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Production Performance of Young Pigs in Varying Ambient Temperature and Cold Stress Response and Management: A Review

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Review Article

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ABSTRACT

Younger pigs tend to be more sensitive to environmental stresses such as changes in temperature (cold stress) because of the failure of their body to thermo regulate properly. The weaning process is one of the most stressful events in the pig's life that can contribute to reduced pig growth, feed intake, and feed conversion efficiency. The review paper describes how temperature can impact subsequent production efficiencies such as average daily gain (ADG) and gain/feed (G/F) ratio as well as discuss cold stress adaptation, survival, and management methods in young pigs. The researchers also incorporate gathered swine experiment data and were classified according into two body weight stage: 0 to 10 kg and 10 to 20 kg BW. Extracted data of ADG (kg/day) and Gain/Feed ratio (kg/kg) were analyzed in response to ambient temperature. During the weaning stage, pig's digestive system was still developing and adjusting to the feed ration thus lower ADG was to be expected especially to the lower weight range pigs. Low feeding level elevates the newly-weaned pig's thermal requirements. In extreme cold temperatures, piglets survive by physical, physiological, and behavioral adaptation techniques until they regain thermo stability as they mature. Alternative methods like heating sow diet manipulation, and providing oxygen has been used to relieve cold stress. Nevertheless, high ambient temperature within the weaning pig's thermo neutral zone produces better ADG and G/F ratio in younger pigs. Understanding the basic concept of interaction between the animal and ambient temperature as well as the animal's adapting mechanism in times of stress can be a basis to further enhance swine productivity and modern cold stress alleviating strategies.

INTRODUCTION

Thermal environment has a strong influence on farm animals with air temperature having the primary effect, but altered by wind, precipitation, humidity, and radiation which is collectively described as ambient temperature [1]. In ad libitum fed animals, changes in metabolic heat production are essential mechanisms to maintain body temperature within a physiologically safe range under cold or heat stress. The adjustments made by the animal have direct consequences on energy intake and/or maintenance requirements which in turn could reduce energy efficiency as conversion of feed to tissue or other products [2].

The newborn pig has a very low capacity to conserve heat, being virtually hairless and devoid of subcutaneous fat [3]. Younger pigs tend to be more sensitive to environmental stresses (more often cold temperature) because of the inefficient capacity of their body to thermo regulate properly. Maintenance of a homoeothermic balance and establishment of early and regular nutrition are of utmost importance for the survival of the pigs [4]. But as body weight (BW) increases, the ability of the body to adapt to the environment was enhanced. Cold resistance is positively related to BW in that the higher the BW is the more resistant to cold the pig is [5,6]. This was also in conjunction with the study made by Schenk et al. [7] which claims that LCT and UCT decrease with increasing BW.

The focus of this review paper is to describe how environmental stress such as changes in ambient temperature on varying

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body weight stages of young pigs (0-10 kg and 10-20 kg) can impact production efficiencies such as growth rate and feed efficiency. Also, it briefly discusses how response to cold stress and some management methods pig.

Zone of Thermo Neutrality

Thermal environment has direct effects on the pigs' energy expenditure and voluntary intake and therefore on its production performance. Hence, interest lies in determining the range of ambient temperatures over which heat loss from the animal is minimal with subsequent maximum energy retention [4]. As defined by the NRC [1], the thermo neutral zone (TNZ) is where body temperature remains normal and the animal does not pant or sweat, and its heat production remains at a basal level. According to studies made by Heitman et al. [8] and Holmes and Close [9], the thermo neutral zone for the pig depends on size, level of feed intake, and wind velocity. Pig has an upper critical temperature (UCT) and lower critical temperature (LCT) bounding the thermo neutral zone. As BW increases, both UCT and LCT decreases and increases, respectively. Pig subjected above UCT and below LCT produces significant consequences in the animal, and sometimes causes death.

Generally, optimum temperature decreases as pig BW increases. In young pigs, zone of thermo neutrality was observed to be located on higher temperature ranges **(Table 1)**. As shown, desirable limits gradually decrease as pigs mature or gain weight. The rate of body fat mobilization depends on the level of food intake and its protein content, and on the environmental temperature [10].

Table 1. Optimal temperature ranges for housed young pigs from various authors.

Animal (BW, kg)	Optimal Range (°C)	Reference/s
Prenursery (5-15)	27-32	
Nursery (15-35)	18-27	NRC [1]
Nursing piglet	32 up	
3-15	26-32	McGlone and Pond [11]
Suckling piglet (1-7)	30	Whittemore and Kyriazakis [12]
Litter-newborn	32-38	
Young pigs (2-5)	27-32	
Young pigs (5-20)	24-30	Myer and Bucklin [13]
Litter-newborn	32-35	
Litter-3 weeks old	24-29	
Nursery (5-14)	24-29	
Nursery (14-23)	21-27	
Nursery (23-34)	16-21	Zimmerman et al. [14]

Determination of the lower and upper critical limits of the zone of thermo neutrality is essential in determining the animal's maximum potential of energy utilization energy and optimal temperature for tissue deposition. Because temperature is affects production efficiencies, it is practical to fully know and implement the proper optimal temperatures of pig according to life stage.

Cold Stress in Young Pigs

Piglets at birth have poor body thermo stability, lack energy reserve, lacks hair coat and have a large surface area to body weight ratio which makes them particularly susceptible to cold stress [15]. In general, initial responses of animals to cold stress rely more on increasing metabolic heat production, but long-term exposure to cold gradually results in adaptive responses [1]. When piglets are subjected to cold stress, certain physiological and behavioral adjustments were made. Such adjustments were mobilization of glycogen reserves in the liver and skeletal muscles [16], reduction of locomotive vigor [17,18], and huddling [19,20]. In terms in productive performance, during times of cold stress VFI of animal increases to produce heat to compensate for the heat loss, meaning more feed was consumed by the animal **(Tables 2 and 3)**. Also, feeds that are supposed to be for gaining muscle tissues were used to produce heat. Consequently, feed efficiency was also compromised.

Table 2. Effect of cold stress on feed intake, growth, and feed conversion efficiencies in young pigs.

Temperature (°C)[a]	Average BW[b]	Performance Variable			%Change			Reference/s
		ADFI	ADG	FCE	ADFI	ADG	FCE	
23	16.6	777	495	0.64*				
12	16.9	946	510	0.54*	+21.8	+3.0	-15.6	Herpin et al. [21]
28	19.15	920	590	0.64*				
12	19.17	1140	580	0.51*	+23.9	-1.7	-20.3	Lefaucheur et al. [22]
26.7	9.3	498	426	0.85				
15.6	9.3	633	437	0.69	+27.1	+2.6	-18.8	Frank et al. [23]
26.05	14.91	971	641	0.66				
14.9	14.40	1003	634	0.63	+3.3	-1.1	-4.6	Kim et al. [24]

*Means data was calculated by the researchers from available data; a: Average temperature throughout the experiment; b: Average BW throughout the experiment

Susceptibility of young pigs to lower temperature became lesser as they mature. Thermal insulation and energy was provided through fat mobilization in the body. Also gain in body mass is also evident as pigs consume more feeds. Thus, LCT reduction and lesser sensitivity to lower temperatures can be observed. Transition from suckling to weaning is a critical stage for pigs. Two weeks after weaning which is noted as the critical period, ambient temperature can be reduced by 2 to 3°C/week until the temperature needed for finisher pigs is reached [25].

Heat Stress in Young Pigs

The temperature inside the sow's uterus ranges from 38 to 40°C and after birth, newly born piglets' environment drops which ranges from 20 to 22°C [26]. Neonatal pigs are virtually hairless and devoid of subcutaneous fat [27]. Compared to adult pigs, younger pigs have fewer fat deposits. Subcutaneous fat (a good insulating material) provides thermal insulation in pigs. As pigs grow, fats are acquired by consumption of feeds. Therefore, younger pigs are more predisposed to cold stress rather than heat stress [28].

Table 3. Effect of heat stress on feed intake, growth, and feed conversion efficiencies in young pigs.

Temperature (°C)[a]	Average BW[b]	Performance Variable			%Change			
		ADFI	ADG	FCE	ADFI	ADG	FCE	References
26.6	8.57*	390	220	0.57				
32.2	8.43*	360	180	0.47	-7.7	-18.2	-17.5	McGlone et al. [29]
23	17.9	1710	667*	0.39*				
33	15.4	1380	505*	0.37*	-25.1	-24.3	-5.1	Collin et al. [30]
23	19.4	1117	914	0.82*				
33	19.8	837	751	0.90*	-25.1	-17.8	+9.8	Collin et al. [31]
26.05	14.91	971	641	0.66				
40.5	14.40	896	575	0.64	-7.7	-10.3	-3.0	Kim et al. [24]

* Means data was calculated by the researchers from available data; a Average temperature throughout the experiment; b Average BW throughout the experiment

Young Pigs

The transition from suckling to weaning causes simultaneous stressors to the pig. Such were separation from the sow and mixing of the litters, changes in housing and climatic environment and in diets which leads to critical period of underfeeding into reduced feed efficiency and growth rate [25]. Weaning itself affects performance as piglets are slow to develop normal feeding patterns [32] and consequently have a compromised feed intake [33,34]. A study from Le Dividich and Herpin [35] claims that temperature requirement of the weaning pig may be divided into two periods: (1) critical period of about 2 weeks following weaning and (2) post critical period. Critical period is the period wherein pigs are in a negative energy balance due to low feed intake but high physical activity due to new social group for 3 or 6 days following weaning [36]. The next period is the post critical period wherein regular feed intake is well established and diarrhea is no longer a problem [4].

0-10 kg BW

Around five studies on pigs with initial and final weight averaging from 0-10 kg were analyzed to determine the effect of temperature with the pig's ADG and Gain/Feed ratio **(Figure 1)**. The date of studies gathered ranges from year 1977 until 2003. As observed, not much study was made using pigs having the said average body weight range.

When pigs are weaned early, they sometimes lose weight or do not gain weight for the first week or two. The digestive tract of the young pig is immature and only partially functioning [37]. Limited gut size of younger pigs also contributes to their limited ability to increase fed intake or meet their nutrient intake requirements [38]. This is consistent to the gathered analyzed results from the different studies, having a slight increase in ADG when pigs were subjected to higher temperature **(Figure 2)**. This period can be associated to the critical period described in a study made by Le Dividich and Herpin [35], wherein weaned pigs have low feed intake with positive nitrogen balance [39,40]. This situation implies that the energy required for maintenance, protein synthesis, and physical activity results in a loss of fat, which becomes more severe if energy is required for thermoregulation [39,41]. Thus during this body weight stage, a lower ADG can be observed although G/F ratio remains unaffected **(Figure 1)**.

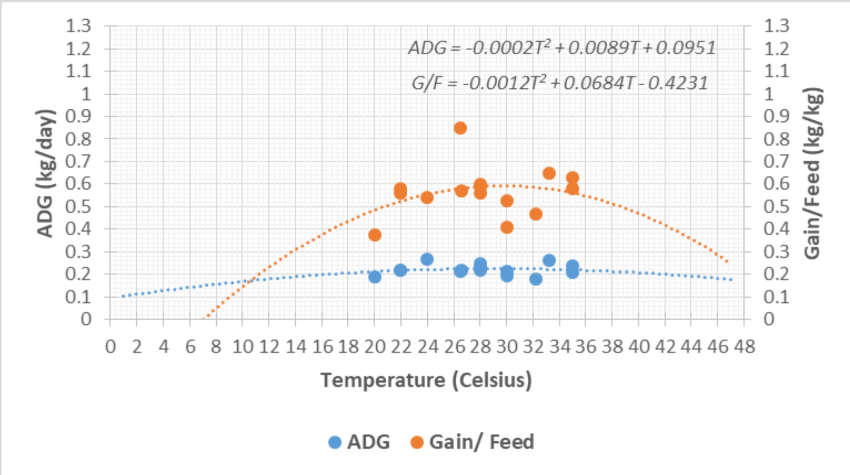

Figure 1. Effect of ambient temperature in ADG and Gain/Feed of 0-10 kg pigs with trendline (5 studies, 15 experiments).

G/F ratio may not only be attributed to temperature but to a lot of factors. Environmental factors such as temperature and humidity may affect digestion-absorption by indirect influence on appetite and feed intake [42]. Digestible energy (DE) intake of pigs can affect G/F ratio in pigs [43]. A more recent study made by Berrocoso et al. [44] claimed that inclusion of a soy protein concentrate (SPC) obtained by aqueous alcohol extraction improves apparent digestibility of most dietary components but does not result in increased growth performance. These results suggest that G/F ratio was also affected by the feed quality of the animal. However, placing weaning pigs on desirable ambient temperature (preferably high temperature environment) can optimize ADG as well as G/F ratio.

10-20 kg BW

As pig became heavier, the piglet's fat deposition increases causing improvement of piglet's thermal insulation which eventually decreases its susceptibility to cold stress. Thus, linear increase of growth rate and feed efficiency can also be associated as age increase which was observed in a study made by Main et al. [45]. This review paper extracted data from 23 experiments from 9 studies conducted from year 1987 to 2009 **(Figure 3)**. According to Myer and Bucklin [13], the optimum temperature requirement for young pigs having 5-20 kg BW falls around 24 to 30°C. Similar temperature range can be observed on **Figure 2**, however the figure shows more specific range in accordance with the animal's body weight. As shown, a marked increase in ADG was seen during this stage which can be associated to the post critical period in weaning as described by Le Dividich and Herpin [35]. Regular feed intake is established and weaned pig is able to compensate for a suboptimum environment by increasing its VFI [4].

Differences in gastrointestinal tract (GIT) structure and function may contribute to the poorer performance seen after weaning in light-for-age pigs [46]. The sudden increase of ADG in the 10-20 kg BW stage in comparison with the 0-10 kg BW stage can also be attributed to the enhanced digestive capability of the animals as days passed. Pluske et al. [47] reported that pigs born light-for-age and weaned at either 2 or 3 wk of age (3.46 and 5.51 kg, respectively) had a less developed GIT, with a post-weaning development that proceeded differently to that of pigs weaned heavier. Important changes in histology and morphology of GIT occur with age and weaning [48]. An increase in proteolytic activity in gastric and intestinal digesta within 6 days after weaning was observed in a study made by Efird et al. [49]. These results suggest that GIT capability increases with age, in which age is relevant with BW. And as BW increases temperature requirement decreases. Compared to lower body BW stage (0-10 kg), optimum temperatures in 10-20 kg BW stage decreases a few degrees consistent with weight.

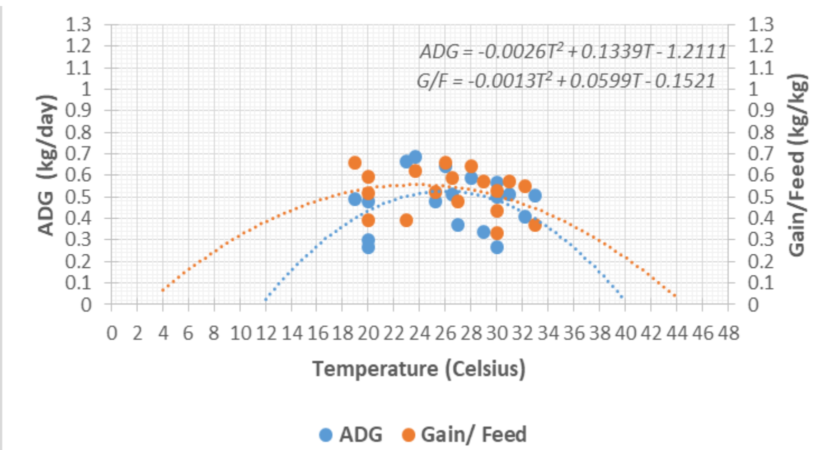

Figure 2. Effect of ambient temperature in ADG and Gain/Feed of 10-20 kg pigs with trendline (9 studies, 23 experiments).

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Postnatal to Weaning Phase: Cold Stress Survival, Adaptation, and Management

One of the most common underlying causes of mortality in young pigs is hypothermia, which is mainly caused by poor body insulation (low lipids/glycogen reserves) and poor thermoregulatory ability (lacks brown adipose tissue). These results to serious losses in the swine industry and thus methods in mitigating cold stress in young pigs were needed. Nowadays, still few studies were conducted regarding the thermoregulatory abilities of young pigs in cold conditions. This review paper will discuss how pigs at birth adapt from the cold environment until attaining thermo stability.

Being born as hairless and devoid of subcutaneous fat, the pig's environmental temperature suddenly drops by 15 to 20°C and eventually rises to 39°C within 48 hours [50,51]. The complex interaction between the environment, sow, and piglet determines the survival of the newborn pig. During this period, piglet mortality was inevitably high due to piglets crushed by sow, diseases, and starvation **(Figure 3)**. Increased thermostatic response was observed in hypothermic a piglet which increases probability of crushing by sow [52]. Low-birth-weight piglets were more at risk because of the inverse relation of body size with heat loss per unit of body weight [53]. Eventually, the piglet's vigor was compromised which leads lesser locomotion then to starvation. Depressed colostrum intake increases its susceptibility to immunological challenges which can sometimes lead to death.

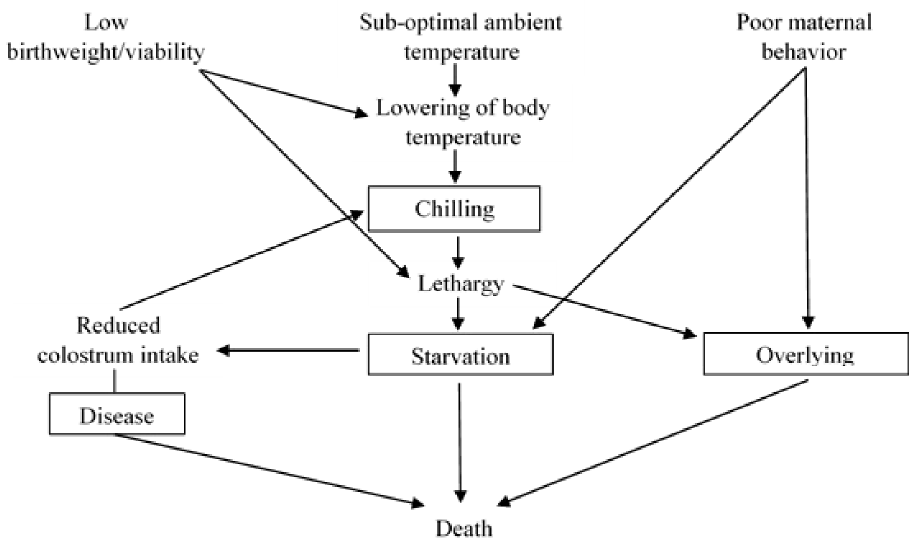

Figure 3. Interactive events occurring in the chilling-starvation-overlying disease complex (adapted from English and Morrison, Edwards et al.).

The relatively high TNZ of newborn piglet signifies their sensitivity to colder environment. Fortunately, the piglet's thermoregulatory ability to tolerate colder temperature increases rapidly with age. After 1 week, LCT declined rapidly from TNZ of about 34°C to approximately 25°C [54]. Improved thermo stability can be attributed to increased fat deposition, improved blood flow, and overall increased in body weight. Fat content gradually increases to nearly 15% from postnatal fat which averages 15 g/kg. Blood flow in hypothermic pigs were compromised as they tend to reduce blood flow to the periphery however, it improves with age. Moreover, overall body weight increase is positively related with age in pigs with fat and muscle accumulation.

Table 4. Thermoregulatory response of young pigs during cold stress.

Physical	Physiological	Behavioral
Piloerection	Reduced peripheral blood flow	Shivering
Vasoconstriction	Increased metabolic rate	Huddling
Increased muscle contraction	Increased glucose turnover rate	Thermotaxic response (Seeks warmth from the sow)

Young pigs elicit some various physical, physiological, and behavioral thermoregulatory response when subjected to c environment **(Table 4)**. These adaptive behaviors lead to the survival of neonates until they regain thermo stability. Within 2 days after birth, both LCT and summit metabolism temperature (SMT) declines which signifies that thermo stability improves markedly with age. These provided relieving effects in counteracting cold stress however; thermostatic response of the piglets can also lead to crushing of piglets which is a common cause of mortality and usually occur during the first 48 hr after farrowing.

Table 5. Influence of dietary fat sources on fat and energy output of sow milk (Lauridsen and Danielsen).

Daily Output	Control	Animal Fat	Rapeseed Oil	Fish Oil	Coconut Oil	Palm Oil	Sunflower Oil	S.E.	P-Value of Diet
Fat in Milk (kg)*	0.43[a]	0.60[b]	0.56[b]	0.44[a]	0.57[b]	0.55[b]	0.47[a]	0.05	0.043
Energy in Milk (MJ)*	30.2[a]	39.8[b]	38.2[b]	30.2[a]	37.4[ab]	36.8[ab]	32.2[a]	2.78	0.047

Some management techniques and precautionary measures were done to lessen the stress load of the animal from the environment. One of the common solutions is the installation of heaters however; the temperature does not fit well with the sow's required ambient temperature. Another method is thru diet manipulation by increasing the dietary fat of sow in late gestation and lactation [55]. Inclusion of fat sources into the sow's diet improves the performance of piglets by increasing the fat and energy output in the sow milk **(Table 5)** [56]. Inhalation of oxygen has been showed to reduce postnatal mortality by 75% caused by hypothermia [57-59]. Oxygen stimulates oxidative metabolism as well as improve pig viability and vigor which yields overall benefit in piglet survival to weaning.

CONCLUSIONS

Temperature plays a major role in animal production. A change of temperature outside the animal's zone of thermo neutrality produces physical, physiological and behavioral response in animals. In weaning pigs, higher temperatures were more preferred. Pigs at birth have inefficient ability to regulate body temperature and less body fat to act as insulation. Therefore, drastic effects on production efficiencies are more pronounced in younger pigs subjected to cold stress.

In this review paper, we have established that temperature affects production efficiencies in young pigs. Compensatory mechanisms by altering VFI have direct effect on ADG and feed efficiency. Critical periods such as change of diet from sow's milk to feeds are also relevant to the growth parameters. Although younger pigs tend to eat less than adult pigs, studies claim that better feed efficiency was observed when pigs are younger. One of the main reasons is that as pigs grow older, more feeds are required for maintenance and for gaining. Nutritional components such as protein were lowered as they mature to save on feed cost. Aside from temperature, it is also important to note other factors such as age and BW alters production parameters. At the start of weaning, sudden dietary change in diet lower feed efficiency. It is evident in younger pigs having lower BW range (0-10 kg). During this period, intestinal morphology is not yet fully developed and enzyme secretion is not yet at its full potential.

More than heat stress, cold stress greatly affects younger pigs than old pigs. The drastic temperature drop from the sow's womb at birth makes the newborn piglet more prone to hypothermia. This underlying cause may lead to losses due to crushing, starvation, and diseases. Fortunately, adaptation methods have been used by piglets to survive until they can regain thermoregulatory stability. Moreover, management techniques have been also used to lessen the animal's stress load.

Nonetheless, having the appropriate temperature range according to BW of young pigs is of great importance in determining its effect on production efficiencies such as ADG and G/F ratio. A curvilinear effect of temperature on production parameters (ADG and G/F ratio) was observed in both BW stages (0-10 kg and 10-20 kg) during weaning. Preferably, thermo neutral zone of young pigs fall on higher ambient temperature range. Wherein temperature requirement gradually decreases as BW increases.

List of Abbreviations

ADG	Average Daily Gain
G/F ratio	Gain to Feed Ratio
VFI	Voluntary Feed Intake
BW	Body weight
LCT	Lower critical temperature
UCT	Upper critical temperature
SMT	Summit metabolism temperature
TNZ	Thermo neutral zone

COMPETING INTERESTS

The authors declare that they have no competing interest.

AUTHORS CONTRIBUTIONS

All authors read and approved the final manuscript.

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