Raidan, F., Charagu, P., Huisman, A. (2026) Thermal imaging as an indicator of pig growth efficiency, *Proceedings 13th World Congress on Genetics Applied to Livestock Production* 24386: https://doi.org/10.31274/wcgalp.24386 ©2026 *Raidan, et al.* CC BY-NC-ND

Thermal imaging as an indicator of pig growth efficiency

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Introduction

Improving feed efficiency in swine production is critical for reducing production costs and minimizing the environmental footprint of animal agriculture. Feed efficiency traits such as feed intake (FI), feed conversion efficiency (FCE), and residual feed intake (RFI) are commonly used to evaluate animal performance and have been incorporated into genetic selection programs (Koch et al., 1963; Arthur et al., 2004; Herd and Arthur, 2009). However, accurate measurement of these traits relies on automated feed station technologies that require substantial capital investment, labour-intensive, and controlled environmental conditions, constraining large-scale application in commercial production systems (Berry and Crowley, 2013). Therefore, alternative methods to evaluate feed efficiency should be investigated.

Feed efficiency is fundamentally determined by how animals acquire, partition, and dissipate energy among maintenance, growth, and heat loss. Classical studies of animal energetics established that metabolic heat production scales with body size and represents a major component of energy expenditure (Brody, 1945; Kleiber, 1975). While indirect calorimetry remains the reference method for quantifying energy metabolism (Young et al., 1975), its cost, technical complexity, and steady-state requirements limit practical use. Proxy measures such as FCE could be associated with unfavourable correlated responses, including increased mature size and maintenance requirements, thereby reducing long-term production efficiency (Tedeschi et al., 2006). Although RFI offers advantages by identifying animals with lower feed intake independent of growth, it remains sensitive to environmental variation and does not explicitly account for productivity (Berry and Crowley, 2012).

Infrared thermography (IRT) has emerged as a non-invasive, real-time technology capable of capturing physiological information related to energy metabolism. By detecting infrared radiation emitted from the body surface, IRT provides quantitative measures of surface temperature that reflect radiant heat loss and underlying metabolic activity. The IRT has been successfully applied across livestock species for monitoring health, welfare, stress responses, and thermal balance (Schaefer et al., 2012; Schaefer and Cook, 2021). In pigs, surface temperature measured by IRT has been associated with growth rate and feed efficiency traits, supporting its potential as an indicator of energetic efficiency (Cook et al., 2020; Schaefer et al., 2023). Recent studies have proposed the Thermal Efficiency Index (TEI), defined as mean body surface temperature normalized to metabolic body weight ($BW^{0.75}$), as a biologically relevant metric linking heat dissipation to energy utilization. Because metabolic heat production scales with body size, normalizing surface temperature to metabolic weight allows comparison among animals differing in size and growth potential. Lower TEI values are hypothesized to reflect reduced heat loss relative to metabolic demand and greater efficiency in energy retention for growth (Schaefer et al., 2018a).

The objective of this study was to evaluate TEI derived from IRT as a rapid, non-steady-state indicator of growth efficiency in growing pigs and to assess its association with conventional feed efficiency traits.

Materials & Methods

A total of 10,071 high-performance male Duroc pigs sourced from a high-health Hendrix Genetics (Boxmeer, The Netherlands) swine nucleus herd in Saskatchewan, Canada, were utilized in the study. Animals were reared in accordance with industry best practices, adhering to the Canadian Code of Practice for swine (NFACC, 2014). The feed scheme met or exceeded nutritional requirements as per the NRC guidelines of 2012, and fresh water was provided ad libitum. The pigs were maintained in an environmentally controlled facility with a mean temperature of 17.4 ± 0.8 ◦C and relative humidity of 54.2 ± 2%. All animals were monitored daily for health status by trained staff.

Performance metrics, including feed intake and growth, were diligently monitored using Nedap feed station technology from approximately 50 kg to 130 kg of body weight. Residual feed intake (RFI) values were computed for each animal employing the methodology described by Koch et al. (1963), where the RFI were determined as the difference between actual FI and predicted FI. The predicted FI was determined by regression of FI – mid weight to the 0.75 power ($MW^{0.75}$), gain/test period, backfat (BF_120) and fixed effects (contemporary group and age at end test period). The mid weight (MW) values were determined as per the method of Willems et al. (2013) where mid weight or MW= [(test start weight + test end weight (WT))/2]$^{0.75}$. The values for residual gain (RG) were determined as the difference between actual gain per test period and the predicted gain per test period. The predicted gain per test period was determined by the regression of gain/test period and $MW^{0.75}$, and feed intake per test period (gain per test period – MW0.75 and FI/test period and BF_120 and fixed effects). The residual intake and gain (RIG) was calculated as [-1 ∗ RFIi/RFIsd)] + [RGi/RGsd].

A non-steady-state method, as described by Schaefer et al. (2018a), was adopted to monitor metabolic rates by temporarily withholding feed for 24-hour period. Following a nine-week performance test, the pigs underwent IRT scans using a FLIR A65 camera system equipped with a wide-angle lens. These scans were calibrated against both environmental backgrounds and a water bath, with temperature corrections made to account for variations in environmental temperature that are known to influence radiated temperature (Schaefer and Cook, 2022). Then, mean surface temperature (TMean) and thermal efficiency index (temperature mean / body weight$^{0.75}$) were estimated for each animal; see Schaefer et al. (2023 for further details.

A bi-variate analysis between TEI and other production traits was performed using the general mixed model in: $\boldsymbol{y_{ij} = X\beta + Zu + e_{ij}}$; where: $\boldsymbol{y_{ij}}$ represents the phenotypic observations from the i-th pigs (i = 1 to 10,071) at the j-th production trait (j = 1 to 2), $\boldsymbol{X}$ is the incidence matrix relating fixed effects in $\boldsymbol{\beta}$ with observations in $\boldsymbol{y_{ij}}$, $\boldsymbol{Z}$ is the incidence matrix relating random additive polygenic effects in $\boldsymbol{u}$ with observations in $\boldsymbol{y_{ij}}$, and $\boldsymbol{e_{ij}}$ is the random residual effects. Fixed effects included in the model were contemporary group (i.e., end test date, room, and pen) and start weight as a covariate nested to the contemporary group. Solutions to the effects in the model as well as variance components were estimated using pedigree analyses in BLUPF90 programs (Misztal et al. 2014).

Results & Discussion

Both thermographic traits showed moderate heritability, with TEI at 0.22 ± 0.03 and TMean at 0.24 ± 0.03. The moderately strong positive genetic correlation between TEI and TMean (r = 0.57 ± 0.07) indicates that they capture overlapping but distinct aspects of thermal physiology (Table 1). While TMean reflects raw energy exchange with the environment, TEI adjusts this signal relative to metabolic size to better relate to metabolic efficiency, providing a more biologically integrated measure for efficiency traits (Schaefer et al., 2023).

Table 1. Summary statistic, heritability and genetic correlation between TEI and performance and feed efficiency traits.

Trait	Mean ± SD	Heritability	Genetic Correlation with TEI
ADG, g	1021 ± 123.34	0.25 ± 0.03	-0.78 ± 0.04
WT, kg	115 ± 12.95	0.25 ± 0.03	-0.78 ± 0.04
BF_120, mm	9.89 ± 1.94	0.43 ± 0.03	-0.49 ± 0.07
FI	148.79 ± 22.89	0.43 ± 0.04	-0.67 ± 0.05
FCE	2.42 ± 0.31	0.17 ± 0.02	-0.17 ± 0.11
RFI	0.00 ± 232.13	0.30 ± 0.03	-0.24 ± 0.09
RG	0.00 ± 53.07	0.14 ± 0.02	-0.48 ± 0.08
RGI	0.00 ± 1.53	0.22 ± 0.03	0.10 ± 0.10
TMean	33.16 ± 2.13	0.24 ± 0.03	0.57 ± 0.07
TEI	0.95 ± 0.11	0.22 ± 0.03	-

[1] ADG: average daily gain; WT: body weight at end test; BF_120: Backfat thickness adjusted to 120 kg;FI: feed intake; FCE: feed consumption efficiency; RFI: residual feed intake; RG: residual gain; RIG: residual intake and gain; TMean: mean surface temperature and TEI: thermal efficiency index at end test.

The TEI was strongly and negatively genetically correlated with WT (−0.78 ± 0.04) and ADG (−0.78 ± 0.04), indicating that pigs with lower TEI tend to grow faster and reach heavier final weights, reflecting reduced heat loss relative to metabolic body weight. This supports TEI as an indicator of biologically meaningful variation in energy utilization, where reduced radiant heat dissipation is associated with greater energy retention for growth (Loughmiller et al., 2005 and Martello et al., 2016). A moderate negative correlation was observed with BF_120 (r = −0.49 ± 0.07), consistent with fat insulating properties limiting surface heat loss (Loughmiller et al., 2000; Montanholi et al., 2009; Schaefer et al., 2018b; Cook et al., 2020).

The RFI, RG, and RIG capture complementary aspects of feed efficiency, each with distinct biological interpretations and selection potential. Heritability estimates were moderate for RFI ($h^2 = 0.30 \pm 0.03$), lower for RG ($h^2 = 0.14 \pm 0.02$), and intermediate for RIG ($h^2 = 0.22 \pm 0.02$; Table 1). The RFI has been most extensively studied, showing moderate heritability (~0.20–0.35) and favorable genetic relationships with production traits, making it a robust selection criterion for improving feed efficiency without strongly antagonistic effects on growth or carcass quality (Koch et al., 1963; Arthur et al., 2004; Herd and Arthur, 2009; Schaefer et al., 2023). The RG primarily captures growth efficiency and typically exhibits lower heritability than RFI (Tedeschi et al., 2006; Berry and Crowley, 2012), while RIG integrates deviations in both feed intake and growth, capturing animals that grow faster than expected for their feed consumption, with moderate heritability in pigs and cattle (0.22–0.34; Montanholi et al., 2009; Berry and Crowley, 2013). The choice of trait emphasis in breeding programs depends on whether the goal is reduced intake (RFI), accelerated gain (RG), or a balanced combination of both (RIG), with RFI and RIG often favored for sustainable feed efficiency (Cook et al., 2020; Schaefer et al., 2023).

The genetic correlations between TEI and feed efficiency traits reveal complementary but sometimes opposing aspects of energy metabolism. The TEI showed a weak negative correlation with RFI (r = −0.24 ± 0.09) and FCE (r = −0.17 ± 0.11) , a moderate negative correlation with RG (r = −0.48 ± 0.08), and a near-zero correlation with RIG (r = 0.10 ± 0.10), highlighting a trade-off: pigs with lower TEI grow faster and retain more energy for tissue accretion but may consume more feed, whereas TEI alone does not identify animals that combine rapid growth with low intake. This pattern is reinforced by strong negative correlations with growth (WT, ADG) and FI (r = −0.67 ± 0.05). It reflects the biological principle that energy cannot be optimized simultaneously for both maintenance and growth (NRC, 2012); the same metabolic drive that promotes rapid growth can also elevate total

energy turnover, leading to higher feed intake requirements. It's worth noting that environmental temperature variations can influence radiated temperature, which may partially explain these discrepances (Schaefer and Cook, 2022).
Overall, TEI aligns more closely with growth efficiency than intake or composite efficiency. Selecting for lower TEI could accelerate growth and shorten time to market but may potentially increase feed costs, representing up to 70% of total expenses in intensive swine systems. Therefore, TEI is most effective when used alongside RFI or RIG to select animals that balance rapid growth with efficient feed use, optimizing both performance and economic sustainability (Montanholi et al., 2009; Cook et al., 2020 and Schaefer et al., 2023).

Conclusions

Infrared thermography-derived TEI is a heritable indicator correlated with growth efficiency in pigs that reflects differences in energy retention and heat dissipation, offering a practical complement to conventional feed efficiency traits. Its integration into multi-trait selection strategies can improve productivity while supporting economic and biological sustainability in swine production.

Acknowledgements

The authors gratefully acknowledge Al Schefer and Hartmut van Gaza for their valuable assistance with data processing and for insightful discussions throughout the study.

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