Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions

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[1]*Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2;* [2]*Prairie Swine Centre Inc., Saskatoon, Saskatchewan, Canada S7H 5N9; and* [3]*Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1 (e-mail: martin_nyachoti@umanitoba.ca).*
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Nyachoti, C. M., Zijlstra, R. T., de Lange, C. F. M. and Patience, J. F. 2004. **Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions.** Can. J. Anim. Sci. **84**: 549–566. The ability of pigs to consume sufficient nutrients for optimal performance is an important consideration in commercial pork production. Nutrient intake levels are directly related to voluntary feed intake. Voluntary feed intake in pigs is influenced by several factors including environmental conditions (e.g. thermal and social conditions), animal status (e.g., age and physiological status), and feed and feeding conditions (e.g. bulkiness of the feed and feed form). Although the individual effects of many of these factors on voluntary feed intake have been investigated and quantified, little has been done to characterize their interactive effects. Under commercial conditions, voluntary feed intake is clearly influenced by multiple factors at any one time. Thus, there is a need for a means to accurately quantify voluntary feed intake in pigs as affected by the different interacting factors. Until quantitative effects of these interactions are established it is suggested that feed intake be monitored. This can be achieved by obtaining feed intake on representative groups of pigs.

Key words: Voluntary feed intake, pigs, determining factors, prediction equations

Nyachoti, C. M., Zijlstra, R. T., de Lange, C. F. M. et Patience, J. F. 2004. **Ingestion volontaire chez les porcs en croissance-finition : récapitulation des principaux paramètres et des approches envisageables en vue de l'obtention de prévisions précises**. Can. J. Anim. Sci. **84**: 549–566. L'aptitude des porcs à consommer assez d'éléments nutritifs pour parvenir au meilleur rendement est un point important dont les éleveurs doivent tenir compte. La quantité d'éléments nutritifs absorbée dépend directement de l'ingestion volontaire des aliments. Or, chez le porc, ce comportement subit l'influence de plusieurs paramètres dont l'environnement (à savoir, chaleur et climat social), l'état de l'animal (son âge et sa physiologie), ainsi que l'aliment et les conditions de l'alimentation (concentration en fibres et présentation de la ration). Bien qu'on ait examiné et quantifié séparément l'incidence de bon nombre de ces paramètres sur l'ingestion volontaire d'aliments, on s'est relativement peu intéressé à leurs interactions. De toute évidence, dans un élevage commercial, l'ingestion volontaire d'aliments subit l'influence de maints facteurs simultanément. On a donc besoin d'une moyenne pour quantifier avec précision l'effet des facteurs qui interagissent sur l'ingestion. En attendant qu'on ait mesuré l'effet de telles interactions, on suggère de surveiller la consommation d'aliments en déterminant la quantité de nourriture qu'ingère un groupe de porcs représentatif.

Mots clés: Ingestion volontaire d'aliments, porcs, facteur déterminant, équation de prévision

The voluntary feed intake (VFI) of pigs determines nutrient intake levels and, therefore, has a significant impact on the efficiency of pork production. The intensive selection programs for pig genotypes with better feed conversion efficiency (FCE) and carcass leanness have inadvertently selected for pigs with reduced VFI (Webb 1989). Consequently, on most commercial swine production farms, adequate VFI is hardly realized, particularly during the growing phase, and this is now regarded as a major factor limiting animal productivity (Mullan 1991). Moreover, feed intake is known to vary considerably between groups of pigs. Therefore, feed intake and the main factors influencing feed intake in growing-finishing pigs must be monitored as manipulation of feed intake represents a direct means to influence growth rate, feed efficiency, carcass quality, and thus profitability in commercial pork production. Also, estimates of feed intake are required to establish optimum dietary nutrient levels.

Abbreviations: **ADG**, average daily gain; **ADFI**, average daily feed intake; **BW**, body weight; **DE**, digestible energy; **DON**, deoxynivalenol; **FCE**, feed conversion efficiency; **HP**, heat production; **LD**, lipid deposition; **ME**, metabolizable energy; **PD**, protein deposition; **RE**, retained energy; $\mathbf{RE_f}$, retained energy as fat; $\mathbf{RE_p}$, retained energy as protein; **T**, environmental temperature; **TNZ**, thermoneutral zone; **VFI**, voluntary feed intake

Feed intake of growing-finishing pigs is influenced by a wide range of factors [National Research Council (NRC) 1981; Henry 1985] that are associated with the thermal environment, social environment, physical environment, health, genotype, and diet. For this reason, feed intake is extremely difficult to predict for specific groups of growing-finishing pigs at the various stages of growth. In fact, prediction of feed intake is one of the biggest challenges in managing growing-finishing pigs. A clear understanding of the key factors involved in determining VFI in pigs is thus an important prerequisite for designing optimum management and feeding strategies.

The effects of specific factors affecting VFI in pigs have been measured previously in several studies (Tables 1 to 4). Most of these data have been derived from studies often involving small groups or individually housed pigs and designed to evaluate a single factor at a time. Whereas data obtained under such conditions provide some indication of how various factors influence VFI in pigs, the results are often difficult to extend to commercial production systems. On a commercial farm, several factors occur simultaneously and interact with each other to determine VFI (Hyun et al. 1998). The present review provides an overview of the control of feed intake, the main factors known to influence VFI, and some means to establish feed intake curves for individual growing-finishing pig units. Areas that deserve further investigation are identified.

I. CONTROL OF FEED INTAKE

The initiation and cessation of feeding and, as a result, VFI is ultimately under hormonal and neural control. In particular, the satiety and hunger centers in the hypothalamus play an important role in the regulation of feed intake (e.g., Forbes et al. 1989). For example, leptin injection in the brain will reduce feed intake and increase secretion of growth hormone (Barb et al. 1998). However, the physiological control mechanisms involved in the short and long-term regulation of feed intake are still not fully understood (e.g., Forbes et al. 1989; Kyriazakis and Emmans 1999; Black 2000).

An alternative working hypothesis is that feed intake reflects the pigs' desire for nutrients and may be constrained by animal, diet and environmental factors (Black et al. 1986; Emmans 1991; Kyriazakis and Emmans 1999; Whittemore et al. 2001a,b,c; Fig. 1). This hypothesis implies that growing pigs eat because they desire to grow, not that pigs grow because they eat, while actual growth rates are determined by realized available nutrient intake and nutrient needs for various metabolic functions. Potential constraints that can limit pigs from expressing desired nutrient intakes include feed bulk and physical feed intake capacity, heat loss to the environment, and environmental "stresses" (disease, social and physical environment). This working hypothesis appears to be consistent with the large effects of genotype on feed intake of pigs that are managed under similar conditions and fed similar diets (e.g., Schinckel 1994). Proper characterization of pig genotypes is thus critical for the prediction of feed intake. Also, this hypothesis implies that nutrients, other than energy, may determine observed feed intakes. It appears insufficient to derive estimates of VFI from relationships between daily digestible energy (DE, kcal d^{-1}) intake and live body weight (BW, kg), as suggested by ARC (1981) and NRC (1987, 1998) and to adjust VFI for empirical effects of gender, pig density, and environmental temperature (NRC 1998).

II. FACTORS THAT INFLUENCE FEED INTAKE IN PIGS

Various factors influence VFI in swine. Factors include the thermal environment where temperature, humidity, radiation, and air circulation have influence. Social factors including, stocking density, group size, and regrouping protocols play a role. Animal factors include the need for nutrients, health status, age, physiological status, and genetics. Dietary factors such as bulkiness, nutrient density, additives, contaminants, processing and ingredient type, feed formulation and presentation, and availability of good quality drinking water are known variables. Detailed effects of these factors on VFI and performance in swine are discussed subsequently.

II.1. Thermal Environment

Air temperature is the most studied environmental factor with respect to its impact on pig performance. Heat exchange between the pig and its environment (heat production in the pigs' body + heat gained from the environment – heat loss to the environment) is an important factor influencing VFI (Bruce and Clark 1979; Verstegen et al. 1987; Black et al. 1986, 1995, 1999; Whittemore et al. 2001a). Simply by adjusting feed intake, growing-finishing pigs can influence heat production (HP, kcal d^{-1}):

$$HP = ME\ intake - RE_f - RE_p,$$

where RE_f is energy retained as lipids and RE_P is energy retained as protein.

This heat exchange is to a large extent influenced by the effective environmental temperature to which pigs are exposed. The effective environmental temperature (i.e., the temperature that is actually experienced by the pig) is the net result of various environmental factors, including air temperature, air speed, type of flooring, temperature, ventilation rate, relative humidity and reflectance characteristics of surrounding surfaces. Important pig factors that influence heat loss to the environment are the proportion of the pig's body surface that is wet, the pig's ability to modify its thermal environment (huddling, selection of specific microenvironments within the pen), and the pig's ability to regulate its skin insulation value by increasing peripheral vasoconstriction (Stombaugh and Roller 1977; Giles et al. 1998) or increasing blood flow to peripheral tissues (Collin et al. 2001a). Alternative cold housing of feeder pigs adds complexity to the influence of this factor.

In general, animals grow optimally within the temperature range often referred to as the thermoneutral zone (TNZ). The TNZ is defined as the range of effective ambient temperature within which the heat from the normal maintenance and productive functions of the animal in nonstressful situations offsets the heat loss to the environment

Table 1. Effect of ambient temperature on feed intake, growth, and feed conversion efficiencies in growing-finishing pigs

	Performance variable				
Temperature (°C)	ADFI (kg d^{-1})	ADG (g d^{-1})	FCE	% change in ADFI	Reference (BW, kg)
21	2.49	854*b*			Phillips et al. (1982) (63.6)
6	2.51	585*b*		+0.8	
24	2.18*a*	876	0.40		Hyun et al. (1998) (35)
28–34	1.99*b*	792	0.40	–8.7	
20	2.94*a*	940*a*	0.32		Lopez et al. (1994) (70.9 to 102)
27.7–35	2.25*b*	680*b*	0.30	–23.5	
20	3.38*a*	920*a*	0.27		Lopez et al. (1991a) (90)
22.5–35	3.01*b*	770*b*	0.26	–11.0	
20	3.67*b*	1030*a*	0.28		Lopez et al. (1991b) (84.5)
–5 to –8	3.88*a*	750*b*	0.19	+5.7	
18–20	2.70*a*	650*a*	0.24		Becker et al. (1993) (84.1 to 105)
27–35	2.25*b*	510*b*	0.23	–16.7	
18–20	3.08	850	0.23		Becker et al. (1993) (84.8 to 110.7)
5–15	4.06	750	0.19	+31.8	

a, b Means within a column and study bearing different letters differ.

Table 2. Effect of space allocation on feed intake, growth, and feed conversion efficiencies in growing-finishing pigs

	Performance variable				
Space (m^2 pig^{-1})	ADFI (kg d^{-1})	ADG (g d^{-1})	FCE	% change in ADFI	Reference (BW, kg)
0.560	2.18*a*	876*a*	0.40		Hyun et al. (1998) (35)
0.250	2.00*b*	734*b*	0.37	–8.3	
0.780	2.58	795*a*	0.31*a*		Brumm and Miller (1996) (27 to 107)
0.560	2.55	765*b*	0.30*b*	–1.2	
0.705	2.36*a*	877*a*	0.37		Gonyou and Stricklin (1998) (25 to 97)
0.436	2.25*b*	832*b*	0.37	–4.7	
0.280	0.675*a*	381*a*	0.56		Kornegay et al. (1993) (7.1 to 19.6)
0.140	0.597*b*	335*b*	0.57	–11.6	
0.545	2.70*b*	834*a*	0.31		Edmonds et al. (1998) (18 to 55)
0.345	2.40*a*	688*b*	0.29	–11.1	
0.740	2.87*a*	700*a*	0.24		McGlone and Newby (1994) (59 to 106)
0.560	2.53*b*	600*b*	0.24	–11.9	

a, b Means within a column and study bearing different letters differ.

without requiring an increase in rate of metabolic heat production (NRC 1981). For growing pigs, the TNZ ranges between 18 and 21°C (Holmes and Close 1977) and temperatures above (heat stress) or below (cold stress) the TNZ do influence VFI and overall growth performance of pigs (Table 1). The impact of hot and cold temperature on VFI in pigs is thought to occur mainly through changes in meal size rather than daily number of meals (Quiniou et al. 2000). This observation demonstrates the complexity of the metabolic processes involved in the regulation of VFI and points out the need for further research in this area. Temperature also influences feeding pattern of pigs. Under hot temperature, pigs will consume more feed during the night (cool period) than during the day (hot period) but cooler temperatures don't seem to have similar effects on feeding patterns (Umboh 1993; Quiniou et al. 2000). For example, in the study by Quiniou et al. (2000), pigs ate 69% compared to 55% of their daily meals during the day when ambient temperature was 19 and 29°C, respectively.

II.1.1. Hot Temperatures

As ambient temperature increases pigs undertake behavioral changes such as changing posture, reducing contact with other pigs and wetting their skin as well as increasing vasodilation (Giles et a. 1998). The effect of air temperature above the TNZ on VFI and other performance variables in pigs has been evaluated (Scott 1981; Close 1989; Hawton 1990; Lopez et al. 1991a; Schenck et al. 1992; Nienaber

Table 3. Effect of regrouping or group size (pigs pen^{-1}) on feed intake, growth, and feed conversion efficiency in growing-finishing pigs

	Performance variable				
Factor	ADFI (kg d^{-1})	ADG (g d^{-1})	FCE	% change in ADFI	Reference (BW, kg)
Regrouping[z]					
–	2.18	876	0.40		Hyun et al. (1998) (35)
+[y]	2.01	777	0.39	–7.8	
–	–	870*a*	0.28		Stookey and Gonyou (1994) (83.4)
+[x]	–	770*b*	0.27	–	
Group size[w]					
10	2.66	710	0.27		McGlone and Newby (1994) (93)
40	2.78	730	0.26	+4.5	
7	2.28*a*	872*a*	0.383*a*		Gonyou and Stricklin (1998) (25 to 97)
15	2.21*b*	822*b*	0.372*b*	–3.1	
1	2.08	742*a*	0.336		De Haer and De Vries (1993a) (25 to 100)
80	1.93	642*b*	0.316	–7.2	

[z]Pigs were either not regrouped (–) or regrouped by mixing with unfamiliar pigs (+).
[y]Pigs were regrouped and measurements taken over a 2-wk period.
[x]Pigs were regrouped at the beginning of weeks 1 and 3 during the 4-wk study period.
[w]In the study by McGlone and Newby (1994) floor space was maintained at 0.74 m^2 per pig; this was not specified in the other two studies.
a, b Means within a column and study bearing different letters differ.

Table 4. Effect of level of immune system activation on feed intake, growth and feed conversion efficiency in growing-finishing pigs

	Performance variable				
Immune system activation	ADFI (kg d^{-1})	ADG (g d^{-1})	FCE	% change in ADFI	Reference (BW, kg)
Low	0.371*a*	327*a*	0.88		Dritz et al. (1996) (5)
High	0.281*b*	246*b*	0.87	–24.3	
Low	1.052*a*	644*a*	0.613*a*		Williams et al. (1997a) (6 to 27)
High	0.954*b*	581*b*	0.581*b*	–9.3	
Low	0.651*a*	451*a*	0.685		Williams et al. (1997b) (10)
High	0.575*b*	408*b*	0.711	–11.7	
Low	2.215*a*	864*a*	0.391*a*		Williams et al. (1997c) (6 to 112)
High	2.095*b*	720*b*	0.344*b*	–5.4	

a,b Means within a column and study bearing different letters differ.

et al. 1996; Brown-Brandl et al. 1998; Collin et al. 2002). Results of many of these studies show that VFI is reduced significantly when pigs are under heat stress, i.e., the effective temperature exceeds the upper critical temperature (Close 1989; Table 1, Fig. 2) and this reduction is associated with changes in feeding behavior such as eating time and meal size (e.g., Collin et al. 2001b). The VFI is reduced by approximately 40 g for every °C above the TNZ (Table 1) although the decrease in VFI at increasing ambient temperature above TNZ is likely more quadratic than linear (Nienaber and Hahn 1983; Quiniou et al. 1998; Quiniou and Noblet 1999). Based on a recent review (Le Dividich et al. 1998), feed intake reductions as a result of increased temperature vary widely from 40 g to 80 g °C^{-1} d^{-1} depending on such factors as pig genotype, body weight, diet composition, and ambient temperature. For example the effects of heat stress on VFI are attenuated when pigs are fed amino-acid-supplemented low protein diets (e.g., Le Bellego et al. 2002) mainly because such diets are associated with lower energy losses as heat (Le Bellego et al. 2001). Whether pigs are housed individually or in a group will also influence VFI (see Section II.3.2). The impact of hot temperature is more pronounced in heavier than in lighter pigs as shown by Quiniou et al. (2000) and Rinaldo et al. (2000). This observation is consistent with the fact that the upper critical temperature of pigs declines as body weight increases (Holmes and Close 1977).

The reduction in VFI allows pigs to minimize further aggravation of increased body temperature due to heat increment under conditions of heat stress (Feddes and DeShazer 1988; Nienaber et al. 1996; Brown-Brandl et al. 1998). Pigs maintained in a hot, cyclic temperature are known to shift their periods of major activities such as feeding to cooler periods so as to minimize the detrimental effects of thermal stress (Curtis 1983; Feddes et al. 1989; Xin and DeShazer 1992; Nienaber et al. 1996). However, after the initial period of heat stress, pigs seem capable of adjusting to hot temperatures and increase feed intake during hot periods. For instance, in a study by Lopez et al. (1991a), feed intake in 90-kg pigs subjected to diurnal heat stress (22.5 to 35°C) was 15.3% less compared to pigs kept in thermoneutral conditions (20°C) during the first 7 d, but

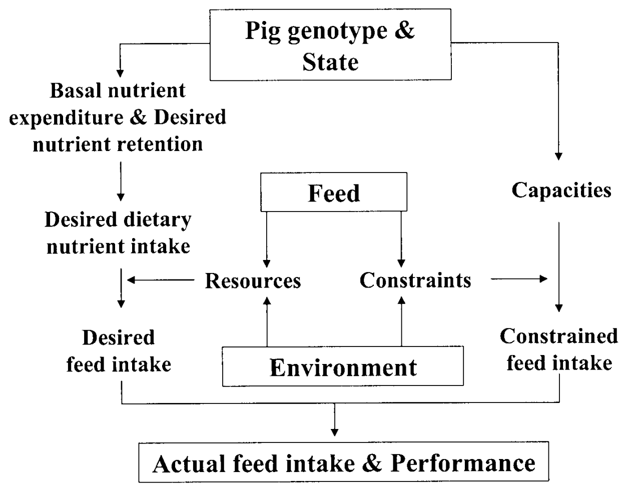

Fig. 1. A schematic representation of feed intake control in growing pigs [derived from Emmans (1991)].

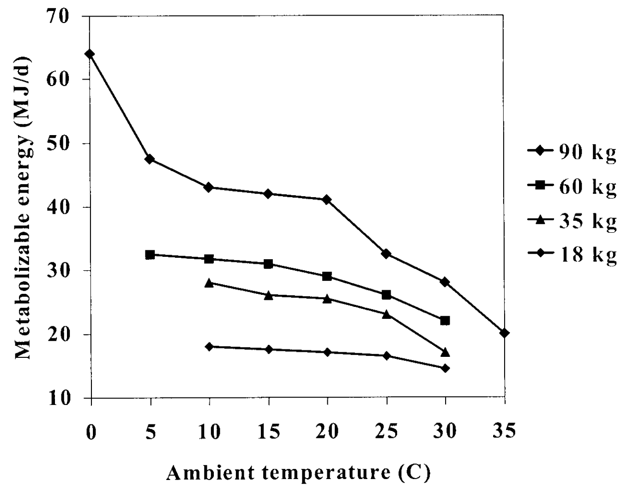

Fig. 2. Effect of ambient temperature on feed intake in growing pigs of various body weights (Close 1989).

this difference was only 1.8% during the subsequent 7 d. This phenomenon has been demonstrated more recently in growing pigs (Umboh 1993, Fig. 3).

Most of the previous studies have only attempted to establish VFI patterns relative to changes in ambient temperature but not how these conditions may impact body composition. Consequently, the magnitude and cause of body composition changes in pigs raised in hot conditions is not fully understood (NRC 1981). However, available data suggest that under hot temperatures backfat deposition is reduced, with an increase in leaf-pad fat (Le Dividich et al. 1987; Rinaldo and Le Dividich 1991; Rinaldo et al. 2000). This adaptive strategy is believed to allow pigs to dissipate more heat through the skin (Katsumata et al. 1996). The reduction in backfat thickness may also be as a result of reduced energy intake, which in turn means that limited energy is available for body lipid deposition. Moreover, most of the previous studies on the effect of heat stress on VFI have been conducted in laboratory or small-scale settings, suggesting that little is known on the impact of heat stress on VFI and overall performance in a commercial setting.

II.1.2. Cold Temperatures

Effects of cold stress on VFI and overall performance in pigs have been examined to a lesser extent compared to those of heat stress. Nonetheless, when heavy pigs are exposed for an extended period of time to extremely low effective ambient temperatures (cold stress), feed intake can increase substantially, although FCE and average daily gain (ADG) are reduced (Verstegen et al. 1982, 1984; Herpin et al. 1987a, b; Becker et al. 1993; Connor 1994; Maenz et al. 1994; Table 1). Pigs exposed to cold stress have a higher metabolic rate (Dauncey and Ingram 1979; Herpin et al. 1987a, b; Herpin and Lefaucheaur 1992) and therefore tend to eat more feed to supply the extra energy required for the increased metabolic heat production (Verstegen et al. 1982; 1984). The extra feed consumed for each °C below the lower critical temperature has been estimated at 25 and 39 g d^{-1} for growing and finishing pigs, respectively, while ADG is reduced by 10 to 22 g d^{-1} (Verstegen et al. 1982, 1984; Connor 1994). It is important to note that these estimates are likely lower for pigs housed in larger groups, because of opportunities to huddle and thereby reduce cutaneous heat loss (NRC 1981). However, the extent to which these parameters are affected may depend on the genotype and the severity of cold stress. For instance, in a series of trials with growing-finishing pigs grouped-housed (170 pigs per group) in straw-bedded structures, ADG was reduced by about 30 g d^{-1} for high lean genotype pigs comapared to 70 to 100 g d^{-1} for low lean genotype pigs when exposed to –10°C or less throughout the grow out period (Connor 1997). Although ambient temperature in hoop structures can drop considerably to sub-zero levels as was the case in the studies by Connor (1997) and Lay (2000), the effective temperatures for pigs are enhanced by the heat generated by the decomposing manure deck. Temperature in the manure deck in hoop structures can be as high as 47°C (Lay 2000).

Younger pigs may be limited in their ability to increase feed intake to meet their nutrient intake requirements because of their limited gut size (Quiniou et al. 2000). This implies that if growing pigs are housed in cold temperatures, the composition of their feed, and in particular its physiological effects (see Section II.5.1) become an important consideration. In such a situation, growing pigs may benefit from high quality feed based on ingredients with little gut fill effects.

Exposure to cold stress may lead to changes in carcass composition. Pigs tend to have thicker backfat layers due to the extra feed consumed and the redistribution of body fat in cold environments (Verstegen et al. 1982, 1984; Connor 1997; Le Dividich et al. 1987; Rinaldo and Le Dividich 1991). However, this may not necessarily be true with growing pigs or lean genotype pigs whose gut capacity may limit their capability to increase VFI substantially (Giles

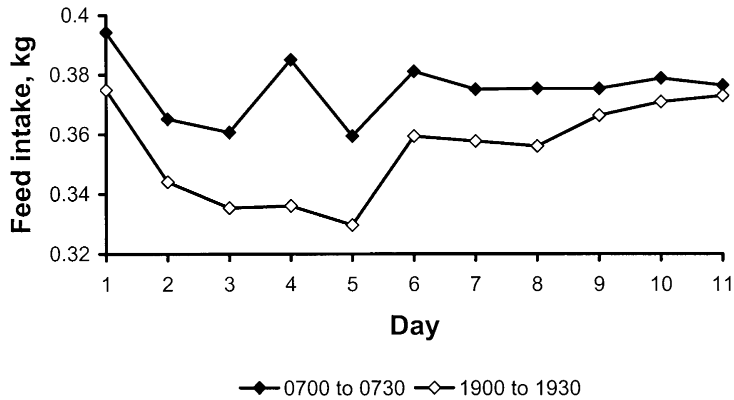

Fig. 3. Feed intake pattern of growing pigs exposed to diurnal heat stress (20 to 35°C in 24 h), n = 5 and SEM = 0.32. Pigs were given ad libitum access to feed at 0700 and 1900 for 30 min and any feed not eaten after that was removed and weighed. From Umboh (1993).

et al. 1998). Furthermore, it can be speculated that for lean genotype pigs, the extra feed may not necessarily be converted into fat, as leaner pigs may be able to efficiently utilize feed. The effect of cold stress on protein deposition is not clear. Phillips et al. (1982) observed a 1% decline in protein energy deposition per °C below the TNZ for 45-kg pigs exposed to 6°C for 15 d. Similarly, Becker et al. (1993) observed a reduced protein deposition rate in recombinant-porcine-somatotropin-treated pigs exposed to cold temperatures (5 to 15°C) for 35 d compared to those in TNZ (18 to 21°C). Carcass quality parameters in pigs raised in hoop shelters during the winter (sub-zero temperatures) were similar to those of pigs raised in conventional barns with TNZ conditions (Connor 1997). However, differences in protein deposition and carcass composition were not observed in weaned piglets exposed to either thermoneutral or cold temperatures (Herpin et al. 1987a,b). The response of modern genotypes to cold stress in terms of VFI and how such conditions influence protein and lipid accretion rates has not been described in the literature. With the introduction of hoop shelters, such information is urgently required to develop feeding programs for pigs raised below the TNZ. Thus far it would seem that although backfat is elevated when modern genotype pigs are exposed to extremely low (–10°C or less) ambient temperature, loin depth may also be elevated, thus leading to carcass yield and index that are similar to those of pigs maintained within the TNZ (Connor 1997).

II.1.3. Predicting Thermal Effects on Voluntary Feed Intake
Given the wide range of factors that determine the effective environmental temperature and the pig's ability to manipulate heat loss to the environment, the quantitative feed intake response of pigs to the thermal environment is difficult to predict. A correct prediction model requires a detailed characterization of the pig, its thermal environment and complex mathematical models (Bruce and Clark 1979; Black et al. 1986; Technisch Model Varkensvoeding 1994). This is illustrated by the non-linear relationship between feed intake and effective environmental temperature (Nienaber et al. 1987), which is in direct contrast to the simple linear relationship suggested by NRC (1998).

The relationship between environmental temperature (T, °C) and VFI kg^{-1} BW$^{0.75}$ d^{-1}), such as that established by Nienaber et al. (1987), appears reasonable for specific experimental conditions:

$$\mathrm{VFI} / \mathrm{BW}^{0.75} = 0.11 + 0.31 \times 10^{-3}\ \mathrm{T} - 0.53 \times 10^{-4}\ \mathrm{T}^{2} - 1.24 \times 10^{-7}\ \mathrm{T}^{3}$$

(pig BW between 43.6 and 87 kg; diet ME content 3035 kcal kg^{-1}; temperature was increased at a 5°C interval from 5 to 30°C)

However, simple relationships connecting environmental temperature to VFI are unlikely to properly represent the effects of effective environmental temperature on heat exchange and feed intake of pigs managed under commercial conditions, e.g., with varying pig genotype, pig density, housing systems and stocking arrangements. Rather than attempting to predict effects of the thermal environment on heat losses from the pig's body, it may be more meaningful to monitor the pig's response to the thermal environment, based on pig behavior, core body or skin temperature, and to use this information to manipulate the pig's thermal environment and feed intake.

II.2. Humidity and Ventilation Rates

The impact of relative humidity on swine performance depends on the prevailing ambient temperature and ventilation rate. The effect of high humidity on VFI, ADG, and FCE is more pronounced during periods of elevated compared to low ambient temperature (Sainsbury 1972). In a study with growing-finishing pigs (25 to 106 kg), average daily VFI was significantly reduced when temperature was increased to 28°C at a relative humidity of 65 to 70% (Massabie et al. 1997). In the same study, increasing relative humidity from 45 to 90% at a constant air temperature of 24°C caused a significant reduction in VFI and ADG. Morrison et al. (1969) also demonstrated a reduction in VFI of 32 g d^{-1} following a 10% increase in relative humidity at an ambient temperature of 33°C. High humidity severely minimizes the ability of pigs under heat stress to dissipate the extra body heat through evaporation. Low ventilation rates leads to increased carbon dioxide levels and microbial proliferation and this in turn adversely impacts on VFI and ADG (Massabie et al. 1997). Similarly, low or insufficient ventilation rates may lead to accumulation of toxic gases like hydrogen sulfide and ammonia, which can negatively impact on pig performance. Although levels of these gases of 10 ppm or more can reduce appetite in swine (Whittemore 1998), little research has been done to clearly quantify the effect of these gases on VFI.

II.3. Physical and Social Environment

Various physical and social factors including space allocation, group size, feeder space, and re-grouping of pigs are reported to influence VFI and the overall performance of pigs primarily by altering the pig's behavior. Notably, the effects of these factors are often confounded in most experiments conducted to evaluate their effects on VFI and growth performance in pigs. Despite these limitations, the present review discusses the effect of each of these factors on VFI in pigs.

II.3.1. Space Allocation

Stocking arrangements can influence VFI in pigs (e.g., Chapple 1993; Black 1995; Morgan et al. 1999) and when group size is larger than about five pigs, the reduction appears mainly related to pig density (see Section II.3.3). For example, Schmolke et al. (2003) reported that feed intake was similar for pigs housed in groups of 10, 20, 40, or 80. In the study, space allowance and feeding spaces (1 wet/dry feeder per 10 pigs) were kept constant across treatments. The effect of feeder type (e.g., wet/dry vs. dry feeders) under different stocking densities has not been characterized.

Compared to pigs housed in environments with adequate spacing, space restricted-pigs show significant reductions in VFI and ADG (Kornegay et al. 1993; Edmonds et al. 1998; Gonyou and Stricklin 1998; Hyun et al. 1998; Table 2). The impact of space restriction on FCE is poorly defined and only a few studies suggest that FCE may be reduced (Brumm and Miller 1996; Edmonds et al. 1998). In a literature review, Black (1995) suggested that feed intake is depressed when floor space allowance per pig is below 0.035 m^2 $BW^{-0.67}$, which is approximately the space allowance required for all pigs in a pen to lie on their sternum. For a 100-kg pig this suggested floor space allowance is 0.766 m^2. When space allowance is further reduced, feed intake is reduced linearly and by about 20% when floor space allowance is 0.020 m^2 $BW^{-0.67}$. Interestingly, minimum floor space allowances to maximize feed intake according to NRC (1998) are substantially larger than these values. It should be noted that these relationships are highly empirical and that environmental factors, such as effective environmental temperature, type of flooring, pen layout, and pig genotype may influence this relationship (e.g. Morgan et al. 1999). The lack of a clear relationship between space restriction and VFI is clearly demonstrated by the data presented in Table 2, which shows that the magnitude of VFI and ADG reduction relative to the level of space restriction is quite variable. For instance, a 36.7% reduction in space allowance for 18 to 55 kg pigs reduced VFI by 11% and ADG by 18% (Edmonds et al. 1998) while a 50% space reduction for 7.1 to 19.6 kg pigs reduced both VFI and ADG by approximately 12% (Kornegay et al. 1993). Hyun et al. (1998) observed only an 8.3% reduction in VFI while ADG was reduced by 16.2% following a 55% space reduction for 35-kg pigs over a 4-wk period. Differences in the absolute reduction in space allocation and in the number and magnitude of other interacting factors present may explain some of the variability in results across different studies.

The negative effects of exposing pigs to reduced space on ADG were not corrected by feeding pigs diets with high nutrient density (Brumm and Miller 1996; Gonyou 1999; Ferguson et al. 2001), suggesting that reduced space may cause chronic stress that impairs the efficiency of feed utilization. Moreover, space restriction in pigs may alter biochemical mechanisms and cause behavioral changes (e.g., increased aggression), which may divert dietary energy away from supporting growth (Bryant and Ewbank 1972; Randolph et al. 1981; Chapple 1993). Indeed, Paterson and Pearce (1991) observed increased plasma adrenocorticotrophic hormone levels in space-restricted pigs compared to those allowed adequate spacing.

II.3.2. Group Size

The number of pigs to be kept in a single pen is an important consideration in a swine farm not only because of its influence on barn design but also because of its possible influence on VFI and overall performance of pigs as well as animal management issues. The influence of group size on VFI, ADG, and FCE is shown in Table 3. Group housing alters the feeding pattern of pigs (de Haer and Merks 1992; de Haer et al. 1993; Hyun et al. 1997; Hyun and Ellis 2001, 2002) and these changes may lead to changes in overall daily VFI. For instance, in a study with growing pigs housed individually or in groups, de Haer and de Vries (1993) observed that group-housed pigs had fewer meals per day, lager meal size and spent more time eating per meal compared with individually housed pigs. Overall, group-housed pigs had a lower daily VFI and spent less time eating. Similar results were reported earlier by de Haer and Merks (1992).

The negative effect of increased group size on VFI in pigs, however, has not been observed consistently. Whereas some studies have reported a decline in VFI as the number of pigs per group increases (Petherick et al. 1989; Gonyou et al. 1992; Gonyou and Stricklin 1998), others have not (McGlone and Newby 1994). Social interactions among group-housed pigs together with the extra effort required to access feed when pigs are housed in a larger space may be responsible for the observed reductions in VFI (de Haer and de Vries 1993; Gonyou and Stricklin 1998). There are indications from the study by Gonyou and Stricklin (1998) that group size may interact with other factors such as space allocation to impact on VFI and this may be related to pig density (Schmolke et al. 2000; Section II.4.1). Furthermore, VFI seems to be negatively affected when growing pigs (Wolter et al. 2000) but not finishing pigs (Spoolder et al. 1999) are kept in large groups of up to 100 pigs per pen probably because finishing pigs can manipulate their feeding behavior to maintain intake (e.g., Hyun and Ellis 2002).

II.3.3. Feeder Space

There are only limited studies that have been done to specifically evaluate the effect of feeder space on pig performance. In group-housed pigs, the effect of feeder space on VFI is more important with regard to the omega (i.e., smallest pig in a group) pig. For example, when growing-finishing pigs were housed in groups of 16 pigs per pen with a wide variation in body weight, smaller pigs consumed significantly less feed (1.55 vs. 1.98 kg d^{-1}) in pens with a single feeder compared with pens with two feeders (Georgsson and Svendsen 2002). Reducing feeder space from 42.5 mm to 32.5 mm per pig reduced VFI from 1.56 to 1.44 kg d^{-1} but no interaction between feeder space and group size was observed (Turner et al. 2002). Thus, these data suggest that there might be no need for differential feeder space for different group sizes. This is consistent with previous studies showing that pigs are capable of altering feeding behavior to maintain performance when feeder space is limited (Hyun and Ellis 2002; O'Connell et al. 2002). However, this may only apply to pigs within a certain BW range. For example, unlike finishing pigs (84 to 112 kg), growing pigs (26 to 48 kg) are unable to maintain feed intake and growth rates when given access to a single feeder and housed in large groups (Hyun and Ellis 2001, 2002). Similarly, Wolter et al. (2002) reported that although feeder-trough space (2 vs. 4 cm per pig) did not affect piglet performance during the first 6 wk post-weaning, growth rates from 6 to 8 wk post-weaning were reduced when feeder space was reduced from 4 to 2 cm per pig. However, feed intake was not influenced by feeder space allowance in that study.

II.3.4. Regrouping

Regrouping unfamiliar pigs is commonly practiced as pigs move through a production facility. Mixing unfamiliar pigs leads to reductions in VFI and ADG and the impact seems to persist even after pigs are re-united with their familiar counterparts (Stookey and Gonyou 1994; Table 3). Based on these observations, Stookey and Gonyou (1994) concluded that market pigs should not be regrouped with unfamiliar pigs within 2 wk before shipping. Similar results were reported by Hyun et al. (1998) in a study with 35-kg pigs. In contrast, however, Rundgren and Lofquist (1989) showed that whereas regrouping reduced ADG by 2% and FCE by 3% from 23 to 100 kg, it had no effect on VFI. Similarly, regrouping 8-wk-old pigs did not have any long-term effect on performance, thus indicating that regrouping is a transient stressor that pigs can overcome if given sufficient time. However, the minimum time required for these effects to disappear has not been determined.

II.4. Animal Factors

Voluntary feed intake of pigs is affected by various factors related to the pig itself. These factors include the need for nutrients, which is closely related to the health status, age and physiological status and genetic composition of the pig. The influence of these factors on VFI is discussed in the following sections.

II.4.1. Desired Nutrient Intake

Voluntary feed intake in pigs is driven by the need to meet specific nutrient demands. Growing pigs require nutrients for body maintenance functions and to support accretion of different body components. The latter include the metabolic inefficiency of depositing such body components. Therefore, an accurate estimation of desired nutrient intake can be made once the pig's desired PD, LD, and basal nutrient needs under non-limiting environmental conditions are established. This requires estimates of: (i) basal (maintenance) nutrient needs under ideal, non-limiting environmental conditions; (ii) rates of whole-body lipid accretion (LD) and whole-body protein accretion (PD) under ideal, non-limiting conditions; (iii) metabolic inefficiency of using dietary available nutrient intake for basal needs, LD, and PD; and (iv) diet nutrient availability. For example, energy requirements may be expressed as:

$$\text{ME intake} = ME_{\mathrm{m}} + 1/k_{\mathrm{p}} \times RE_{\mathrm{p}} + 1/k_{\mathrm{f}} \times RE_{\mathrm{l}}$$

where ME_{m} represents daily maintenance metabolizable energy (ME) requirements; k_{p} and k_{f} represent the marginal efficiency of using ME intake over maintenance for daily body energy retention as protein (RE_{p}) and lipid (RE_{l}), respectively (NRC 1998).

For a detailed discussion on the various aspects of nutrient utilization in growing pigs, the reader is referred to Kyriazakis (1999) and Birkett and de Lange (2001a,b,c). Important points that must be considered include the fact that at sub-optimal diet amino acid levels, amino acid intake—and not energy intake—will determine desired feed intake (e.g., Ferguson and Gous 1997), feed intake may be depressed when diet nutrients are unbalanced, for example, when the dietary ratio of tryptophan to large neutral amino acids is low (Henry et al. 1992b), and the metabolic efficiencies of using available nutrient intake for basal needs, LD, and PD are influenced by diet nutrient composition (Black 1995; Emmans 1999; de Lange 2000; Birkett and de Lange 2001a,b,c). These points illustrate the difficulty of estimating accurately the desired nutrient intake in specific groups of growing-finishing pigs.

Differences in VFI between genders reflect gender differences in basal nutrient needs and growth potentials (NRC 1987, 1998). The following adjustment (kcal d^{-1}; added for barrows; subtracted for gilts) was suggested by NRC (1998):

$$\text{Adjustment to DE intake} = \text{DE intake} \times (-0.083 + 0.00385 \times \text{BW} - 0.0000235 \times \text{BW}^2)$$

However, gender effects on desired nutrient intake vary among pig genotype (e.g., NRC 1987; Schinckel 1994); therefore, making general statements about gender effects on feed intake are of little value for individual growing-finishing pig units.

II.4.2. Health Status

Although the health status of an animal is an important determinant of overall performance, our understanding of the quantitative effects of disease on growth performance and feed intake of growing-finishing pigs has only started to become clearer (e.g., Verstegen et al. 1987; Stahly 1996; Black et al. 1995, 1999; Williams 1997a,b,c). Digestive disease such as collibacillosis and transmissible gastroenteritis results in various degrees of diarrhea, which could reduce nutrient digestibility and may result in sudden drastic changes in feed intake, growth rate and feed efficiency (Whittemore 1998). Respiratory disease may reduce feed intake via increased fever and reduced ability to acquire oxygen to support normal metabolism (Bray et al. 1993).

In general, the immune system responds to the presence of pathogenic agents by synthesizing and releasing compounds known as cytokines [e.g., Interleukin–1 (IL-1), Interleukin-6 (IL-6), and Tumor Necrosis Factor-α (TNFα)] that influences VFI and nutrient utilization as well as cellular and humoral components of the immune system (Klasing and Johnstone 1991; Stahly 1996; Johnson 1997a,b). High activation of the immune system represents a form of stress (i.e., immunological stress) and pigs use physiological and behavioral strategies to maintain homeostasis during a disease challenge (Johnson 1997a, b). During disease infection, potential anabolic hormones are inhibited and VFI, ADG and FCE are reduced (Table 4). Pigs with an activated immune system have lower VFI, FCE, and body protein accretion compared to pigs with low immune system activation (Johnson and von Borell 1994; Williams et al. 1997a,b,c). In the study by Johnson and von Borell (1994), barrows injected peritoneally with 50 $\mu g\ kg^{-1}$ BW of lipopolysaccharide (a model for bacterial infection) consumed 31% less feed in a 24-h period compared to pigs that received a saline injection (1953 vs. 2838 g). In addition to compromised VFI and growth performance, disease infection also influences the use dietary nutrients for various body functions. Diseased animals exhibit a shift in the partitioning of dietary nutrients away from lean muscle accretion towards metabolic responses that support the immune system, and also accelerate the breakdown of muscle proteins (Reeds et al. 1994; Johnson 1997a,b; Webel et al. 1997). In response to pathogenic invasion, the synthesis by the liver of acute phase proteins is increased to help the immune system in dealing with the infection. The synthesis of these proteins together with an up-regulated immune system impose a major energy and amino acid demand, thus leading to poor performance (Reeds et al. 1994; Misutka 1995; Dritz et al. 1996; Johnson 1997). Furthermore, the synthesis and secretion of cytokines in response to immunological challenge may be responsible for the increased protein catabolism observed in disease-infected pigs (Webel et al. 1997).

Unfortunately, insufficient quantitative information is available to relate indicators of immune system activation (e.g., lung damage, arterial oxygen saturation, plasma levels of selected cytokines to depressions in performance potentials, increases in basal nutrient requirements, or plasma levels of IL–1, IL-6, TNFα or other cytokines) to depressions in lipid and protein deposition, changes in basal nutrient needs and reductions in VFI. An accurate representation of disease effects on growth performance potentials and nutrient metabolism is a big challenge in mathematical modeling of growth in the pig.

II.4.3. Age and Physiological Status

Age or body weight and physiological state are important factors that determine VFI of pigs. As the pig grows, the need for dietary nutrients increases and pigs thus consume more feed to meet daily nutrient requirements. In a study on the effect of growth potential at three growth stages on the feeding behavior of Pietrain, Large White and Meishan, representing lean, conventional and fat types of pigs, respectively, Quiniou et al. (1999) observed a linear increase in feed intake, the magnitude of which depended on pig type. In the same study, VFI was significantly influenced by the type of pig, thus leading to a conclusion that differences in body composition seen among pig genotypes are closely associated with differences in VFI and feeding behavior. This means that to develop optimal strategies for enhancing VFI in different pig genotypes a clear understanding of how body composition changes as the pig grows and a good description of the feeding behaviors of different pig genotypes will be required.

Voluntary feed intake in swine is also influenced by the stage of growth and the physiological status of the pig. Not only the nutrient needs but also the pig's capacity to ingest, digest and metabolize nutrients are influenced by genotype, body weight or age, and physiological status. As will be discussed in the next section central to the discussion on physical feed intake capacity is characterized by the "bulkiness" of a specific diet or feed ingredients.

II.4.4. Genetic Effects

The potential for rate and composition of gain varies among genetic lines. Feed intake levels and patterns differ among pigs of divergent genetic lines (Cop and Buiting 1977; de Haer and de Vries 1993) and pigs selected for faster gain have a higher VFI levels than pigs with slow gain potential (Clutter et al. 1998). In a non-limiting environment and when pigs have access to a diet that is not limiting in essential nutrients, VFI will be determined by desired nutrient intake and some limit to the animal's capacity to ingest and digest food and/or to metabolize digested nutrients. This implies that an accurate prediction of VFI requires that growing pigs are characterized for basal (or maintenance) nutrient needs and for desired rates of body protein (PD) and body lipid deposition (LD). If feed intakes are to be predicted over various body weight ranges then basal nutrient needs, desired rates on PD and LD, as well as physical feed intake capacity are to be represented dynamically. Related issues that must be considered include, lack of sufficient information on LD and PD curves for the main pig genotypes managed under ideal, non-limiting conditions (e.g., Schinkel 1999) and the fact that basal energy needs vary up to 20% among pig genotypes and how best to express these needs in prediction equations. According to Noblet et al.

(1991), basal energy needs are better expressed per kg $BW^{0.60}$ than per kg $BW^{0.75}$.

In general, daily VFI level is directly related to the respective daily amounts of lean and fat deposited (about three to four times more energy is required to deposit fat compared to lean tissue) and the efficiencies for utilization of dietary energy for the accretion of body components (Smith and Fowler 1978; Henry 1985; Metz et al. 1980). Pigs with a high potential for lean tissue growth tend to have a lower voluntary VFI compared to those with low muscle accretion rate (Henry 1985; Gu et al. 1991). It is important to note that the impact of genetic selection on VFI depends on the selection criteria used and the environment under which pigs are selected. For example, Smith et al. (1991) showed that when genetic selection for pigs is done under ad libitum feeding conditions with emphasis on increased carcass leanness and improved feed efficiency, feed intake is reduced. However, when increasing lean growth rate was emphasized, feed intake was actually increased. Furthermore, Cameron and Curran (1994) have reported that when selection for lean growth rate emphasizes liveweight gain and carcass lean content both growth rate and feed intake can be increased. Selection for carcass leanness and feed efficiency appears to correspond to selection against fat tissue growth, thus reducing diet energy needs and VFI. Selection for lean tissue growth slightly increased diet energy needs as it appears to have little effect on fat tissue growth. A clear example of environmental effects on selection for VFI is the study by Stern et al. (1994). When pigs fed lysine-limiting diets were selected for lean tissue growth, pigs were in essence selected for VFI so that they could satisfy needs for lysine to support lean tissue growth, while the lean tissue growth potential was increased only slightly. In contrast, meaningful improvements were made in lean tissue growth potential in pigs that were selected for lean tissue growth when fed lysine adequate diets, while changes in VFI were minimal. These studies suggest that selection criteria and the conditions under which genetic selection is performed are important factors that could explain part of the variation in VFI that exist among pig genotypes and that it is important to quantify these traits for specific pig genotypes (Ellis and Augspurger 2001).

Physical feed intake capacity in different pig genotypes is yet to be clearly established. Developing such relationships will require that the units for physical feed intake capacity are established (see Section II.5.1) and that feed intake is measured in these units in different pig genotypes under non-limiting conditions, while bulky diets are fed. Feed intake capacity is determined by sizes of digestive organs and either rate of digesta passage (stomach), absorptive capacity (intestine) and/or metabolic capacity (liver) per unit of tissue mass. Observed differences in sizes of digestive organs among pig genotypes fed similar diets (Quiniou et al. 1996; Schinckel 1999) suggest that genotype effects on feed intake capacity exist. However, these studies should be interpreted with some caution as pig genotypes were confounded with feeding levels. Feed intake has direct effects on sizes of visceral organs (Zhao et al. 1995; Jorgensen et al. 1996; Nyachoti et al. 2000). Moreover, diet and animal effects on absorptive and metabolic capacity per unit of tissue mass need to be established.

Variations in the levels of satiety hormones in blood of pigs of different genetic potentials may also explain the observed differences in VFI and overall performance potentials of different pig genotypes. For instance, Clutter et al. (1998) observed a greater concentration of CCK-8, a putative satiety hormone, per unit of feed consumed in slow-gain pigs compared to fast-gain pigs. These findings suggest that levels of CCK-8 may play a role in genetic differences between genetic lines for VFI (Clutter et al. 1998). The response of pigs in terms of growth rate to heat stress and perhaps other stressors depends on the genetics of the pig. Nienaber et al. (1997) demonstrated that pigs of high lean growth potential are more susceptible to the effects of heat stress than those of moderate growth potential.

II.5. Dietary Factors

A number of diet-related factors may influence feed intake in pigs. These factors include dietary energy content, dietary protein and specific amino acids content, feed additives (e.g., antibiotics, flavors, etc.), feed processing, ingredient type, feed form and presentation, and availability of drinking water. The impact of these factors is described in the following sections.

II.5.1. Feed Bulk and Physical Feed Intake Capacity

The bulkiness of a feed determines the amount a pig can consume to achieve gut fill. The ability to consume sufficient amounts of a feed with a given bulkiness to meet the desired nutrient intake (Section II.4.1) depends on the physical capacity to ingest the feed. In young pigs, up to about 20 kg BW, the physical capacity to ingest and digest feed appears to limit feed intake. Growing pigs, up to about 50 kg BW, cannot compensate for reductions in diet DE density below 3350 kcal kg^{-1} (Black et al. 1986). It is thus important that diet and animal characteristics, which contribute to gut fill are identified and quantified.

Until recently, gut fill and physical feed intake capacity (F_{phys}, kg d^{-1}) have been expressed in units of feed intake (Black et al. 1986; 90% feed DM content):

$$F_{phys} = 0.111 \times BW^{0.803}$$

or in units of indigestible feed intake (Whittemore 1993):

$$F_{phys} = 0.013 \times BW / [1 - Dig]$$

Even though these approaches yield similar estimates of feed intake, both approaches fail to recognize the impact of diet fat (Revell and Williams 1993) and diet fiber (Eastwood et al. 1983; Kyriazakis and Emmans 1995) on VFI. For example, for a series of diets with extreme ingredient compositions, diet water-holding capacity appeared a better predictor of VFI than dry matter, crude fiber or neutral detergent fiber content (Kyriazakis and Emmans 1995; Tsaras et al. 1998). Moreover, the addition of a combination of xylanase, glucanase and cellulase to wheat-based diets largely eliminated the substantial effect of wheat variety on feed intake in young pigs (Choct et al. 1999). Clearly, more effort is required to characterize diet constituent that contribute to gut fill and physical feed intake capacity and to determine animal and environmental effects on physical feed intake capacity in individual groups of pigs (e.g., Whittemore et al. 2001b,c).

II.5.2. Dietary Nutrient Content and Balance

Feed composition in terms of nutrient content and nutrient balance is an important determinant of VFI in swine. In general, pigs consume feed to meet their requirement of the first limiting nutrient, which in most cases are energy yielding nutrients (Cole et al. 1968; Henry 1985; NRC 1998; McNeilage 1999). As the dietary available energy content is reduced, pigs attempt to maintain energy intake by eating more feed, until feed intake is limited by physical feed intake capacity or other environmental factors (see Section II.5.1).

Dietary crude protein content and the balance of dietary amino acids may influence VFI in pigs (Robinson et al. 1974; Henry et al. 1992a, b, 1996). Pigs fed low protein diets or diets deficient in one or more essential amino acids responded by consuming more feed in an attempt to meet requirements for the limiting amino acids (Henry 1985) although this may not always be the case (Robinson 1975; Henry 1995). However, VFI may not be affected when pigs are fed amino acid supplemented low protein diets in an equal energy intake situation (Le Bellego et al. 2002).

II.5.3. Feed Additives

Various additives are incorporated into swine diets to enhance performance through a variety of mechanisms, including enhancing feed intake. Inclusion in pig diets of exogenous enzymes targeting the non-starch polysaccharides components of the feed increases VFI primarily by reducing the bulkiness of the feed (Campbell and Bedford 1992). Additives such as spray-dried plasma that help maintain gut health and the general health of the pig may enhance VFI (Coffey and Cranwell 1995). Flavoring agents may increase VFI of pigs by enhancing the taste or adding an acceptable taste of feed or by masking an unacceptable taste (Whittemore 1998). Addition of 100 g kg^{-1} dextrose to a diet containing equal amounts of canola meal and soybean meal was shown to increase VFI of starter pigs to the same level as those fed soybean control diet (Baidoo et al. 1986). In the same study, commercial feed flavors were shown to improve intake of canola meal containing diets by young pigs. Weaned pigs consumed 136 g d^{-1} of a flavored diet compared with 103 g d^{-1} of non-flavored diet during week 1 post-weaning, but no differences were noted in subsequent weeks, thus suggesting that the benefit of feed flavors may be limited only to critical periods in the pig's life (McLaughlin et al. 1983). Similarly, Campbell (1976) showed increase VFI in piglet during the first week after weaning but not 3 wk after weaning. Danielsen et al. (1994) reported improvements in VFI in pigs when a flavoring agent was added to diets containing dehulled rapeseed meal. As discussed elsewhere (Patience et al. 1995; Whittemore 1998), the effectiveness of flavoring agents has not been consistently observed in different studies.

II.5.4. Dietary Contaminants

Contamination of feed grains with mycotoxins is a major challenge facing the swine industry worldwide. Feeding mycotoxin-contaminated grains to pigs reduces VFI and production performance in general. The exact effect on pig performance, however, will depend on the type of mycotoxin present in the feed. In an Australian study, VFI of growing pigs was dramatically reduced when diets containing 500 or 750 g kg^{-1} of corn naturally contaminated with *Fusarium graminearum* (Williams and Blaney 1994; Fig. 4). Voluntary feed intake of growing-finishing pigs from about 23 to 110 kg body weight was significantly lower (2.20 vs. 2.38 kg d^{-1}) when a diet containing 2 ppm of deoxynivalenol (DON) from naturally contaminated barley compared to a control with no measurable DON was fed (House et al. 2002). However, subsequent studies with the same pig genotype failed to show a reduction in VFI of growing-finishing pigs fed a 4 ppm DON diet or starter pigs fed a 2 ppm diet compared to a 0 ppm control diet (House 2003). Furthermore, feed intake of piglets fed diets containing 2 ppm DON from naturally contaminated barley was not different from control in a recent study (House et al. 2003). These observations suggest that the levels of dietary DNO at which pig performance is negatively affected need to be re-examined. They also raise an important question as to whether the impact of DON depends on the presence of other mycotoxins and if so which mycotoxins are involved and at what levels they influence the effects of DON. The need for further research to better characterize the effect of mycotoxins on VFI of pigs is evident from these studies.

II.5.5. Feed Processing and Ingredient Type

The use of by-products of the grain-processing in industry as alternative feedstuffs in swine diets may have specific effects on VFI levels and the ability of pigs of different genotypes to ingest adequate amounts of such diets to meet their nutrient demand needs to be established. Furthermore, dietary characteristics that contribute to gut fill must be identified and quantified. Dietary factors such as viscosity and water-holding capacity that could be used to predict VFI (Kyriazakis and Emmans 1990, 1995) need to be adequately evaluated.

II.5.6. Feed Form and Presentation

The presentation of feed can influence VFI in pigs. Two items of concern are diet presentation as a mash versus pellet and wet versus dry. Generally, pelleting of feed reduces feed intake but improves growth performance due to improved nutrient digestibility of the feed (Wondra et al. 1995). Offering feed as pellets as opposed to mash improves FCE, as does wet feeding compared to dry feeding (Patience et al. 1995; Botermans et al. 1997; Gonyou 1999). Wet feeding improves VFI of both pelleted and mash diets particularly in young or lighter pigs, which also seem to benefit greatly from liquid feeding (Chae-Byung 2000). However, the benefit of wet-dry feeding in market hogs is somewhat limited perhaps due to the greater ability of pigs at this phase to consume dry feed. In a recent study, presentation of a mash diet in a wet versus a dry form increased VFI 6% in

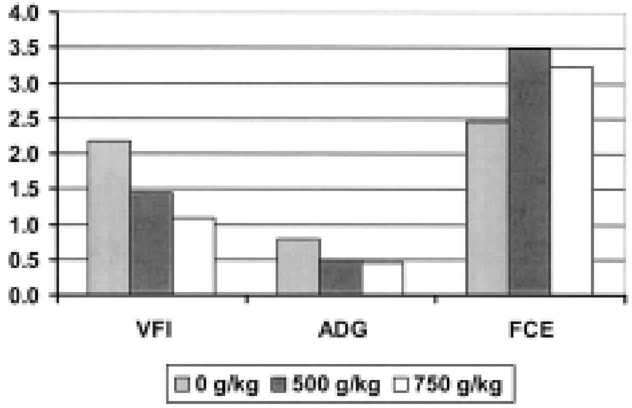

Fig. 4. Voluntary feed intake (VFI, kg d^{-1}), average daily gain (ADG, kg d^{-1}), and feed conversion efficiency (FCE) of growing pigs fed diets containing varying levels of corn naturally contaminated with *Fusarium graminearium* (11.5 mg nivalenol and 3 mg zearalenone kg^{-1}). Adapted from Williams and Blaney (1994).

growing pigs on a dry matter equivalent basis (Gonyou and Lou 2000). Pigs fed from the wet feeders had no access to additional drinking water.

II.5.7. Availability of Drinking Water

The effect of drinking water per se on VFI of pigs has not been explicitly studied. However, as water is essential for various physiological functions including digestion and nutrient utilization (NRC 1998; Thacker 2001), its availability will certainly impact on VFI of pigs. Also, through its role in body temperature regulation, it can be speculated that availability of drinking water will have an impact on VFI via mitigation of temperature effects on VFI (Mount et al. 1971; Nienaber and Hahn 1984). The water:feed ratio that optimizes pig performance is poorly defined as revised but there is likely a minimum ratio below which performance will be negatively impacted (Mroz et al. 1995). For weaned pigs, availability of drinking water soon after weaning is an important factor determining VFI (Brooks et al. 1984; Gill et al. 1986).

It is generally recommended that pigs be supplied with good quality water to ensure acceptable performance. However, the impact of water quality on VFI in pigs remains unclear and existing data suggest that water quality may not have an effect on VFI of pigs (Patience et al. 1995; Nyachoti and Patience 2003). For example, in a study with young pigs, feed intake was 0.55 kg d^{-1} for water containing 217 ppm and 0.57 kg d^{-1} for water containing 4390 ppm of total dissolved solids (McLeese et al. 1992). As water quality is affected by many different factors whose individual and collective effects on VFI of pigs have not be clearly characterized, it is prudent to argue that provision of good quality water is important for supporting acceptable pig performance (Nyachoti and Patience 2003).

III. MONITORING FEED INTAKE

From the previous discussion it is clear that accurate predictions of feed intake in specific groups of growing-finishing pigs and over the various body weight ranges are extremely difficult. Even when feed usage is monitored for specific growing-finishing pig units, feed intake (feed disappearance and feed wastage) should be monitored at the various stages of growth (Moughan and Verstegen 1988; Moughan et al. 1995). Observed feed intakes, combined with some measurements of environmental conditions, can then be used to make projections for future feed intake levels.

Even though average VFI levels differ among individual growing-finishing pig units, VFI curves (VFI, kg d^{-1}, versus BW, kg) generally follow a predictable pattern (Fig. 5). This implies that mathematical equations can be used to represent the general shape of feed intake curves, while parameters included in these mathematical equations will differ among growing-finishing pig units (de Lange et al. 1993; Schinckel and de Lange 1996; Schinckel 1999; de Lange et al. 2001; Whittemore et al. 2001a). Curves can be fitted based on detailed observations on sub-samples of representative groups of pigs. Alternatively, observations from entire grower-finisher pig units may be used, provided that pig body weights within the unit are uniform and that accurate records on average body weight, pig inventory, and feed delivery are available. The type of mathematical equation and repeatability of the observations will determine the number of observations needed to fit these curves for individual pig units (Schinckel and de Lange 1996).

For fitting VFI curves, two types of equations are often used to relate VFI to BW (de Lange et al. 1993): an exponential function ($VFI = a \times BW^b$; e.g., ARC 1981) and a generalized asymptotic function ($VFI = a \times [1 - e^{BW \times b}]$; e.g., NRC 1998). The exponential function implies that feed intake increases continuously with body weight, while the asymptotic function implies that there is a maximum feed intake that pigs can achieve. In addition, some mathematical routines may be included to reflect a (rapid) change in feed intake level when diet formulations are changed (PorkMa$ter 1997). This applies, for example, when a high energy-dense grower diet is changed to a finisher diet with a lower energy density. A minimum of five data points is suggested for curve fitting with at least two observations per diet or feeding phase. Each data point should represent the feed usage of one group of pigs (one pen or one feeder) determined over at least a 2-wk period. In addition, the average body weight of these groups of pigs over these periods should be determined. If feed intakes are established over periods that are shorter than 2 wk, feed intakes will appear highly variable and the fitted intake curve will not be very reliable (de Lange et al. 1993). In a "continuous flow" operation, these feed intake curves can be developed from observations obtained over a 2 wk period as data points can be obtained simultaneously from different pens in the unit. Relatively simple and inexpensive devices are now available to weigh the amount of feed placed into individual feeders. Unfortunately, feed wastage is difficult to quantify accurately. Feed wastage is generally about 5% of feed usage but may exceed 10% when substantial amounts of feed are observed around the feeder (Patience et al. 1995).

It is important to assess the accuracy and reliability of the curves, when observations on feed usage versus body weight

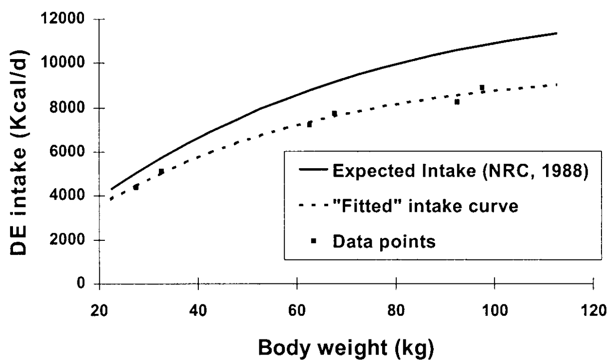

Fig. 5. Relationship between body weight and daily digestible energy (DE) intake in growing-finishing pigs [derived from de Lange et al. (2001)].

or body weight versus time are used to fit feed intake and growth curves. The assessment can be done visually (Fig. 5) or statistically. The variability of data points and accuracy of fitted curves will vary considerably among pig units. A high variability of observations within units and a poorly fitted curve are often a reflection of sub-optimal management.

For this reason, the process of developing feed intake and growth curves in itself can already be a useful exercise. Because of differences in variability among units, it is difficult to provide "rules of thumb" on the number of observations required to develop reliable feed intake and growth curves. Generally, on well-managed farms six data points that are spread out over the entire body weight range should result in reliable growth and feed intake curves. As the overall performance calculations are sensitive to feed intake and growth rates in pigs just prior to market weight, it is important that some observations are made in pigs that are close to market weight. Feed intake and growth curves should be established routinely and at least twice per year to reflect (seasonal) changes in performance within pig units.

Over the past 10 yr, numerous feed intake and growth curves have been established on commercial farms in Ontario, Canada (Agribrands Purina, unpublished). These observations have illustrated the large variability that exists in feed intake between pig units [from below 70% to more than 100%, and with an average of about 90% of voluntary feed intake according to NRC (1988)], and the use of feed intake information to further fine-tune feed intake management and feeding programs with the ultimate aim of improving profits on growing-finishing pig units.

IV. SUMMARY AND CONCLUSIONS

Feed intake in swine is closely associated with growth performance and production efficiency. Consequently, in studying the impact of different factors on pig performance, many studies have measured feed intake as one of the performance parameters. Several factors related to the environment, social interactions, diet, health status, and pig genotype influence VFI in swine. The influence of these factors on VFI is mediated through their individual or interactive effects on physiological status, immune system activation, nutrient requirements, growth potential, and composition of growth. The actual daily VFI depends on feed intake traits (e.g., number of daily visits to the feeder, time spent eating at each visit, feeding rate, etc.). VFI is evidently regulated by more than one factor at any one time in commercial conditions. Therefore, efforts to establish factors regulating VFI in pigs should take an integrated approach in which key factors are evaluated concurrently to reflect their occurrence and impact in commercial conditions. To fully understand how specific factors influence VFI, simultaneous determination of VFI traits and perhaps physiological and biochemical changes should be integrated.

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