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The relationships among slaughter age, final body weight, carcass weight, dressing percent, marbling, and income of crossbred Angus beef

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Abstract In 156 crossbred Angus beef cattle, final body weight (FBW) and carcass weight (CW) were highly correlated ($r = 0.964$, $R^2 = 0.930$, $P < 0.001$). Income (THB) showed significant positive correlations with slaughter age ($r = 0.450$, $R^2 = 0.202$, $P < 0.001$), FBW ($r = 0.688$, $R^2 = 0.470$, $P < 0.001$), CW ($r = 0.751$, $R^2 = 0.564$, $P < 0.001$), dressing percentage (DP) ($r = 0.392$, $R^2 = 0.153$, $P < 0.001$), and marbling score ($r = 0.734$, $R^2 = 0.538$, $P < 0.001$), with CW and marbling showing the strongest associations. Slaughter age was positively correlated with FBW ($r = 0.503$, $R^2 = 0.253$, $P < 0.001$) and CW ($r = 0.486$, $R^2 = 0.236$, $P < 0.001$), and weakly correlated with marbling ($r = 0.160$, $R^2 = 0.025$, $P < 0.05$). DP was positively correlated with CW ($r = 0.338$, $R^2 = 0.114$, $P < 0.001$), marbling ($r = 0.280$, $R^2 = 0.078$, $P < 0.001$), and income ($r = 0.392$, $R^2 = 0.153$, $P < 0.001$), but not with slaughter age or FBW. Network analysis confirmed CW, marbling, and FBW as central variables influencing income, highlighting their potential as key production indicators. These findings indicated that optimizing FBW, CW, and marbling could substantially enhance economic returns in crossbred Angus beef systems in Thailand.

Keywords: Production efficiency, Carcass traits, Economic sustainability, Food security, Livestock

Introduction

The beef cattle industry in Thailand has seen growth in recent years due to increased demand from both domestic and export markets. The government has implemented programs to improve breeding and selection of local cattle to enhance the quality and productivity of the industry. Additionally, efforts have been made to promote sustainable practices and adopt modern technologies to increase efficiency (Bunmee *et al*., 2018).

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The beef cattle sector in Thailand primarily serves domestic demand. However, the country has yet to fully meet consumer demand for high-quality beef (Phoemchalard *et al*., 2022). In 2025, the Department of Livestock Development recorded a total of 9,464,147 head of beef cattle with 1,357,184 beef cattle farmers, equivalent to a 4.4% and 5.39% decrease in cattle and farmer numbers from the previous year (Department of Livestock Development, 2025). The domestic market accounts for the major proportion of beef production in Thailand. In 2025, Thailand imported 16,496.6 tons of beef valued at 5.2 billion baht, a 26.6% increase in value compared with previous years (Nationthailand, 2025). Thai native cattle make up 50% of the national cattle population and are well adapted to tropical environments but are constrained by low growth rates. Crossbreeding of beef cattle is becoming increasingly common in the Thai beef industry (Bunmee *et al*., 2018; Phoemchalard *et al*., 2022; Phoemchalard and Uriyapongson, 2015). Hybridization offers advantages such as improved heat tolerance, disease resistance, and productivity in tropical environments (FAO, 1981). Crossbred animals can possess superior growth rates, carcass quality, and adaptability to local conditions (Cooke *et al*., 2020a; Cooke *et al*., 2020b). Currently, only 1% of Thai beef production is destined for the premium markets, determined by marbling, while about 40% goes for the modern retail market, largely focused on muscling traits (Bunmee *et al*., 2018; Phoemchalard *et al*., 2022).

Therefore, genetic improvement of growth and carcass traits is necessary to increase the competitiveness of the beef industry and sustainability for smallholders in the long run. Traits related to slaughter age, final body weight, carcass weight, dressing percentage, and marbling score can affect the overall profitability of beef cattle production by influencing yield, grading outcomes, and consumer acceptance (Gardner *et al*., 1996; Alam *et al*., 2013). Optimizing these factors can increase profitability for producers, improve Thailand's competitiveness in regional markets and benefit the smallholder farmers in the country (Khunchaikarn *et al*., 2022; Nationthailand, 2025; Koonawootrittriron *et al*., 2011). Thus, the aim of this research was to clarify the complicated interdependence among these factors in crossbred Angus beef cattle, and the aim is to determine the most appropriate parameters in production that can maximize the income return of beef producers.

Materials and methods

Study design and data collection

The secondary data were 156 Angus carcasses sourced commercially in Mukdahan province in Thailand in 2022. Carcass characteristics examined in the

research were slaughter age, final body weight (FBW), carcass weight (CW), dressing percentage (DP), marbling score, and total income.

Statistical analysis

The 156 crossbred Angus beef cattle were subjected and analyzed to Pearson correlation coefficient using JASP 0.19.3.0 (JASP Team, 2025). The R^2 and P-values were calculated through the linear regression models in R (R Core Team, 2025) with the use of the R Studio (RStudio Team, 2025). The graph theory principles of network analysis were followed, and centrality measures and community detection algorithms were considered (JASP Team, 2025). A personal computer with an AMD Ryzen 7 4800H, 16 GB of RAM, 512 GB SSD, and an NVIDIA GeForce GTX 1650 card and Windows 11 were used to conduct the computational analysis.

Results

Six production characteristics were summarized in raincloud plots (Figure 1). There was a relatively homogeneous slaughter age with slaughter age of 2.5-3.5 years constituting the majority of the slaughter age range. There was more variation in final body weight, about 300-900 kg, but most animals fell in that range of 500-700 kg. Carcass weight was similarly distributed around the means of 300-350 kg with a few light and heavy outliers ranging between 150 and above 500 kg. Carcass percentage or dressing percentage distribution was very close, i.e., 50-60%, with most of the distributions centered around 53-58, indicating that there were consistent dressings across animals. Marbling scores were normally low and moderate with most of the animals' ratings 2 to 3, with few having scored above 4. The largest spread was observed in total income with a range of about 35,000 to more than 150,000 THB with a central tendency of 50,000 to 100,000 THB. These distributions show that although dressing percentage and slaughter age were relatively similar throughout the population, it was found that market weight, carcass weight, marbling, and total income had a higher level of variability, which implies their possible importance to the production efficiency and economic returns.

The correlation analysis done by Pearson showed that there were high interrelationships between the production traits (Figure 2). Final body weight and carcass weight had the highest positive correlation ($r = 0.964$, $P < 0.001$) such that heavier animals at market always produced heavier carcasses. Income was also significantly correlated with both market weight ($r = 0.688$, $P < 0.001$) and

carcass weight (r = 0.751, P < 0.001) which proved their direct contribution to economic returns.

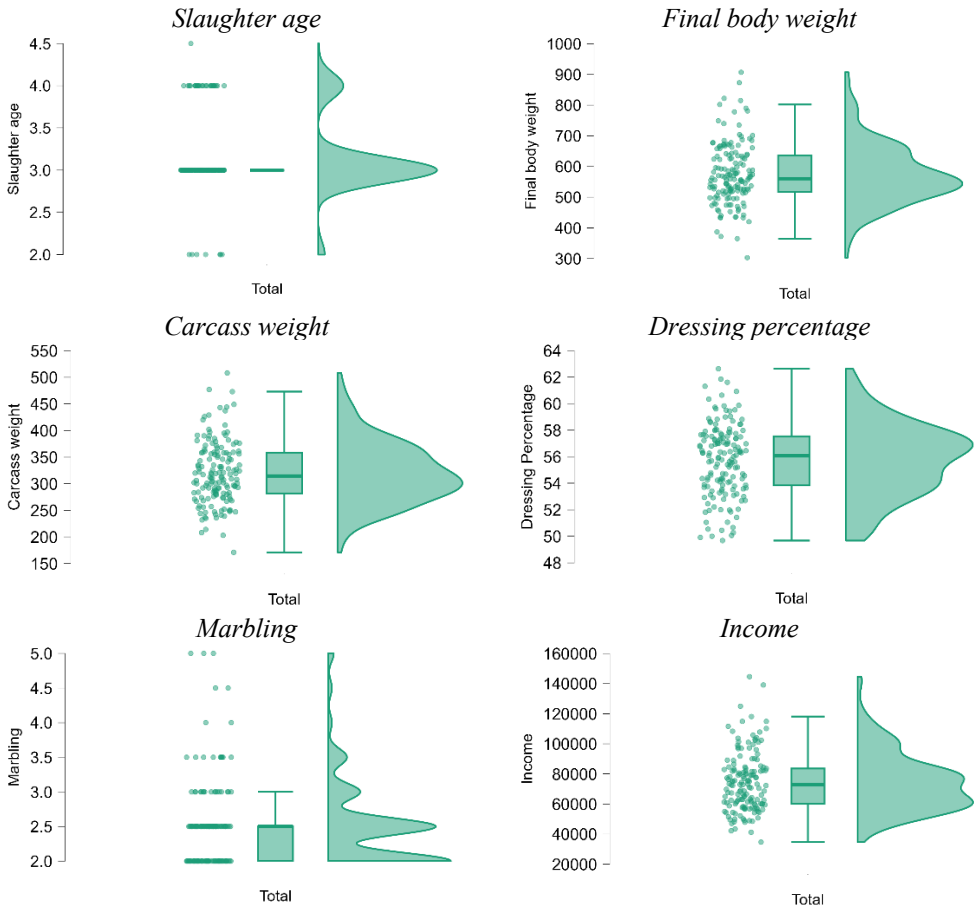

Figure 1. Raincloud plots of productive performance traits in crossbred Angus beef cattle (n = 156)

Carcass weight (r = 0.338, P < 0.001) and marbling (r = 0.280, P < 0.001) had moderate relationships with dressing percentage, which shows that the yield and quality traits interact to develop carcass performance. Marbling itself was also positively correlated with income (r = 0.734, P < 0.001) which suggests its significance in the carcass value determination. Slaughter age showed an average relationship with both final body weight (r = 0.503, P < 0.001) and carcass weight (r = 0.486, P < 0.001) but it was not as strong as income (r = 0.450, P < 0.001), which means that whereas age has some influence on growth characteristics, it does not have a decisive role in profitability. The correlations between age and marbling were not high (r = 0.160, P < 0.05). Consequently, carcass weight, final

body weight and marbling have the strongest effect on income and the age and dressing percentage have a supportive role in production and economic performance.

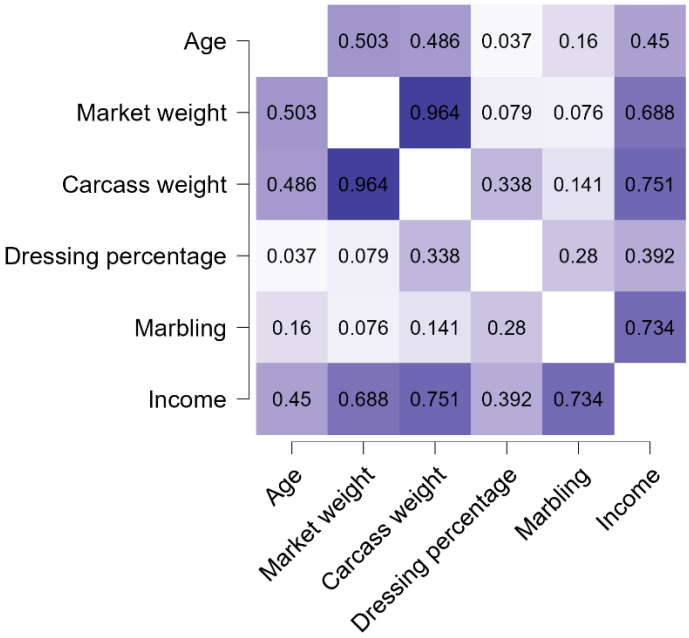

Figure 2. Pearson's r heatmap of productive performance traits in crossbred Angus beef cattle

The linear regression's models indicated that the carcass weight, and marbling were the most influential predictors of income, and the rest of the factors (slaughter age and dressing percentage) played a minor role in profitability (Figure 3). Final body weight was significantly and positively associated with the carcass weight ($R^2 = 0.93$, $P < 0.001$), where increase in live weight at slaughter directly corresponded to heavier carcasses. The effect of slaughter age on income was less but significant ($R^2 = 0.20$, $P < 0.001$) and indicated that older animals were more likely to yield higher returns but had very high variations. Contrastingly, the final body weight accounted to almost half the variance of income ($R^2 = 0.47$ $P < 0.001$), which confirms that it is a significant predictor of profitability. Similarly, the carcass weight had a significant positive impact on income ($R^2 = 0.56$, $P < 0.001$), which emphasizes that it is the core aspect of producer revenue generation. Income only had a weak association with dressing percentage ($R^2 = 0.15$, $P < 0.001$), meaning the effects were small in comparison with weight and quality traits. Lastly, marbling score was significantly and positively correlated with income ($R^2 = 0.54$, $P < 0.001$), which

supports the relevance of the carcass quality in addition to yield characteristics in the determination of economic outcomes.

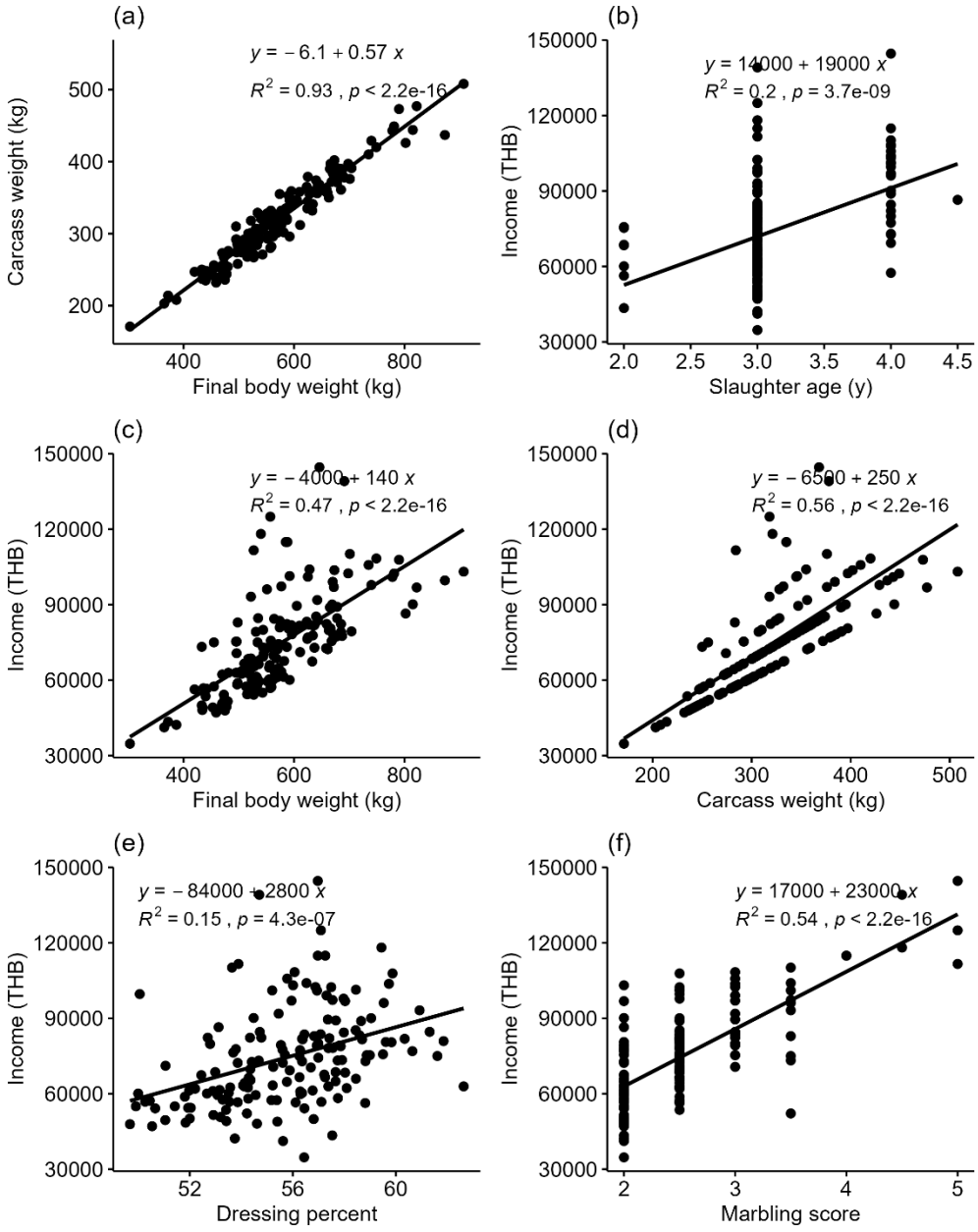

Figure 3. Linear regression of productive performance traits

The patterns of connectivity between economically significant production traits were observed with the help of network analysis. These relationships were given a visual representation in the network plot (Figure 4). There were significant positive correlations (blue edges) between income and carcass weight, final body weight and marbling, which highlight the importance of income as a hub, where biological performance is related to economic performance. Marbling had a positive but weak or negative association with other characteristics indicating it, complex relationship with the quality of the products and their market prices. The percentage of dressing displayed a significant negative correlation to the final body weight, and it represents the possibility of trade-offs between yield measures. Slaughter age had been fairly isolated within the network, and was weakly linked to other traits, showing that its role in determining system dynamics was limited.

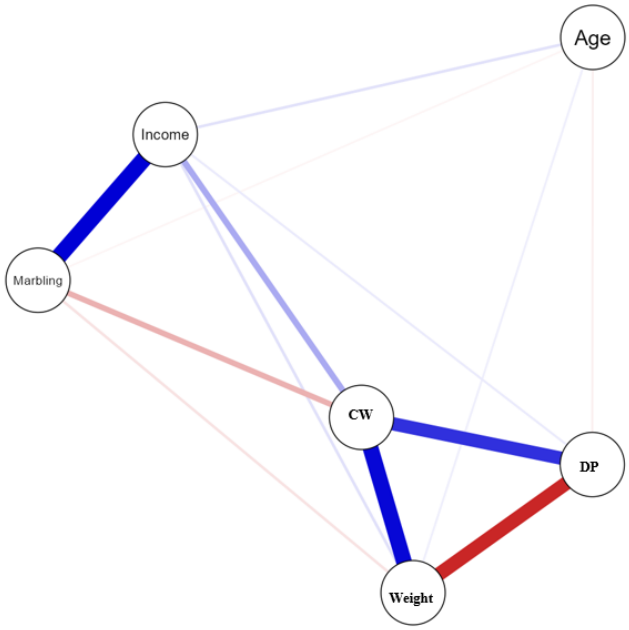

Figure 4. Network plot of production traits in crossbred Angus beef cattle. Nodes are characteristics (income, marbling, carcass weight, dressing percentage, final body weight and slaughter age), and edges are relationships between characteristics: The strength of the relationship is reflected by the thickness of the lines with blue denoting positive associations and red denoting negative associations. The key nodes became income, carcass weight, and marbling, with the strongest positive links, and age was placed in the periphery with comparatively poor links to the other characteristics. This visualization supports the conclusion that income, carcass weight, and marbling are major integrators in the production system as they influence both biological and economic results

Income, carcass weight, and marbling were always most central to the measurement (measures of centrality) as shown in Figure 5. Betweenness centrality also revealed that carcass weight and income were the prominent bridging nodes, connecting several traits in the system. The proximity of income and marbling indicated that the traits were better related to other attributes, which implied an increased ability to affect the whole network. Strength and expected influence also confirmed the superior positions of income and marbling with dressing percentage, final body weight and age in particular taking a more of a background role.

Collectively, these findings (Figures 4 and 5) highlight that income, carcass weight and marbling are structural keystones in the production network that combine both biological characteristics and profitability findings. Their key positions indicate that management and breeding approaches that focus on these characteristics will be more likely to produce the most positive shifts in performance efficiency as well as in economic returns.

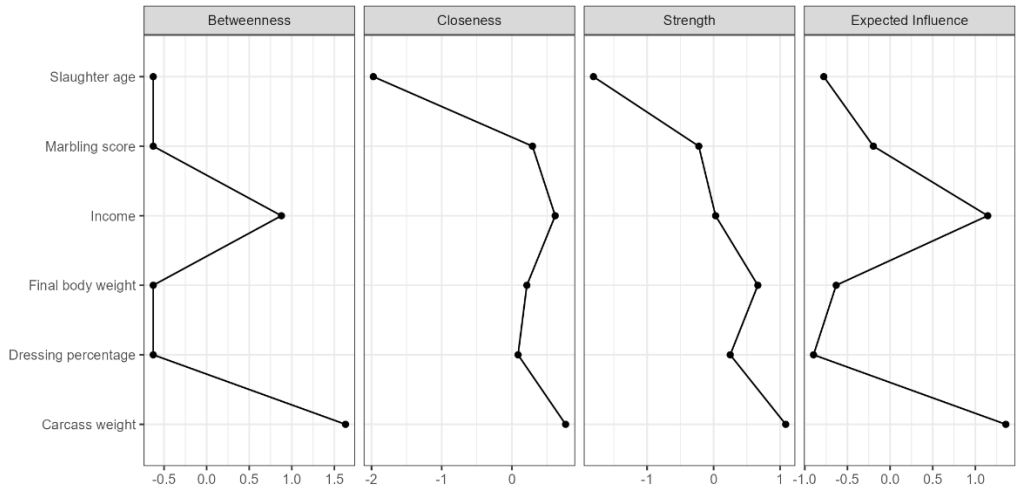

Figure 5. Network-based centrality plot of production traits. Betweenness, closeness, strength and expected influence are presented as centrality indices: They are slaughter age, final body weight, carcass weight, dressing percentage, marbling score and income. A greater value represents the increased centrality in the network. The most central traits across measures were always found to be income, carcass weight, and marbling but age played an insignificant role in network connectivity

Discussion

The distributions of production traits can give significant information about variability in the herd. There was an even spread between 2.5 and 3.5 years in slaughter age because of standard management practices in tropical beef systems where slaughter time is adjusted to maximize growth and cost (Koonawootrittriron *et al*., 2011). Final body and carcass weights were in contrast to each other and varied widely, indicating the differences in growth performance because of genetic background and nutrition and management. Since carcass weight is directly related to yield and income, its fluctuation underlines the significance of the strategies intended to enhance uniformity and efficiency (Li *et al*., 2022).

The dressing percentage was more precisely distributed with majority being 55-57. Such stability indicates that dressing yield is rather predictable as opposed to live weight traits and less influenced by environmental effects, and thus it is a stable indicator in carcass performance (Waritthitham *et al*., 2010). Marbling scores tended to be low to moderate, with little proportion greater than a score of 4. This is in line with tropical cattle breeds, where the level of intramuscular fat deposition is generally small, but the marbling is an important consumer desirability and price constituent (Beak *et al*., 2021). The range of all traits was the greatest with income with modest returns on one end and high returns on the other. This similar to report of Kang *et al*. (2019), who found that marbling score contributed the most to auction prices among carcass traits and slaughter seasons (68.63%). Sun *et al*. (2012) also noted that marbling score is strongly correlated with the auction price (0.690) and total price (0.574). This variability is a reflection of synergized effects of carcass weight, marbling, and market factors, and highlights the necessity of concerted efforts that enhance growth and quality.

The patterns of correlations that are witnessed in this research highlight the high interdependence of growth, carcass, and economic characters in crossbred beef cattle. Expectedly, final body and carcass weights showed near perfect correlation ($r = 0.964$), which is the biological connection between live weight at slaughter and carcass production. In studies, final body weight was always the best predictor of carcass weight. In Thailand, Charolais crossbreds had a higher carcass weight than Brahman crosses, and larger slaughter weights tended to promote carcass weight among the breeds and regions (Waritthitham *et al*., 2010; Tathong and Phoemchalard, 2023). This has been persistently recorded in temperate and tropical beef systems where a live weight is a useful indicator of a carcass yield (Koonawootrittriron *et al*., 2011; Li *et al*., 2022).

The carcass weight and final body weight were both strongly positively correlated with income, which supports their role as the major drivers of the economy. These are consistent with the earlier reports that carcass weight has the most significant impact on carcass value particularly in under-pricing systems where payment is highly yield-based (Waritthitham *et al*., 2010). Nevertheless, the correlation between marbling and income is very high (r = 0.734) and is a reminder that the qualities of meat quality may also considerably impact profitability, especially in the markets where premium pricing and grading incentivize marbling (Beak *et al*., 2021).

The dressing percentage and marbling showed moderate positive correlations with carcass weight which implied that yield and quality characteristics are partially consistent but not entirely independent. Surprisingly, slaughter age had moderate relations with final body and carcass weights but weak relations with income, because even though older cattle are usually heavier, there is also a possibility that the longer the finishing time, the less profitability can be earned. This observation justifies suggestions to adjust the slaughter age to achieve a balance between weight gain and feed efficiency and carcass quality (Waritthitham *et al*., 2010).

The regression analyses supported the correlation and network analyses and identified carcass weight, and marbling as the most significant variables that predict income. Final body weight was also a strong predictor of carcass weight ($R^2 = 0.93$), which agrees with prior results that live weight at slaughter is a useful surrogate of carcass yield in beef production systems (Koonawootrittriron *et al*., 2011; Li *et al*., 2022). Nevertheless, heavier animals tended to raise incomes, but the regression including final body weight ($R^2 = 0.47$) had more variation than carcass weight ($R^2 = 0.56$). This brings out the weight of the carcass as an additional more direct economic motor especially where under-pricing strategies are practiced that favour yield.

Another important factor of profitability was also found to be marbling ($R^2 = 0.54$), which supports its position in the markets of premium beef, where intramuscular fat is a strong factor in determining the grading and consumer willingness (Beak *et al*., 2021). Marbling in Korea was shown to be the main determinant of the auction price fluctuation, with an explanation of over 85 percent (Yun, 2021; Beak *et al*., 2021) and has been proved to be the most significant factor in Hanwoo value. The decisive impact of marbling on earnings, even though it is not distributed widely across the population, highlights the possibility of increasing economic returns via genetic selection and nutritional intervention to increase carcass quality in the tropical systems.

Conversely, only weak correlations existed between income and slaughter age and dressing percentage implying that there was no economic incentive to

extend finishing times or only concentrate on yield proportion. Equally, Thai data also showed that dressing percentage had a positive relationship with selling price, although the impact was not as strong as that of carcass weight (Tathong and Phoemchalard, 2023). This confirms the inference of the raincloud and correlation results that these characteristics are comparatively fixed yet not so conclusive to profitability as carcass weight and marbling.

The network analysis revealed the trends of interconnectedness of production characteristics explicitly, which gives an insight of how biological performance is translated to economic performance. The main central hub became income which had a strong positive relationship with carcass weight, final body weight and marbling. This core position strengthens the notion that traits that are closely related to income can be enhanced to produce macro-level benefits throughout the production system and thus are of particular importance to both breeding and management strategies (Li *et al*., 2022; Koonawootrittriron *et al*., 2011). Marbling showed positive relationships with carcass weight but had weaker or negative relationships with other characteristics. It is a reminder of the dual nature of marbling because it may not increase the yield statistics, but on the other hand, it is a major factor that defines the quality of meat and consumer value that might attract a higher price (Yao *et al*., 2024). Dressing percentage on the other hand exhibited a strong negative correlation with final body weight indicating that there is a yield trade-off whereby, heavier cattle do not necessarily provide carcass yields in the same magnitude. The slaughter age proved to be comparatively far-fetched in the network, and its relationships with other traits were weak, which highlights the fact that it did not have a significant impact on the results throughout the whole system. Age is an important management factor but when used alone it is unlikely to increase profitability as much as more central traits would.

The analysis of network centrality also revealed that income, carcass weight, and marbling were the most central ones, which implies that they played a major role in their connection between biological performance and economic results. The high betweenness was observed in carcass weight and income, and they served as the bridging characteristics that linked other production parameters. This implies that the management techniques that aim at achieving carcass weight gains like the optimization of finishing techniques can have system-wide effects on the yield and profitability. Closeness and strength centrality also demonstrated the efficiency of income and marbling as well as efficiently connected and influential qualities. Marbling is a well-established condition of consumer preference and higher prices in markets in which intramuscular fat is directly related to grading and carcass worth (Beak *et al*., 2021; Connolly *et al*., 2019). In comparison, other characteristics like slaughter

age and final body weight were peripheral, meaning they hardly have an integrative effect even though they play a crucial role in day-to-day management.

These results highlighted the importance of breeding and management initiatives, which can increase carcass weight and marbling at the same time, especially when working with tropical systems where crossbreeding has the potential to increase both adaptability and product quality (Gajaweera *et al*., 2023). Although the current analysis does not show causal pathways but phenotypic associations, the study highlights that a focus on central phenotypes such as marbling and carcass weight can provide the best possibilities to enhance profitability and to maintain the competitiveness of Thailand beef industry.

It can be concluded that greater final body weight was correlated with greater values on all traits. Carcass weight and marbling and returns in crossbred Angus beef systems in Thailand may be significantly improved in the future by maximizing final body weight and marbling. With prioritization of these characteristics, stakeholders will be able to realize more economic payoffs in the progression of competitiveness and sustainability of crossbred Angus beef systems.

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Conflicts of interest

The authors declare no conflict of interest.

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