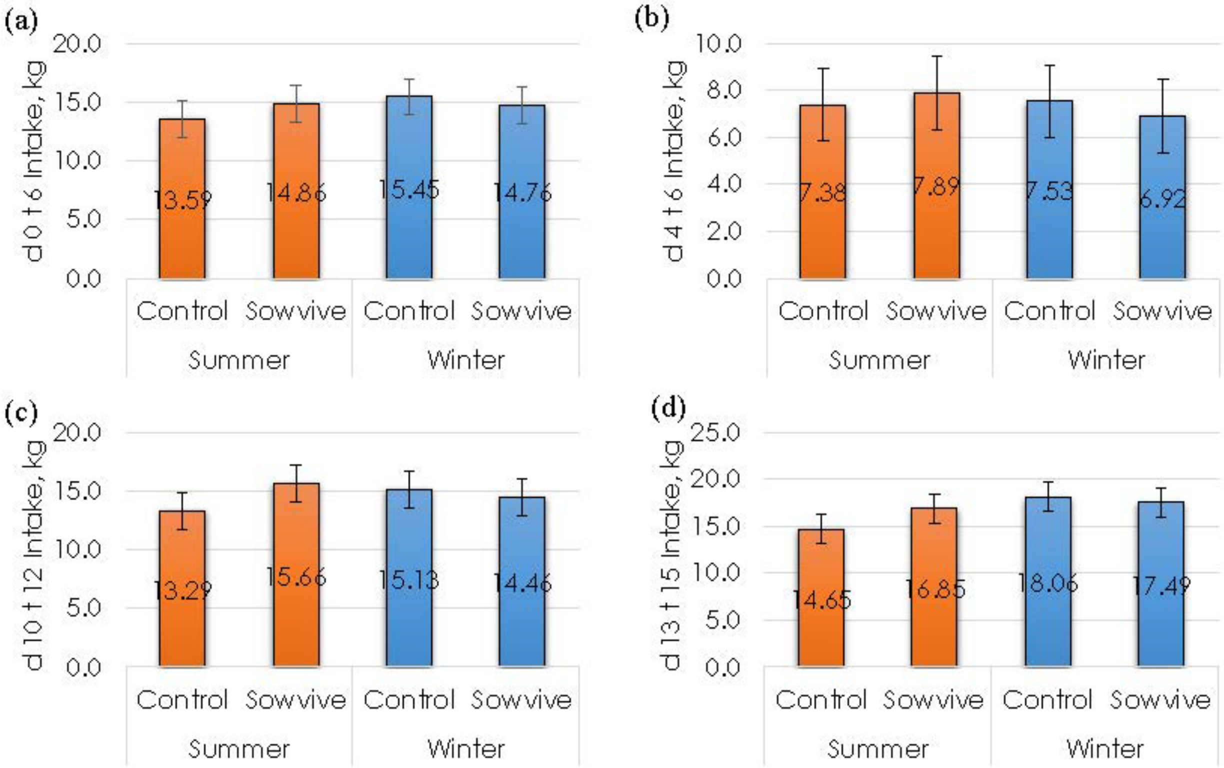


Figure 3. SowVive by season interaction effect on (a) d 0-6, (b) d 4-6, (c) d10-12 and (d) d 13-15 average daily feed intake ($P < 0.010$, $P = 0.037$, $P = 0.08$, and $P = 0.065$, respectively)

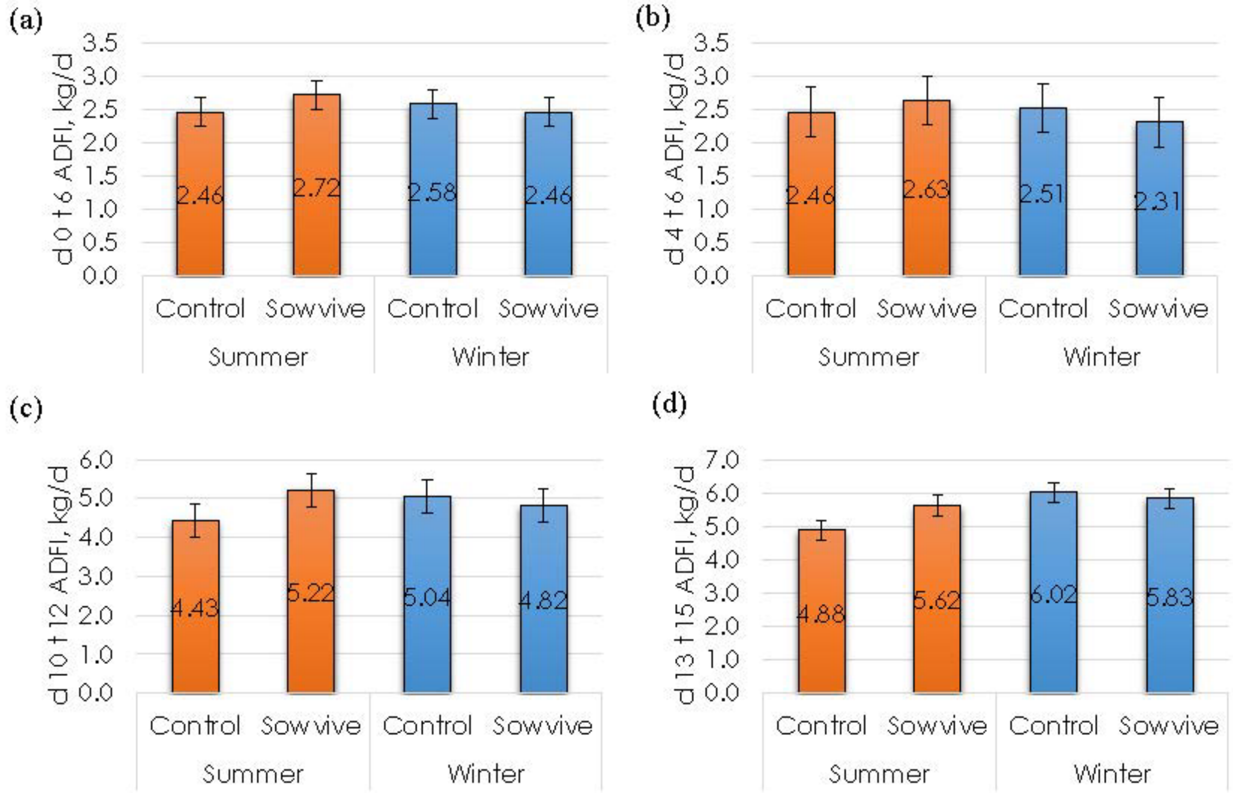
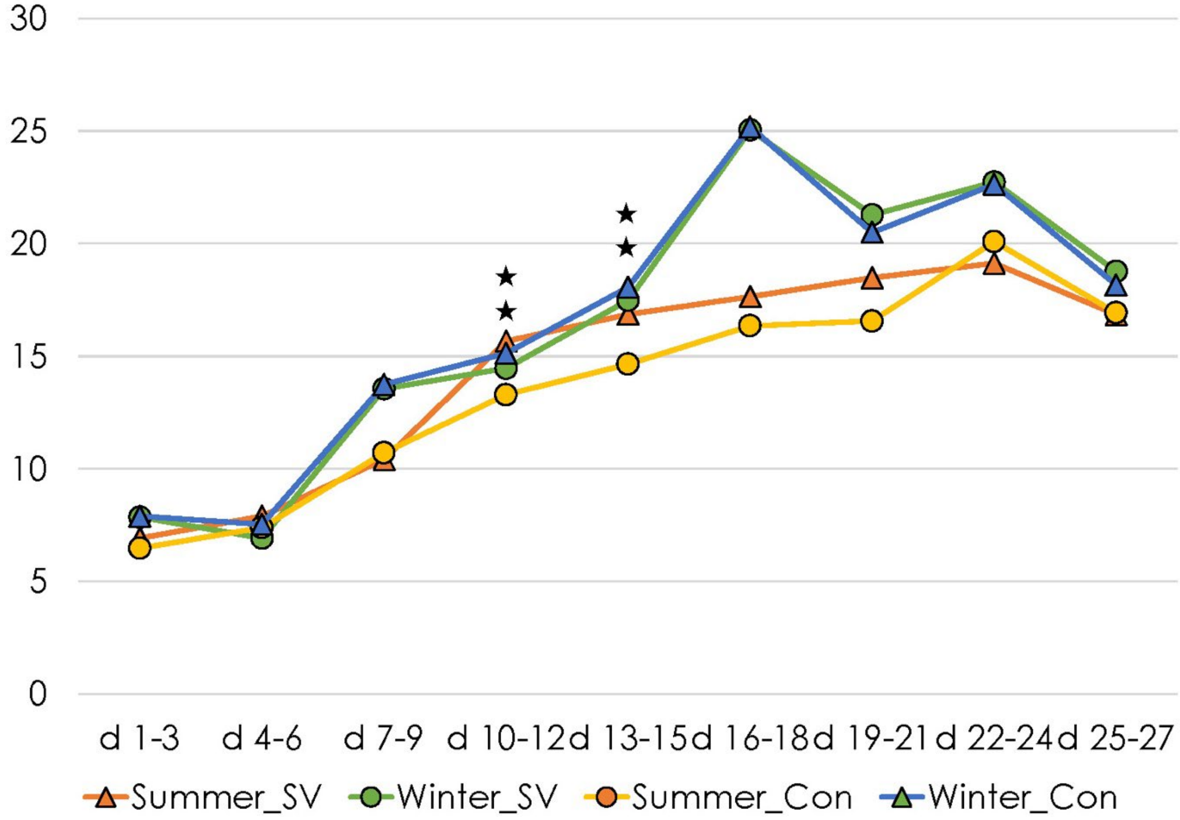


Figure 4. SowVive by season interaction effect on sow average daily feed intake (P ≤ 0.05)



Chapter 3: The effects of sensory additives on growth performance in nursery pigs

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Abstract:

The abrupt changes in the diet and environment of piglets at weaning leads to reduced feed intake and post-weaning diarrhea. Certain feeds or its substances exert nutraceutical properties which have shown benefits on appetite, health, and disease prevention, which can help pigs overcome weaning stress. A total of 270 PIC 1050 X PIC 29 piglets at approximately 21 days of age from the University of Arkansas Animal Science Swine Research Farm, were used for the study. Upon weaning, pigs were blocked by bodyweight and then randomly assigned to one of five diets that were provided: 1. Negative Control: carrier without antioxidant (Luctanox) and phosphoric acid (Luctacid); 2. Positive Control: carrier plus antioxidant (Luctanox) and phosphoric acid (Luctacid); 3. As 2 + sensory additive A; 4. As 2 + sensory additive B; 5 As 2+ sensory additive C. There were a total of 9 replicates (pens) per group with 6 pigs/pen, and 45 pens. The piglets had a three-phase feeding regimen: phase 1, 14 days; phase 2, 14 days; and phase 3, 14 days. All pigs had free access to feed and water during the experiment. Pigs remained on the same treatments throughout all nursery phases. Individual piglets were weighed, and intake was recorded on d 0, 7, 14, 21, 28, and 42. Blood samples and rectal swabs were collected on d 0, 14, 28, and 42 from a median BW pig of each pen. There were no statistical differences between PC and NC on ADG, BW, and feed efficiency measured during Wk 1 and 2, but feed intake was numerically higher in PC in Wk1 compared to NC (Table 15, P = 0.102) but not in the overall trial.

Neither gain nor BW were significantly improved by the addition of any of the sensory additives in this study, however sensory additives B and C had the greatest intake during the overall study (wk1 to 6) and started to differentiate from PC and NC from wk 4, although differences were not significant. We conclude that supplement Luctacid HC and Luctanox 5888 alone or together with C may improve the growth performance of nursey pigs.

Keywords: Nursery, sensory additive, growth performance

Introduction

The abrupt changes in the diet and environment of piglets leads to reduced feed intake and post-weaning diarrhea (Oostindjer et. al., 2010). The growth retardation induced by weaning stress brings huge losses to animal husbandry. Certain food or its substances exert nutraceutical properties which have shown benefits on appetite, health and disease prevention, which can help pigs overcome weaning stress (Le Dividich et. al., 1999). Sensory additives have been showed promising effects on intake stimulation in sows and benefits on phenotypes extend to offspring in the nursery stage. However, more study is needed to investigate the effect of sensory additives on growth when supplemented directly in weaning pig diets.

Materials and Methods

Animal Management and Feeding Methods

The experiment was carried out in accordance with the Animal Care Protocol issued by the University of Arkansas Animal Care Committee. Upon weaning, nursery piglets were transferred into nursery facilities and the experiment lasted for 42 days.

Diets were formulated to meet or exceed NRC (2012) recommendations for nursery pigs. All diets were in mash form. Feed was prepared by the University of Arkansas System Division of Agriculture Animal Science Feed Mill. Feed samples from each diet were stored at -20°C for future nutritional analysis. The piglets had a three-phase feeding regime: 1) phase 1, 14 days; 2) phase 2, 14 days; and 3) phase 3, 14 days. All pigs had free access to feed and water during the experiment. One of five diets were provided: 1. Negative Control: carrier without antioxidant (Luctanox) and phosphoric acid (Luctacid); 2. Positive Control: carrier plus antioxidant (Luctanox) and phosphoric acid (Luctacid); 3. As 2 + sensory additive A; 4. As 2 + sensory additive B; 5 As 2+ sensory additive C.

Pigs remained on its treatments throughout the overall nursery phase. There were a total of 9 replicates per group with pigs housed 6 pigs/pen. All diets were free of feed additives antibiotics, and pharmaceutical levels of zinc and copper were provided in all complete diets during phase 1 and 2, while only high copper was added in all phase 3 diets.

Animal Performance Measurements

Individual piglets were weighed on d 0,7, 14, 21, 28, and 42. Pen feed intake was recorded on d 7, 14, 21, 28, and 42.

Leukocyte differential and blood chemistry panel

Blood samples were collected on d 0, 14,28, and 42 from a median BW pig of each pen into K_2EDTA tube and 1 mL of whole blood was aspirated into micro centrifuge tubes for complete blood cells count using the Hemavet instrument. (Drew Scientific, Miami Lakes, Florida) Afterward, remaining samples were centrifuged, and plasma was aspirated into 5 mL sample storage tubes and stored at -20°C for BUN and BUN/Creatinine determination.

Animal Facilities

Pigs were housed in a nursery, and each 4.90 × 3.95-foot pen was equipped with a two-hole feeder and one waterer for ad libitum access to diets and water. Ambient temperature was set at 29℃ upon pig arrival and was decreased by two degrees per week to approximately 23.8˚C at the end of nursery.

Animal care

The pigs in this study were cared for according to typical commercial management procedures. This experiment was carried out in accordance with the Animal Care Protocol for swine experiments issued by the University of Arkansas Animal Care Committee. Any animal suffering from minor illness was reported to the Study Director and treated. All medical treatments were recorded. Any animal that died or became ill was weighed and removed from the study. An animal removal form was completed detailing the reason for removal, date, time, and animal disposition.

Statistical Analysis

The University of Arkansas was responsible for statistical analysis. The data of quantitative traits were analyzed using the MIXED procedure of SAS. For binary data including weaning BW, mortality, and scour occurrence, data were analyzed by Frequency procedure of SAS and Chi-square test was used to assess the statistical significance among treatments. Comparisons between treatments were considered significantly different when the probability was ≤ 0.05.

Data recording

Data were recorded using permanent ink onto data forms or into a bound laboratory notebook. The investigator reviewed all data sheets. Data sheets from analytical measurements were retained in the notebook. Each raw data record contained a date and initials of recorder. All data were manually entered into an spreadsheet for determination of replicate means. The investigator had responsibility for assuring that the experimental data were accurately and promptly recorded in ink and verified if necessary.

Data corrections and transcriptions

Any correction of handwritten data was accomplished with a single stroke through the mistake. The original entry was not obscured; therefore, the use of whiteout or erasing was prohibited. The correction was initialed, dated, and given a code that represented a reason for the change. The investigator provided a key for all error codes used during data collection. Should an original data sheet need to be transcribed, all data and properly noted changes were transcribed. The reason for the transcription was expressed in a note on the data sheet or in a separate memo signed and dated by the individual making the transcription. The original sheet(s), the transcribed sheet and any explanatory memos were retained together.

Study records maintenance

Study records were maintained together including all raw data, observations, documentation, and all study related correspondence generated during the conduct of the study.

Results

Pigs used for this trial were healthy in general and only two pigs were removed during the study, one from PC and one pig from the C treatment. There were no statistical differences between PC and NC on ADG (Table 13, BW(Table 13), or feed efficiency (Table 15) measured during wk 1 and 2, but feed intake was numerically greater in PC compared to NC in kg1 (Table 15, P = 0.102) but not in the overall study. This resulted in a small increase of 0.01 g per day in intake but 0.48 kg heavier pigs at the end of the nursery study in pigs fed the PC (P= 0.1448) compared to those fed the NC diet. Neither gain nor BW were improved by the addition of any of the sensory additives in this study. However, among all the sensory additives, A appeared to have the lowest weight gain among all treatments in wk 3 (P = 0.0131), which coincided with low ADFI during wk 3 to 4 (P = 0.0016) and overall intake (wk 1 to 6, P = 0.0367). This resulted in the lowest final BW among the treatments (P = 0.1448), whereas pigs fed sensory additives B and C had the greatest intake during the overall study (wk 1 to 6) and started to differentiate from PC and NC from wk 4, although differences were not significant. Feed intake in pigs fed B and C were 45 and 60 g greater than NC fed pigs and were 26 and 45 g more than PC fed pigs, respectively although differences were not statistically significant. Although pigs fed both B and C demonstrated a tendency for intake stimulation, this was not reflected in weight gain differences between the two treatments. Pigs fed C were 76 and 28 g heavier than NC and PC at the end of trial, respectively, while little or no difference was observed in pigs fed B. The beneficial effect of of Luctanox and Luctacid were mainly observed in first week after weaning in this trial while the intake promoting effect from B and C were not observed until after week 4 when the synergistic effects of Luctanox and Luctacid and the sensory additives (B and C) were exhibited. The results suggest that Sensory additive C tended to promote intake and weight gain especially during late nursery period, which suggested that inclusion rate of C in the early nursery phase should be designed based on the intake level of each station to optimize the potential benefit in nursery pigs.

Serum chemical results are displayed in Table 15 and 16 with means separated by day and treatment, respectively. The vast majority of serum chemical measures showed age effects with the exception of alanine transaminase (Table 6, day $P = 0.3367$) and Anion Gap (day $P = 0.4218$). Of all chemicals where the age effect was observed, alkaline phosphatase (day $P < 0.0001$), cholesterol (day $P < 0.0001$), and total bilirubin (day $P < 0.0001$) were decreased more than two folds from weaning to the lowest read in phase 1 and elevated slightly in phase 2 and 3. In contrast, Creatine decreased linearly from weaning to phase 3 (day $P <0.001$). Other chemicals, such as aspartate transaminase (day $P < 0.0001$), Phosphorous (day $P <0.001$), Calcium (day $P <0.001$), γ-glutamyl transferase (day $P < 0.001$), and glucose (day $P < 0.001$) were reduced at phase 1 and later restored in phase 2 and 3. While a reduction in phase 1 also observed in Albumin (day $P < 0.001$), Creatine Kinase (day $P < 0.001$), and Chloride (day $P < 0.001$), an upward trend was observed in phase 3. A continuous increasing trend was observed in tCO2 (day $P < 0.001$) and Total protein (day $P < 0.001$) from weaning to phase 3. Sodium (day $P < 0.001$) and Osmolality (day $P < 0.001$) were similar from weaning to phase 1 and at phase 2. Potassium on the other hand, increased from weaning to phase 1. While potassium level remained similar in phase 2, it increased again in phase 3 (day $P < 0.001$). Blood urea nitrogen (day P < 0.001) and BUN/Creatine ratio (day P < 0.001) increased from weaning to phase 1 and levels were restored to similar to weaning. In phase 2 and 3. Globulin increased from weaning to phase 1 and 2 and decreased in phase 3 (day P < 0.001). Among all chemicals, significant treatment responses were observed for Calcium and Creatine (Table 8). Serum calcium was lower in NC and A fed pigs when compared to PC, B, and C fed pigs (Trt P = 0.0077). Creatine was lower in pigs fed A, and C when compared to pigs fed PC and B and levels in pigs fed NC were intermediary (Trt P = 0.0438). Treatment by day interactions were observed on sodium, albumin, phosphorous, and total protein. A distinctive response pattern across age was observed in albumin and total protein among pigs fed the NC diet when compared to pigs fed other treatments. In total protein, pigs fed the NC diet tended to decrease over time while total protein in pigs from other treatments increased from phase 1 to phase 3 (Figure 6, Trt × day P = 0.0973). Albumin was reduced in pigs fed the NC diet from phase 1 to 2, while albumin in pigs from other treatments was reduced in phase 1 but increased during later phases (Figure 7, Trt × day P = 0.0422). Pigs fed A also exerted specific patterns in serum sodium and phosphorus across age. Sodium and phosphorous decreased moderately from weaning to phase 1, this decrease was evident through phase 2 in pigs fed A. The magnitude of increase was less from phase 1 to 2 in pigs fed A than pigs fed other treatments (Figure 3 and 4, Trt × day P = 0.01 and 0.0898, respectively).

Circulating complete blood cell counts are presented in Tables 17 (day) and 18 (treatment). Age associated responses were observed in most traits except absolute count of eosinophil (day P = 0.326), basophil (day P = 0.107), and the percentage of basophil over total white blood cells (day P = 0.211). Absolute count of neutrophils decreased from weaning (d 0) to phase 3 (d 42), whereas absolute lymphocyte and monocyte counts increased from weaning and peaked at phase 2 (d 28), and phase 1 (d 14). Similarly, the percentage of neutrophils decreased from 59.42% at weaning to 42.05% at phase 2 (d 28), while the percentage of lymphocytes and monocytes increased and peaked at 51.11% in phase 2 (day $P < 0.001$) and 3.71% in phase 1 (day $P < 0.001$), respectively. Hence, total white blood cells were similar in weaning and phase 1 but were reduced from phase 2 onward (day $P < 0.001$). For red blood cell (RBC) characteristics, RBC, and hematocrit increased from weaning to phase 1, and while hematocrit remained steady through phase 3 (day $P < 0.001$), RBC decreased moderately from phase 1 to 2 and was similar in phase 3 (day $P < 0.001$). Hemoglobin deceased from weaning to phase 2, and level was restored to phase 1 levels at phase 3 (day $P = 0.036$). MCV (day $P < 0.001$), MCH (day $P < 0.001$), and MCHC (day $P < 0.001$) decreased from weaning to phase 1 and then continued to increase through phase 3.

Absolute lymphocyte counts were higher in PC and NC fed pigs when compared to pigs fed A and B and counts in pigs fed C was intermediary (Table 18, Trt $P = 0.0017$). The results of percentage of lymphocyte mirror absolute lymphocyte count with pigs fed PC and NC having higher percentage of lymphocyte than pigs fed A and B and counts in with pigs fed C was intermediary (Trt $P < 0.001$). Pigs fed B and PC tended to have higher percentage of hematocrit when compared to pigs fed C (Trt $P = 0.0712$). MCV was higher in pigs fed B when compared to pigs fed A, C and NC (Trt $P = 0.0499$). MPV was lower in pigs fed the

NC when compared to pigs fed A and PC (Trt P = 0.0284). Platelet to lymphocyte ratio was higher in pigs fed B when compared to pigs fed PC, NC, and C(Trt P = 0.02). Day by treatment interaction effects were observed for percentage of eosinophils (Figure 10), hemoglobin level (Figure 11), MCH (Figure 12), and percentage of RDW (Figure 13). Percentage of eosinophils elevated rapidly from phase 1 to phase 2 and remained at the elevated level throughout the study in pigs fed PC when compared to other treatments (Figure 10,day by treatment, P = 0.0397). After a reduction in hemoglobin from weaning to phase 1, pigs fed PC responded with increasing hemoglobin levels from phase 1 to phase 3 while hemoglobin levels in pigs fed other treatments tended to decline by d 28 and 42 (Figure 10, day by treatment P = 0.0194). MCH and percentage of RDW responses over time in pigs fed A were distinguished (Figures 12 and 13, respectively). MCH and percentage of RDW decreased from weaning to phase 1. While the MCH levels for all treatments tended to decrease in phase 1, pigs fed A continued to have lower levels until phase 2 before responding with increased levels during phase 3. The percentage of RDW was gradually reduced from phase 1 levels during phase 2 in all treatment groups, however, pigs fed A continued to decline through study completion while levels of RDW in pigs fed other treatments tended to stabilize (Figure 13, day by treatment P = 0.0215). Pigs fed PC and NC which contained carrier alone had similar level of absolute lymphocyte, percentage of lymphocyte, neutrophil, and platelet:lymphocyte ratio, while sensory additives particularly, A and B modulated the levels of these measurements. In addition, for those pigs fed diets contained phosphoric acid (PC, A, B, and C) serum albumin and total protein were altered when compared to NC. Pigs fed A exerted a specific patterns on serum sodium, phosphorous, MCH and percentage of RDW and feeding this diet resulted in the poorest growth performance in the overall study. Moreover, serum calcium concentration appears to correspond with weight gain and BW.

Discussion

The results demonstrated that supplementing nursery pigs with the sensory additives showed no statistical differences in ADG, BW, FE. Feed intake was numerically greater for the PC during wk 1 but not during the remaining trial. This resulted in 0.01 g per day higher intake and 0.48 kg heavier pigs at the end of nursery than NC fed pigs. This suggests that PC alleviated dietary stresses (toxins or oxidation) levels during early weaning (wk 1), and lead to a numerically heavier end BW as the differences in BW between PC and NC remained consistent throughout the trial after Wk 1.

Previous studies have demonstrated that increasing the palatability of nursery feed rations can help facilitate the initiation of feed at weaning and limit anorexia during this time period (Solà-Oriol et al., 2007). Furthermore, some studies hypothesize that pigs that are heavier at weaning can be predicted to exit the nursery with a heavier body weight. However, some of the heaviest pigs do not maintain the body weight advantage throughout the nursery phase (de Grau et al., 2005). According to other studies piglet weight gains can be highly variable in the first and, more subtly, the second week post farrowing. During the first week, for example, some piglets will more than double their birth weight, while others will gain only minute amounts. These early gains are virtually uncorrelated with the piglet’s birth weight. However, in the latter weeks of lactation piglet’s rate of gain becomes more closely related with their body weight during that time (Thompson and Fraser, 1988). In our findings we were able to see that the piglets that entered the nursery with a heavier BW were able to maintain this BW advantage throughout the duration of the nursery period. This could be because they might not have adapted to solid feed as well or quickly than the average body weight pigs.

The variation in feed intake during wk 1 could be correlated with the drastic change in environment compounded with the challenge of transitioning to feed. Studies have hypothesized that lower feed consumption in the post-weaning phase and consequent hindered growth can impede performance and have negative effects on the pig’s metabolism and health status. The change in the pig’s environment at weaning such as diet type, waterers, etc. imposes a big challenge to the newly weaned pigs, especially when relating this back to voluntary feed intake (Laskoski et al., 2019). The results suggest that Sensory additive C tends to promote intake and weight gain especially during the late nursery period, which suggests that inclusion rate of C in early nursery should be designed based on the intake level of each station to optimize the potential benefit in nursery pigs.

Conclusion

Supplementing Luctacid HC and Luctanox 5888 alone or together with sensory additive C may improve the growth performance of nursey pigs.

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Appendix

Table 11. Nursery phase 1 diets composition (As fed)

	A	B	C	NC	PC
Ingredients					
Corn, Yellow Dent	51.693	51.693	51.693	51.808	51.693
Soybean meal, 48%	22.25	22.25	22.25	22.25	22.25
Fat (Darling, Yellow Grease)	1.75	1.75	1.75	1.75	1.75
Monocalcium P	1.12	1.12	1.12	1.3	1.12
Limestone	0.125	0.125	0.125	0.0425	0.125
Salt	0.6	0.6	0.6	0.6	0.6
Trace Mineral Premix (NB-8534)	0.15	0.15	0.15	0.15	0.15
Vitamin Premix (NB-6508)	0.25	0.25	0.25	0.25	0.25
Choline chloride 60%	0.045	0.045	0.045	0.045	0.045
Calcium carbonate	0.8	0.8	0.8	0.8	0.8
Milk, Whey Powder	10	10	10	10	10
Carrier_5793	0	0	0	0.1	0.1
A	0.1	0	0	0	0
B	0	0.1	0	0	0
C	0	0	0.1	0	0
Luctacid HC 40667Z	0.2	0.2	0.2	0	0.2
Soycomil-P_ADM	3.45	3.45	3.45	3.45	3.45
Lactose	3	3	3	3	3
Luctanox 5888	0.0125	0.0125	0.0125	0	0.0125
Ronozyme HiPhos 2700 (GT)	0.015	0.015	0.015	0.015	0.015
Hamlet 300	3.5	3.5	3.5	3.5	3.5
Total	100	100	100	100	100

Feed grade amino acids were added to meet the requirement suggested by NRC (2012)

The vitamin premix provided the following per kg of complete diet: 397.5 mg of Ca as CaCO3, 11,022.9 IU of vitamin A, 1,377.9 IU of vitamin D3, 44.09 IU of vitamin E, 0.0386 mg vitamin B12, 4.41 mg of menadione, 8.27 mg of riboflavin, 27.56 mg of D-pantothenic acid, and 49.6 mg of niacin. The mineral premix provided the following per kg of complete diet: 84 mg of Ca as $CaCO_3$, 165 mg of Fe as $FeSO_4$, 165 mg of Zn as $ZnSO_4$, 39.6 mg of Mn as $MnSO_4$, 16.5 mg of Cu as $CuSO_4$, 0.3 mg of I as CaI_2, and 0.3 mg of Se as $Na2SeO_3$.

Table 12. Nursery phase 2 diets composition (As fed)

	A	B	C	NC	PC
Ingredients					
Corn, Yellow Dent	54.1025	54.1025	54.1025	54.19	54.1025
Soybean meal, 48%	25	25	25	25	25
Corn DDGS, >6 and <9% Oil	5	5	5	5	5
Fat (Darling, Yellow Grease)	1.4	1.4	1.4	1.4	1.4
Monocalcium P	0.52	0.52	0.52	0.655	0.52
Limestone	0.105	0.105	0.105	0.045	0.105
Salt	0.6	0.6	0.6	0.6	0.6
Trace Mineral Premix (NB-8534)	0.15	0.15	0.15	0.15	0.15
Vitamin Premix (NB-6508)	0.25	0.25	0.25	0.25	0.25
Calcium carbonate	0.89	0.89	0.89	0.89	0.89
Milk, Whey Powder	5	5	5	5	5
Carrier_5793	0	0	0	0.1	0.1
A	0.1	0	0	0	0
B	0	0.1	0	0	0
C	0	0	0.1	0	0
Luctacid HC 40667Z	0.15	0.15	0.15	0	0.15
Soycomil-P_ADM	1.5	1.5	1.5	1.5	1.5
Lactose	1.5	1.5	1.5	1.5	1.5
Luctanox 5888	0.0125	0.0125	0.0125	0	0.0125
Ronozyme HiPhos 2700 (GT)	0.015	0.015	0.015	0.015	0.015
Hamlet 300	2.75	2.75	2.75	2.75	2.75
Total	100	100	100	100	100

Feed grade amino acids were added to meet the requirement suggested by NRC (2012)

The vitamin premix provided the following per kg of complete diet: 397.5 mg of Ca as CaCO3, 11,022.9 IU of vitamin A, 1,377.9 IU of vitamin D3, 44.09 IU of vitamin E, 0.0386 mg vitamin B12, 4.41 mg of menadione, 8.27 mg of riboflavin, 27.56 mg of D-pantothenic acid, and 49.6 mg of niacin. The mineral premix provided the following per kg of complete diet: 84 mg of Ca as CaCO3, 165 mg of Fe as FeSO4, 165 mg of Zn as ZnSO4, 39.6 mg of Mn as MnSO4, 16.5 mg of Cu as CuSO4, 0.3 mg of I as CaI2, and 0.3 mg of Se as Na2SeO3.

Table 13. Nursery phase 3 diets composition (As fed)

	A	B	C	NC	PC
Ingredients					
Corn, Yellow Dent	56.1705	56.1705	56.1705	56.233	56.1705
Soybean meal, 48%	26.5	26.5	26.5	26.5	26.5
Corn DDGS, >6 and <9% Oil	12.5	12.5	12.5	12.5	12.5
Fat (Darling, Yellow Grease)	1	1	1	1	1
Monocalcium P	0.65	0.65	0.65	0.74	0.65
Salt	0.54	0.54	0.54	0.54	0.54
Trace Mineral Premix (NB-8534)	0.15	0.15	0.15	0.15	0.15
Vitamin Premix (NB-6508)	0.25	0.25	0.25	0.25	0.25
Calcium carbonate	1.025	1.025	1.025	0.985	1.025
Carrier_5793	0	0	0	0.1	0.1
A	0.1	0	0	0	0
B	0	0.1	0	0	0
C	0	0	0.1	0	0
Luctacid HC 40667Z	0.1	0.1	0.1	0	0.1
Luctanox 5888	0.0125	0.0125	0.0125	0	0.0125
Ronozyme HiPhos 2700 (GT)	0.015	0.015	0.015	0.015	0.015
Total	100	100	100	100	100

Feed grade amino acids were added to meet the requirement suggested by NRC (2012)

The vitamin premix provided the following per kg of complete diet: 397.5 mg of Ca as CaCO3, 11,022.9 IU of vitamin A, 1,377.9 IU of vitamin D3, 44.09 IU of vitamin E, 0.0386 mg vitamin B12, 4.41 mg of menadione, 8.27 mg of riboflavin, 27.56 mg of D-pantothenic acid, and 49.6 mg of niacin. The mineral premix provided the following per kg of complete diet: 84 mg of Ca as CaCO3, 165 mg of Fe as FeSO4, 165 mg of Zn as ZnSO4, 39.6 mg of Mn as MnSO4, 16.5 mg of Cu as CuSO4, 0.3 mg of I as CaI2, and 0.3 mg of Se as Na2SeO3.

Table 14. Effect of sensory additives on BW and ADG in nursery pigs (LSmeans)

							P - Value
	A	B	C	NC	PC	SEM	Trt
BW, kg							
Initial	5.39	5.41	5.40	5.39	5.40	0.19	0.9128
Wk1	5.75	5.93	5.87	5.75	5.92	0.18	0.1176
Wk2 (phase1)	6.33	6.48	6.46	6.35	6.57	0.22	0.3074
Wk3	7.95^{x}	8.34^{xy}	8.53^{y}	8.41^{y}	8.49^{y}	0.31	0.0935
Wk4 (phase2)	10.42^{x}	11.13^{xy}	11.45^{y}	11.14^{xy}	11.30^{y}	0.45	0.1058
Wk6 (end)	17.54	18.51	19.09	18.33	18.81	0.65	0.1448
ADG, kg/d							
Wk1	0.045	0.065	0.058	0.045	0.065	0.008	0.1978
Wk2	0.116	0.109	0.115	0.119	0.130	0.015	0.7694
Wk3	0.232^{a}	0.267^{ab}	0.295^{b}	0.295^{b}	0.275^{b}	0.017	0.0131
Wk4	0.353	0.398	0.418	0.390	0.400	0.026	0.3016
Wk5-6 (end)	0.548	0.568	0.588	0.553	0.575	0.020	0.4254
Wk1-2 (phase1)	0.072	0.082	0.082	0.074	0.090	0.008	0.3541
Wk3-4 (phase2)	0.293^{x}	0.333^{xy}	0.356^{y}	0.343^{y}	0.338^{y}	0.019	0.0633
Wk 4-6	0.240	0.254	0.264	0.248	0.257	0.010	0.2785
Wk1-6 (Overall)	0.304	0.328	0.342	0.323	0.335	0.014	0.1419

$^{a.b.c.}$ LSmeans with different superscript differ significantly at $P \le 0.05$.

$^{x.y.z.}$ LSmeans with different superscript tend to be differ at $0.05 < P \le 0.10$

Table 15. Effect of sensory additives on ADFI and gain to feed ratio in nursery pigs (LSmeans)

							P - Value
	A	B	C	NC	PC	SEM	Trt
ADFI, kg/d							
Wk1	0.105^{x}	0.130^{y}	0.119^{xy}	0.111^{x}	0.122^{xy}	0.007	0.1022
Wk2	0.195	0.200	0.199	0.202	0.199	0.012	0.9939
Wk3	0.326^{a}	0.390^{b}	0.371^{b}	0.379^{b}	0.370^{b}	0.017	0.0093
Wk4	0.453^{a}	0.566^{b}	0.572^{b}	0.542^{b}	0.535^{b}	0.029	0.003
Wk5-6 (end)	0.750	0.805	0.831	0.749	0.781	0.031	0.1714
Wk1-2 (phase1)	0.140	0.157	0.150	0.146	0.151	0.007	0.5508
Wk3-4 (phase2)	0.390^{a}	0.478^{b}	0.472^{b}	0.460^{b}	0.453^{b}	0.022	0.0016
Wk 4-6	0.646^{a}	0.722^{b}	0.740^{b}	0.676^{ab}	0.695^{ab}	0.029	0.0589
Wk1-6 (Overall)	0.426^{a}	0.480^{b}	0.484^{b}	0.452^{ab}	0.462^{ab}	0.018	0.0367
G:F							
Wk1	0.385	0.494	0.469	0.403	0.527	0.054	0.2468
Wk2	0.573	0.540	0.567	0.594	0.644	0.062	0.6279
Wk3	0.699^{xy}	0.691^{x}	0.796^{z}	0.782^{yz}	0.743^{xy}	0.031	0.059
Wk4	0.769	0.712	0.730	0.718	0.746	0.022	0.3823
Wk5-6 (end)	0.732	0.708	0.712	0.737	0.737	0.015	0.4524
Wk1-2 (phase1)	0.503	0.518	0.524	0.507	0.588	0.035	0.1898
Wk3-4 (phase2)	0.741	0.699	0.756	0.744	0.744	0.019	0.3009
Wk 4-6	0.742	0.709	0.717	0.732	0.740	0.014	0.4101
Wk1-6 (Overall)	0.712	0.685	0.708	0.714	0.724	0.013	0.306

$^{a.b.c.}$ LSmeans with different superscript differ significantly at $P \leq 0.05$.

$^{x.y.z.}$ LSmeans with different superscript tend to be differ at $0.05 < P \leq 0.10$.

Table 16. Effect of age on serum chemistry profile in nursery pigs (LSmeans)

	day					
	0	14	28	42	SEM	day
Alkaline phosphatase	710.30^{d}	234.04^{a}	399.16^{c}	291.98^{b}	20.59	<0.0001
Alanine transaminase	35.11	35.51	37.02	36.11	1.00	0.3367
Aspartate transaminase	49.43^{b}	36.13^{a}	51.23^{b}	45.03^{b}	2.51	<0.0001
AlGlo[1]	1.56^{b}	1.37^{a}	1.39^{a}	1.89^{c}	0.05	<0.0001
Albumin	2.85^{b}	2.68^{a}	2.82^{b}	3.26^{c}	0.05	<0.0001
Blood urea nitrogen (BUN)	7.35^{a}	10.60^{c}	8.69^{ab}	9.22^{bc}	0.50	<0.0001
BUN/Creatine	7.89^{a}	11.74^{c}	9.72^{b}	12.15^{c}	0.60	<0.0001
Creatine kinase	770.90^{b}	392.47^{a}	738.44^{b}	1115.78^{c}	75.03	<0.0001
Chloride	102.54^{b}	101.67^{a}	102.18^{ab}	103.16^{c}	0.33	0.0023
Ca	10.47^{b}	10.09^{a}	11.11^{c}	10.67^{b}	0.10	<0.0001
Cholesterol	213.19^{c}	60.06^{a}	65.68^{b}	66.50^{b}	5.10	<0.0001
Creatine	0.96^{c}	0.90^{b}	0.89^{b}	0.78^{a}	0.02	<0.0001
γ-glutamyl transferase	69.84^{b}	61.58^{a}	69.24^{b}	68.98^{b}	2.50	<0.0001
Globulin	1.90^{a}	2.03^{b}	2.09^{b}	1.79^{a}	0.05	<0.0001
K	4.57^{a}	5.28^{b}	5.28^{b}	5.91^{c}	0.11	<0.0001
Na	138.41^{a}	137.73^{a}	141.89^{b}	141.44^{b}	0.34	<0.0001
Osmolality	275.90^{a}	275.07^{a}	282.51^{b}	276.24^{ab}	2.08	<0.0001
P	9.35^{c}	7.74^{a}	8.51^{b}	9.85^{d}	0.14	<0.0001
Total Bilirubin	0.51^{c}	0.08^{a}	0.15^{b}	0.16^{b}	0.01	<0.0001
Triglyceride	65.60^{c}	43.11^{a}	53.80^{b}	58.11^{bc}	3.43	<0.0001
Total protein	4.74^{a}	4.71^{a}	4.92^{b}	5.05^{c}	0.06	<0.0001
Amylase	1418^{b}	1275^{a}	1927^{d}	1830^{c}	93	<0.0001
Anion Gap	19.48	19.21	20.17	18.87	0.49	0.4218
Glucose	122.60^{b}	110.56^{a}	117.04^{b}	120.38^{b}	2.41	<0.0001
TCO_2	20.98^{a}	22.20^{b}	24.82^{c}	25.38^{c}	0.44	<0.0001

1. Albumin/Globulin ratio

Table 17. *Effect of sensory additives on serum chemistry profile in nursery pigs (LSmeans)*

								P - Value	
	Units	A	B	C	NC	PC	SEM	Trt	Trt*day
Alkaline phosphatase	IU/L	390.8	458.1	361.8	420.8	412.6	28.6	0.163	0.315
Alanine transaminase	IU/L	37.94	35.42	35.44	35.61	35.28	1.51	0.690	0.581
Aspartate transaminase	IU/L	47.78	45.71	45.11	44.34	44.32	3.58	0.955	0.984
Albumin	g/dL	2.76	3.00	2.91	2.91	2.94	0.07	0.148	0.042
Blood urea nitrogen (BUN)	mg/dL	8.94	8.92	8.28	9.80	8.89	0.64	0.591	0.673
BUN/Creatinine		10.70	9.92	10.34	11.29	9.62	0.80	0.616	0.574
Creatine kinase	IU/L	664.6	808.4	693.4	724.2	881.1	88.4	0.376	0.635
Chloride	mEq/L	102.0	102.8	102.1	102.4	102.4	0.35	0.359	0.669
Ca	mg/dL	10.29	10.73	10.69	10.48	10.73	0.11	0.007	0.546
Cholesterol	mg/dL	99.62	104.2	103.2	110.7	88.87	9.10	0.535	0.543
Creatine	mg/dL	0.84	0.93	0.83	0.89	0.93	0.03	0.043	0.133
K	mEq/L	5.24	5.11	5.25	5.52	5.18	0.15	0.394	0.630
Na	mEq/L	139.3	140.3	139.2	139.8	140.5	0.46	0.17	0.01
P	mg/dL	8.61	8.84	8.84	8.90	9.14	0.20	0.452	0.089
Total Bilirubin	mg/dL	0.23	0.21	0.21	0.24	0.24	0.02	0.713	0.308
Triglyceride	mg/dL	47.69	53.50	57.89	59.36	57.33	4.76	0.423	0.445
Total protein	g/dL	4.85	4.85	4.82	4.83	4.91	0.08	0.918	0.097
Amylase	IU/L	1792	1688	1240	1753	1589	199	0.293	0.498
Anion Gap	mEq/L	18.73	20.05	19.16	19.49	19.75	0.62	0.588	0.377
Glucose	mg/dL	113.3	118.3	116.3	120.5	119.6	3.38	0.525	0.784
TCO_2	mEq/L	23.67	22.64	23.42	23.33	23.67	0.57	0.706	0.861

Table 18. Effect of age on circulating complete blood cell counts in nursery pigs (LSmeans)[*]

	day					
	0	14	28	42	SEM	day
Concentration, k/μl						
WBC	19.62^{bc}	20.81^{c}	19.01^{b}	16.27^{a}	0.75	<0.0001
Neutrophil (NEN)	11.84^{b}	11.12^{b}	8.04^{a}	7.55^{a}	0.56	<0.0001
Lymphocyte (LYN)	7.29^{a}	8.30^{b}	9.69^{c}	7.56^{ab}	0.34	<0.0001
Monocyte (MON)	0.46^{ab}	0.76^{c}	0.60^{b}	0.42^{a}	0.06	<0.0001
Eosinophil (EON)		0.56	0.64	0.70	0.11	0.326
Basophil (BAN)		0.06	0.04	0.04	0.01	0.107
NE/LY	1.81^{c}	1.47^{c}	0.87^{a}	1.07^{b}	0.09	<0.0001
MO/LY	0.06^{a}	0.10^{b}	0.06^{a}	0.06^{a}	0.01	0.008
% over WBC						
Neutrophil (NEP)	59.42^{d}	52.96^{c}	42.05^{a}	46.65^{b}	1.65	<0.0001
Lymphocyte (LYP)	38.36^{a}	40.55^{a}	51.11^{b}	46.17^{b}	1.61	<0.0001
Monocyte (MOP)	2.39^{a}	3.71^{b}	3.23^{b}	2.55^{a}	0.33	<0.0001
Eosinophil (EOP)		2.49^{a}	3.39^{b}	4.35^{c}	0.46	0.001
Basophil (BAP)		0.27	0.20	0.25	0.04	0.211
RBC, M/μl	5.98^{a}	6.97^{c}	6.67^{b}	6.59^{b}	0.10	<0.0001
Hemoglobin, g/dL	10.94^{b}	10.58^{ab}	10.27^{a}	10.57^{ab}	0.16	0.036
Hematocrit, %	35.32^{a}	40.11^{b}	39.62^{b}	40.26^{b}	0.64	<0.0001
MCV	59.37^{b}	57.64^{a}	59.47^{b}	61.12^{c}	0.72	<0.0001
MCH, Pg	18.37^{c}	15.27^{a}	15.46^{a}	16.05^{b}	0.21	<0.0001
MCHC, g/dL	30.88^{c}	26.48^{b}	25.95^{a}	26.33^{b}	0.16	<0.0001
RDW, %		26.62^{c}	24.02^{b}	22.97^{a}	0.41	<0.0001
PLT, k/μl		635.2^{c}	526.3^{b}	483.9^{a}	20.4	<0.0001
MPV, fL		9.44^{a}	9.90^{b}	10.04^{b}	0.19	<0.0001
PLT/LYM		83.71^{c}	57.69^{a}	67.57^{b}	3.63	<0.0001
MPV/PLT		0.017^{a}	0.019^{a}	0.022^{b}	0.001	0.006

Mean corpuscular volume: average of red cells
Mean corpuscular hemoglobin: hemoglobin amount per red blood cell
Mean corpuscular hemoglobin concentration: hemoglobin amount relative to size of hemoglobin per red blood cell
Red cell distribution width: calculation of variation in size of red blood cell
Platelet
Mean platelet volume: calculation average size of platelet
Neutrophil:Lymphocyte ratio
Monocyte:Lymphocyte ratio
Platelet:Lymphocyte ratio
MPV:Platelet ratio

[*] The CBC was assayed at service lab (AR Veterinary diagnostic laboratory) because of technique issue associated with automatic hematology analyzer in our lab. Therefore, some of reading are not available on d 0

Table 19. Proximate analysis of nursery phase 1diets (DM basis)

	NC	PC	A	B	C
Analysis					
DM, %	91.58	91.64	91.84	91.85	91.88
ASH, %	4.91	5.15	4.44	4.97	5.13
NDF %	20.89	20.83	28.03	26.86	23.18
ADF %	3.64	3.14	3.25	3.40	3.45
N, %					
Energy, Kcal/kg	4256	4180	4258	4202	4255
Mineral, %					
P	0.913	0.849	0.929	0.992	0.837
K	1.436	1.359	1.414	1.373	1.479
Ca	1.051	1.215	1.015	1.251	1.174
Mg	0.200	0.176	0.202	0.196	0.189
S	0.340	0.313	0.289	0.304	0.319
Na	0.553	0.541	0.370	0.440	0.524
Fe	0.039	0.043	0.036	0.035	0.044
Mn	0.007	0.008	0.002	0.003	0.010
Zn	0.010	0.010	0.015	0.031	0.006
Cu	0.002	0.003	0.002	0.003	0.005
B	0.001	0.001	0.002	0.002	0.002

Table 20. Proximate analysis of nursery phase 2 diets (DM basis)

	NC	PC	A	B	C
Analysis					
DM, %	90.87	91.00	90.19	90.26	90.25
ASH, %	4.09	4.21	4.36	4.27	4.51
NDF %	23.31	27.53	18.34	14.93	15.64
ADF %	3.64	4.21	4.12	3.36	3.70
N, %					
Energy, Kcal/kg	4247	4247	4309	4327	4352
Mineral, %					
P	0.624	0.689	0.741	0.761	0.725
K	1.184	1.286	1.411	1.337	1.313
Ca	0.995	1.075	1.031	1.028	0.900
Mg	0.171	0.187	0.214	0.204	0.202
S	0.302	0.311	0.322	0.305	0.302
Na	0.437	0.491	0.345	0.324	0.360
Fe	0.035	0.035	0.027	0.033	0.027
Mn	0.002	0.007	0.004	0.018	0.005
Zn	0.020	0.010	0.025	0.028	0.022
Cu	0.003	0.003	0.003	0.002	0.003
B	0.001	0.001	0.002	0.002	0.002

Table 21. Proximate analysis of nursery phase 3 diets (DM basis)

	NC	PC	A	B	C
Analysis					
DM, %	90.29	90.20	91.22	91.12	91.30
ASH, %	5.13	4.48	4.09	4.32	4.31
NDF %	15.61	17.81	17.34	18.22	19.21
ADF %	3.48	5.30	4.13	4.16	4.10
N, %					
Energy, Kcal/kg	4418	4396	4401	4434	4377
Mineral, %					
P	0.767	0.828	0.838	0.848	0.817
K	1.231	1.317	1.257	1.244	1.259
Ca	0.960	1.218	0.801	0.961	1.012
Mg	0.217	0.234	0.227	0.222	0.216
S	0.300	0.336	0.314	0.339	0.308
Na	0.194	0.329	0.239	0.293	0.261
Fe	0.022	0.028	0.027	0.033	0.023
Mn	0.002	0.005	0.006	0.009	0.002
Zn	0.021	0.027	0.015	0.025	0.022
Cu	0.001	0.002	0.002	0.002	0.002
B	0.002	0.002	0.002	0.002	0.002

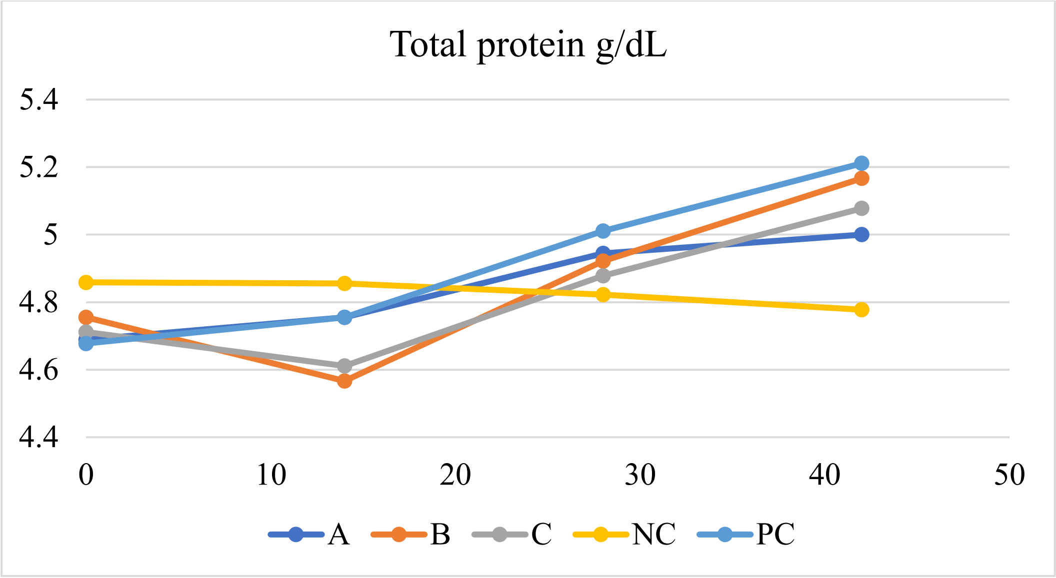

Figure 5. Treatment by day interaction effect of sensory additives on serum Total Protein in nursery pigs (LS means).

A significant treatment by day interaction was observed for serum Total Protein (P = 0.0973).

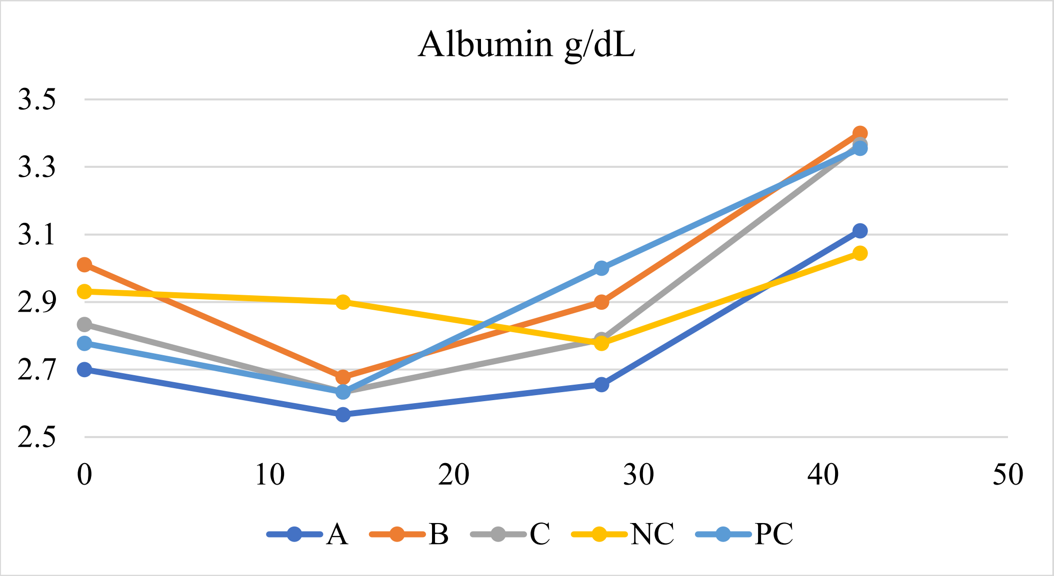

Figure 6. Treatment by day interaction effect of sensory additives on serum Albumin in nursery pigs (LS means).

A significant treatment by day interaction was observed for serum albumin (P = 0.0422).

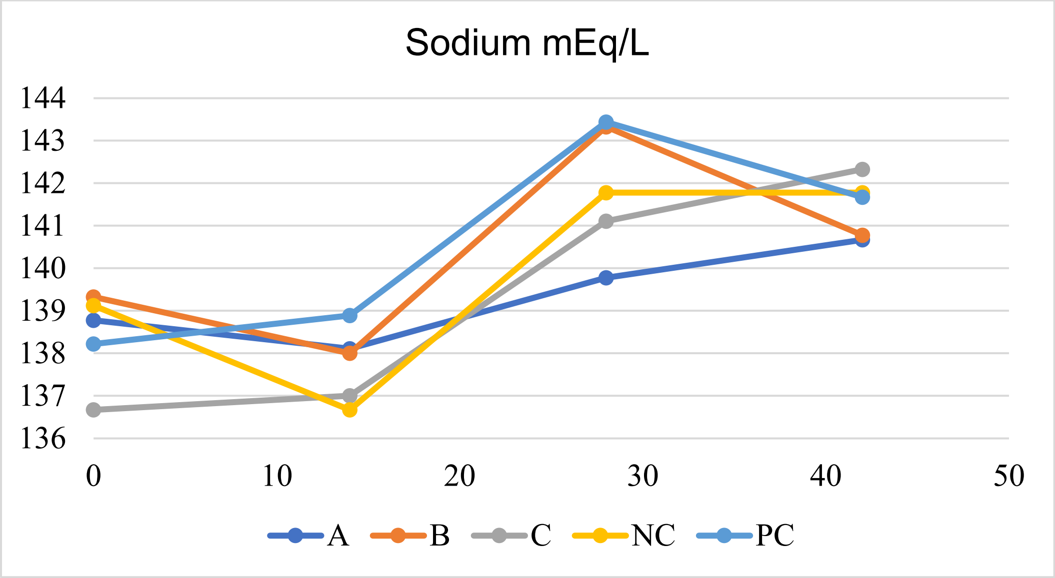

Figure 7. Treatment by day interaction effect of sensory additives on serum Sodium in nursery pigs (LS means).

A significant treatment by day interaction was observed on serum Sodium (P = 0.01).

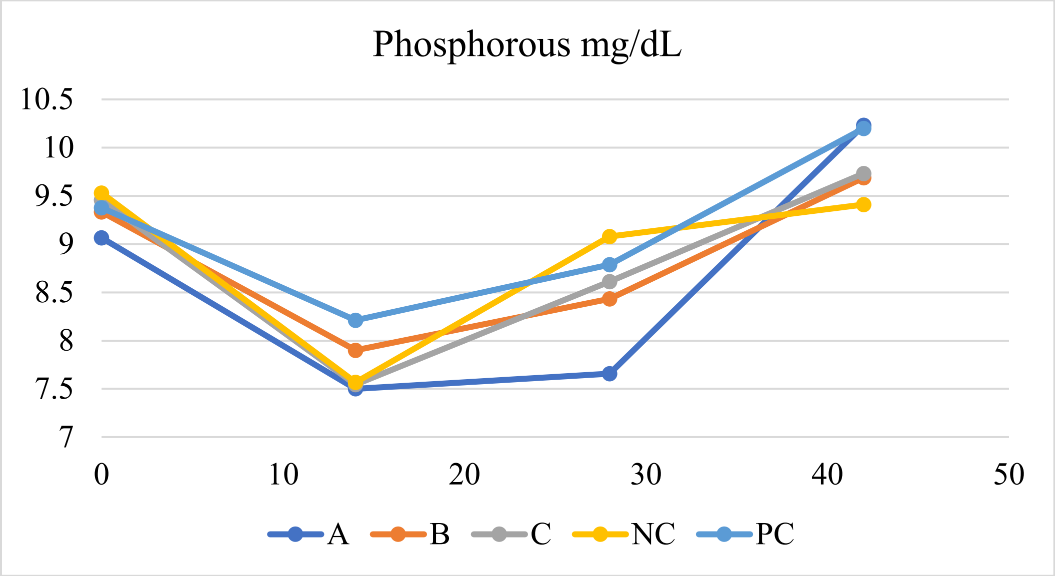

Figure 8. Treatment by day interaction effect of sensory additives on serum Phosphorous in nursery pigs (LS means).

A significant treatment by day interaction was observed on serum Phosphorous (P = 0.0898).

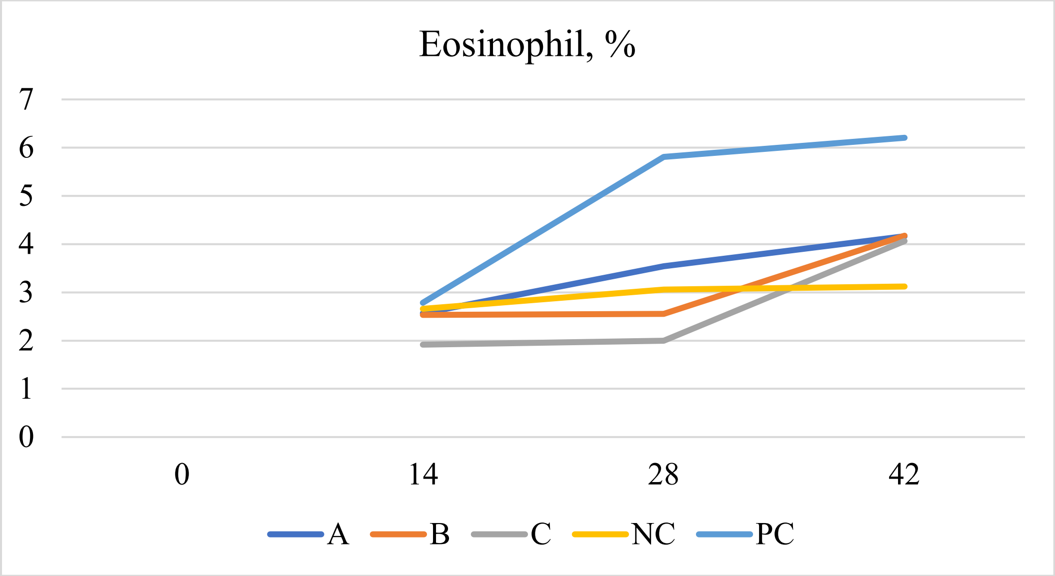

Figure 9. Treatment by day interaction effect of sensory additives on percentage of eosinophil in nursery pigs (LS means).

A significant treatment by day interaction was observed on percentage of eosinophil (P = 0.0397).

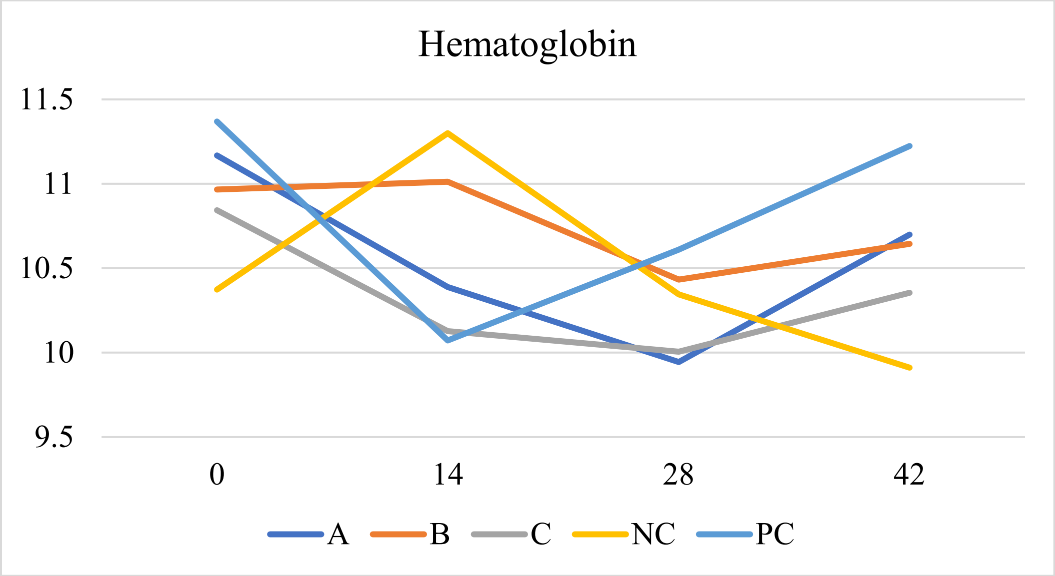

Figure 10. Treatment by day interaction effect of sensory additives on hemoglobin in nursery pigs (LS means).

A significant treatment by day interaction was observed on hemoglobin (P = 0.0218).

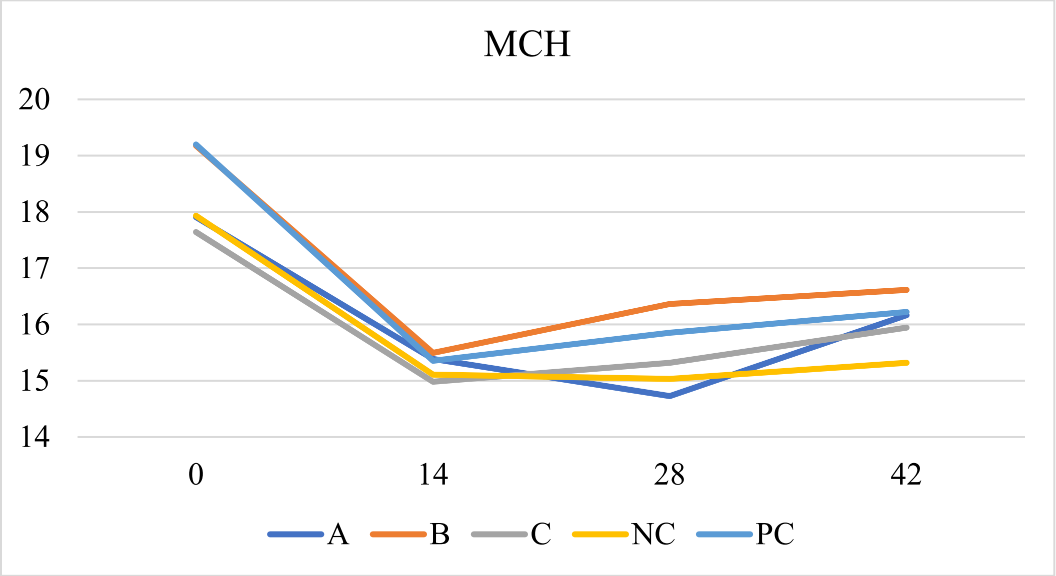

Figure 11. Treatment by day interaction effect of sensory additives on MCH in nursery pigs (LS means).

A significant treatment by day interaction was observed on MCH (P = 0.0194).

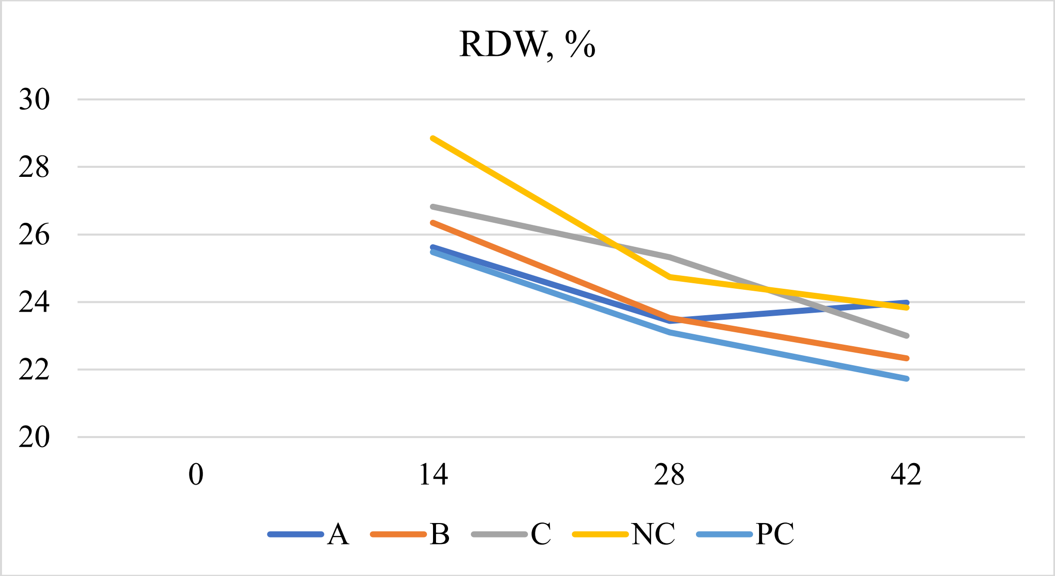

Figure 12. Treatment by day interaction effect of sensory additives on percentage of RDW in nursery pigs (LS means).

A significant treatment by day interaction was observed on the percentage of RDW (P = 0.0215).

Chapter 4 Conclusion

Sensory additives such as SowVive (Lucta, Barcelona, Spain) demonstrated in this study that they may increase sow intake during lactation during the summer months, but winter intake remained unaffected. The inclusion of certain sensory additives to nursery pig diets demonstrated in this study that piglets were able to show a slight increase in average daily feed intake.