The Relationship of Different Measures of Growth with Feed Efficiency in Central Highland Bucks

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Abstract

Improving the efficiency of feed utilization is a primary goal in goat breeding strategies. Thus, different measures of feed efficiency were evaluated, their relationships with growth-related traits of the Central Highland bucks were estimated, and estimation equations for feed efficiency were developed. The measures of growth such as initial weight (IWT), final weight (FWT), absolute growth rate (AGR), relative growth rate (RGR), growth efficiency (GE), and Kleiber ratio (KR) were measured from twenty-four bucks. The feed efficiency traits were dry matter intake (DMI), feed conversion ratio (FCR), feed efficiency (FE), residual feed intake (RFI), and residual weight gain (RWG). Data were analyzed using the GLM procedure of statistical analysis system. The mean FWT, DMI, AGR, FCR, FE, RGR, GE, KR, RFI, and RWG of bucks were 26.1±2.73 kg, 801.2±102.1 g/day, 54.8±23.6 g/day, 17.6±9.44 g DMI/g AGR, 0.07±0.02 g AGR/g DMI, 321.7±10.4%/day, 22.1±10.6%, 4.73±1.87 g/kg $^{0.75}$, 0.46±0.07 g/day and -0.50±0.02 g/day, respectively. The result showed that FCR was highly correlated with AGR (r=-0.78), GE, (r=-0.77) and KR (r=-0.81). Moreover, strong correlations were observed among FE and growth-related traits (r=0.95 for FE-AGR, 0.97 for FE-GE and 0.96 for FE-KR). The FWT (R^2=0.47) and GE (R^2=0.94) were the important predictors for DMI and FE, respectively. The combination of GE, KR, and RGR appeared to be more useful traits in predicting the FCR (R^2=0.86). The GE and IWT were significantly predicted the RWG with higher accuracy (R^2=0.95). The efficiency of feed utilization of bucks can be estimated with high accuracy using some growth-related traits. However, further research using enough sample size is imperative to ensure reliability and to enhance the accuracy of prediction.

Keywords: feed efficiency, growth efficiency, Kleiber ratio, relative growth rate, residual feed intake

1. Introduction

Goats play imperative roles for rural communities by improving their livelihood by creating job opportunities, used as a feed source and increasing family income from the sale of live animals and products. In addition, goats also act as an income buffer to the risks associated with erratic climatic changes [1]. Despite their valuable contributions, the productivity of indigenous goats is low due to many interrelated factors including genetics.

Different attempts have been done on improving the growth performance of goats through selection. In any genetic improvement program aimed at increasing growth performance, improving the efficiency of feed conversion is necessary to enhance the efficiency of meat production and to reduce the cost of production [2]. The inclusion of feed intake and gain information in the selection program would facilitate genetic improvement of feed efficiency and profitability of goat production [3, 4]. However, it is difficult to measure the feed intake of goats in all production systems and to estimate the feed efficiency of goats managed extensively. Hence, the existing genetic improvement programs do not include feed efficiency as a breeding objective.

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The positive correlations between feed efficiency traits and growth-related traits were reported by several authors [2, 5-8]. Consequently, growth-related traits provide a good indication of how economically an animal grows and it is recommended as an efficient selection criterion for feed efficiency under a low-input production system [9]. Moreover, growth-related traits are estimated without measurement of feed intake [5]. Several studies conducted in sheep [4, 10] and cattle [5, 7, 11, 12]. To our knowledge, however, no study has yet been undertaken to analyze the relationship of measures of feed efficiency with growth-related traits in goats, except for Mokhtari et al. [13]. Therefore, the objectives of this study were to estimate the correlation between measures of feed efficiency and growth-related traits and to develop equation for estimation of the feed efficiency from intake independent growth-related traits of Central Highland bucks.

2. Materials and methods

Location and animal management

The study was conducted at Sirinka Agricultural Research Center, which is located at 1˚45'00"N, 39˚36'36"E at an altitude of 1850 m.a.s.l. The rainfall pattern is bimodal, with the two-rainfall season, *Belg* (Feb./Mar.-April) and *Meher* (July–Oct./Nov.) and the mean annual rainfall amount is on average about 950 mm. The area is a moderately warm temperature zone with mean daily temperature ranges from 16-21ºC.

Twenty-four intact Central Highland bucks with similar age (approximately 9 months) were purchased from the local market. Those goats were quarantined for 21 days in an isolated holding yard at the station and were treated for internal and external parasites before the experiment. Following quarantine, the experimental animals were placed in experimental house partitioned into individual pens (1.25 × 0.9 m) that was equipped with feeding trough and watering buckets. All the experimental goats received natural grass hay and water *ad libitum* throughout the experimental period. In addition to grass hay, a concentrate mix was provided at 3% of their body weight per head. The ration used in this experiment was comprised of pigeon pea leaf hay (25%), wheat bran (49%), Noug seed cake (25%) and salt (1%). The chemical compositions and digestibility of feed were presented in Table 1. The trial lasted for 100 days including the adaptation period. Animal care and all experimental procedures were complied with FASS [14] and were approved by the Amhara Agricultural Research Institute animal health and welfare researchers.

Table 1. Chemical composition and digestibility (%) of experimental feeds used

Experimental feeds	DM	Ash	CP	NDF	ADF
Grass hay	89.0	12.3	9.60	64.4	30.2
Concentrate mix	88.7	9.80	24.1	41.9	27.7
Digestibility (%)	68.9	-	71.1	66.8	59.0

DM=dry matter; CP=crude protein; NDF=neutral detergent fiber; ADF=acid detergent fiber

Data and evaluated traits

The traits investigated in this study were initial live weight (IWT), final live weight (FWT), dry matter intake (DMI), feed conversion ratio (FCR), feed efficiency (FE), absolute growth rate (AGR), relative growth rate (RGR), growth efficiency (GE), Kleiber ratio (KR), residual feed intake (RFI) and residual weight gain (RWG). The amount of feed offered and refused by each animal was weighed and recorded each morning using a sensitive balance with 1g precision. Daily feed intake for each goat was calculated as the difference between daily feed offered and leftover. The live weight of each experimental animal was measured after overnight fasting to account for differences in gut fill at the beginning of the experiment and weekly intervals during the experimental period. The formula for other traits is shown in Table 2.

Estimated DMI (DMIe) used for the calculation of residual feed intake (RFI) was obtained by the following regression equation:

$$\mathbf{DMIe=\alpha+\beta_1 AGR+\beta_2 MWT^{0.75}+\varepsilon} \quad (1)$$

where: α is the intercept and β1 and β2 are the regression coefficients of dry matter intake (DMI) on absolute growth rate (AGR) and metabolic mid-weight ($MWT^{0.75}$), respectively, and ε is RFI.

The estimated absolute growth rate (AGRe) used for the calculation of residual weight gain (RWG) was obtained by the regression equation:

$$\mathbf{AGRe=\alpha+\beta_1 MWT^{0.75}+\beta_2 DMI+\varepsilon} \quad (2),$$

where: α is the intercept and β1 and β2 are the regression coefficients of absolute growth rate (AGR) on metabolic mid-weight ($MWT^{0.75}$) and dry matter intake (DMI), respectively, and ε is RWG.

Table 2. Definition of traits investigated

Trait	Abbreviation	Definition	Formula
Initial weight	IWT	Weight at the beginning	-
Metabolic mid-weight	$MWT^{0.75}$	Weight at the mid of experimental period	(Weight at 42 day)$^{0.75}$
Final weight	FWT	Weight at the end	-
Dry matter intake	DMI	Dry matter feed intake/day	Feed offered-refusal
Absolute growth rate	AGR	Weight gain/day	(FWT-IWT)/days on test
Kleiber ratio	KR	Weight gain per unit metabolic body weight	AGR/ $FWT^{0.75}$
Growth efficiency	GE	The superiority of weight at a specific age relative to initial weight	(FWT-IWT/IWT)×100
Relative growth rate	RGR	Growth relative to instantaneous size	[ln (FWT)–ln (IWT)/day on test]×100
Feed conversion ratio	FCR	Dry matter feed intake per unit weight gain	DMI/AGR
Feed efficiency	FE	Weight gain per unit of dry matter feed intake	AGR/DMI
Residual weight gain	RWG	AGR net of the expected feed requirements for maintenance and growth, with AGRe obtained by regression of AGR on DMI and $MWT^{0.75}$	AGR–AGRe
Residual feed intake	RFI	DMI net of the expected feed requirements for maintenance and growth, with DMIe obtained by regression of DMI on $MWT^{0.75}$ and AGR	DMI–DMIe

DMIe=estimated DMI; AGRe=estimated AGR; Sources: [5, 7, 10, 15]

Data analysis

The data were analyzed using the general linear model procedures of the Statistical Analysis System [16]. Pearson's correlation coefficient was estimated among investigated traits. The stepwise multiple regression procedure of SAS was used to obtain models for estimation of feed efficiency from intake independent growth-related traits based on the significance of their parameters ($p \leq 0.05$). The higher value of the coefficient of determination (R^2) was used to determine explanatory variables that contribute much to the response variable. The multivariate relationships between variables were analyzed through principal component analysis (PCA). The model for the analysis of multiple linear regressions was:

$$\boldsymbol{Y_i=\alpha+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\beta_4 X_4+e_i} \quad (3),$$

where: Y_i is the response variables; α is the intercept; X_1, X_2, X_3 *and* X_4 are the predictor variables such as Kleiber ratio, relative growth rate, absolute growth rate, growth efficiency; β_1, β_2, β_3 and β_4 are the regression coefficient of the variables X_1, X_2, X_3 *and* X_4, and e_i is the residual random error.

3. Results and discussion

The efficiency of feed utilization and growth-related traits of Central Highland goat is presents in Table 3. The prediction equation for estimated DMI (DMIe) was:

$$\mathbf{DMIe=-0.0167+0.88*AGR+0.0668*MWT^{0.75}}$$

and for estimated AGR (AGRe) was:

$$\mathbf{AGRe=-0.0698+0.006*MWT^{0.75}+0.07*DMI}$$

The mean dry matter intake (DMI), absolute growth rate (AGR), feed conversion ratio (FCR), feed efficiency (FE), relative growth rate (RGR), growth efficiency (GE), and Kleiber ratio (KR) of Central Highland goat were 801.2 g/day, 54.8 g/day, 17.6 g DMI/g AGR, 0.07 g AGR/g DMI, 321.7%/day, 22.1% and 4.73 $g/kg^{0.75}$, respectively. The live weight of Central Highland goats fed 3% their live weight for 84 days was

26.1 kg at yearling age and their growth trend is presented in Figure 1. The higher values of GE, FE, RGR, KR, RWG and lower values of FCR and RFI are preferable.

The value for AGR, RGR, GE, and KR of bucks in this study is higher than the report of Mokhtari et al. [13] for goat and Ghafouri-Kesbi and Gholizadeh [10] for sheep during the post-weaning growth phase. The FCR in this study was higher than the value (10 kg DM/ kg weight gain) noted by Asizua et al. [17] for Mubende and Mubende Boer crossbred goats and higher than the report (10.3 kg DM/ kg weight gain) of Rahman et al. [18]. The higher FCR indicates that Central Highland bucks needs more feed to gain 1 g of weight. The quality of feed and the genetic potential of the breed could be the possible sources of variation for observed differences.

A relatively higher AGR (70.6 g/day) was noted by Tesema et al. [19] for the same breed than the current finding. However, the AGR in the present study is higher than the report of Deribe and Taye [20] and Tilahun et al. [21] for the same breed. The variation among studies could be explained by the difference in the genetic potential of the breeds, rearing type, and the nutrient composition of feed. The higher coefficients of variations were noted for AGR, FCR, FE, GE, RWG, and KR. These higher values indicate that there was slightly more variation in the feed efficiency and growth-related traits of Central Highland goat and this will open the window for within-breed selection.

Table 3. Feed efficiency and growth-related traits of Central Highland goat

Variable	Mean	SD	CV (%)
IWT (kg)	21.4	2.58	12.8
$MWT^{0.75}$	10.4	1.86	12.6
FWT (kg)	26.1	2.73	10.1
DMI (g/day)	801.2	102.8	10.8
AGR (g/day)	54.8	23.6	34.3
FCR (g DMI/g AGR)	17.6	9.44	47.9
FE (g AGR /g DMI)	0.07	0.02	37.5
RGR (%/day)	321.7	10.4	3.11
GE (%)	22.1	10.6	40.3
KR (g/kg $^{0.75}$)	4.73	1.87	32.6
RFI (g/day)	0.46	0.07	28.2
RWG (g/day)	-0.50	0.02	32.0

IWT=initial weight; $MWT^{0.75}$=metabolic mid-weight; FWT=final weight; DMI=dry matter intake; AGR=absolute growth rate; FCR=feed conversion ratio; FE=feed efficiency; RGR=relative growth rate; KR=Kleiber ratio; GE=growth efficiency; RFI=residual feed intake; RWG=residual weight gain; SD=standard deviation; CV=coefficient of variation

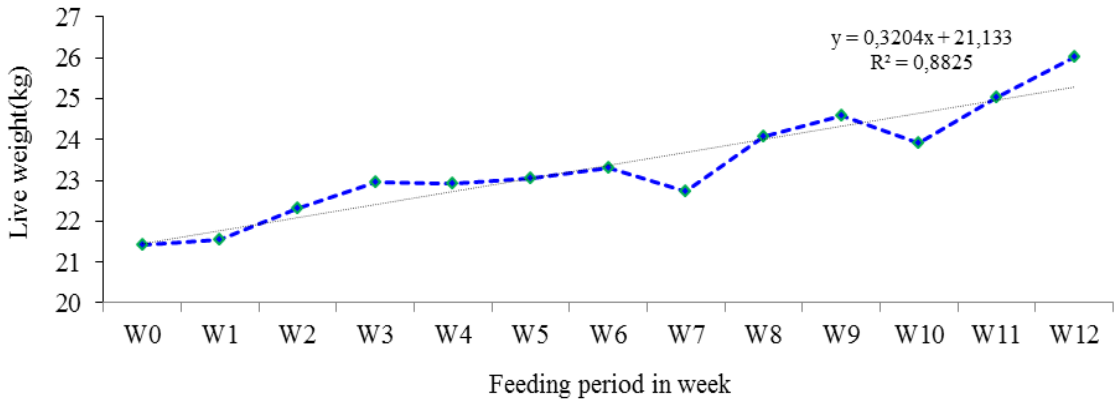

Figure 1. The growth trend of Central Highland bucks

Phenotypic correlation among feed efficiency and growth-related traits

The matrix of phenotypic correlations among measures of feed efficiency and growth-related traits are presented in Table 4 and Figure 2. The feed conversion ratio (FCR) is a measure of an animal's efficiency in converting feed mass into increases of the weight gain.

The correlations of FCR with growth-related traits (AGR, GE, and KR) were found to be significant ($p<0.001$) and higher (-0.77 to -0.81). Likewise, Arthur et al. (2001) reported higher genetic correlation of FCR with RGR (r=-0.90) and Kleiber ratio (r=-0.81) and also Talebi et al. [4] noted higher phenotypic relationship (r=-0.88) for FCR-KR in sheep.

Table 4. Correlation among feed efficiency and growth-related traits of Central Highland goat

	IWT	FWT	DMI	AGR	FCR	FE	RGR	GE	KR	RFI	RWG
IWT											
FWT	0.72^{***}										
DMI	0.37^{ns}	0.68^{***}									
AGR	-0.30^{ns}	0.44^{*}	0.46^{*}								
FCR	0.50^{*}	-0.09^{ns}	-0.30^{ns}	-0.78^{***}							
FE	-0.46^{*}	0.25^{ns}	0.16^{ns}	0.95^{***}	-0.77^{***}						
RGR	0.72^{***}	0.99^{***}	0.67^{***}	0.44^{*}	-0.09^{ns}	0.26^{ns}					
GE	-0.51^{*}	0.21^{ns}	0.28^{ns}	0.96^{***}	-0.77^{***}	0.97^{***}	0.22^{ns}				
KR	-0.47^{*}	0.27^{ns}	0.36^{ns}	0.98^{***}	-0.81^{***}	0.96^{***}	0.27^{ns}	0.99^{***}			
RFI	0.004^{ns}	0.006^{ns}	0.71^{***}	0.002^{ns}	-0.13^{ns}	0.25^{ns}	-0.01^{ns}	-0.06^{ns}	0.01^{ns}		
RWG	-0.67^{***}	-0.002^{ns}	-0.001^{ns}	0.87^{***}	0.76^{***}	0.96^{***}	0.01^{ns}	0.95^{***}	0.93^{***}	$-.25^{ns}$	

IWT=initial weight; FWT=final weight; DMI=dry matter intake; AGR=absolute growth rate; FCR=feed conversion ratio; FE=feed efficiency; RGR=relative growth rate; KR=Kleiber ratio; GE=growth efficiency; RFI=residual feed intake; RWG=residual weight gain;*=p<0.05; **=p<0.01; ***=p<0.00; ns=not significant

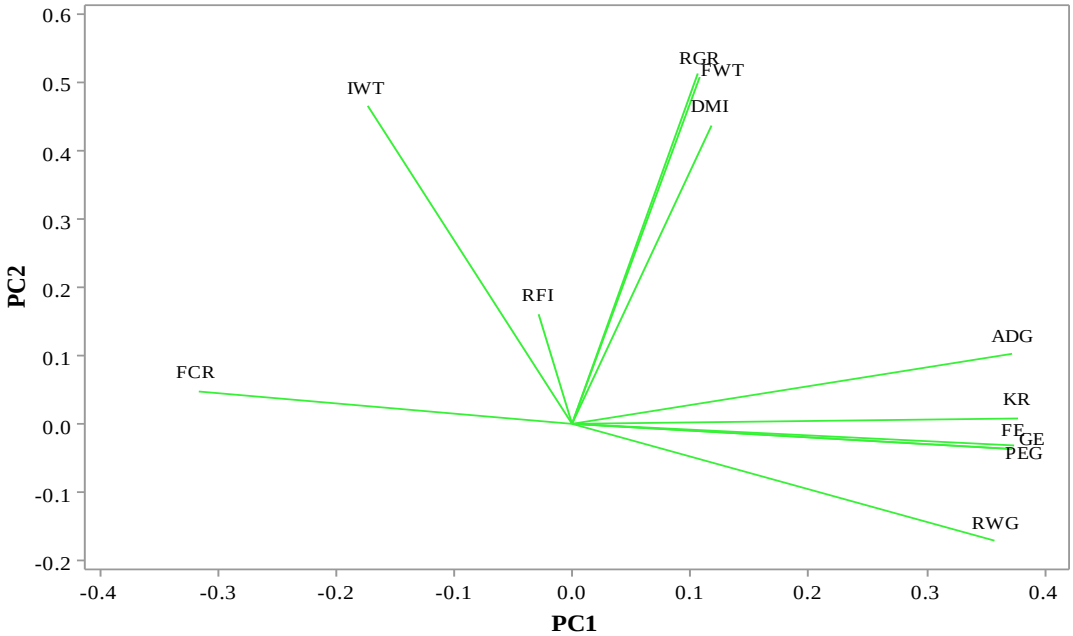

Figure 2. The multivariate relationship between variables

IWT=initial weight; FWT=final weight; DMI=dry matter intake; AGR=absolute growth rate; FCR=feed conversion ratio; FE=feed efficiency; RGR=relative growth rate; KR=Kleiber ratio; GE=growth efficiency; RFI, residual feed intake; RWG=residual weight gain

According to Ghafouri-Kesbi et al. [2] and Tesema et al. [22], animals that have high KR require less maintenance energy and are considered efficient users of feed. Likewise, Hoque et al. [12] noted that selection for KR will improve feed conversion ratio and relative growth rate with no effect on feed intake traits. The higher heritability estimates (0.39-0.54) for KR in sheep was noted by Mahala et al. [23] and a moderate level of additive genetic variance was reported by Bangar et al. [24]. This indicates that improving KR and GE resulted in a low feed requirement per gram of weight gain. These traits (KR and GE) do not require measurement of feed intake and thus could be used as an indirect selection parameter for feed conversion ratio.

Feed efficiency showed how much weight was gained from consuming one gram of feed. The higher and significant correlations were observed among feed efficiency and growth-related traits (0.95 for FE-AGR, 0.97 for FE-GE, and 0.96 for FE-KR). Comparable associations of FE with KR (0.95) and with AGR (0.95) were reported by Talebi et al. [4]. Likewise, the relationship of DMI with FWT and RGR was found to be significant and higher. These all suggest the possibility of prediction of feed efficiency from growth-related traits of a goat. To select animals for feed efficiency, the daily feed intake of animals must be recorded. However, it is difficult to obtain such a type of record and new technologies for monitoring individual feed intake are limited in developing countries. In this situation, selection for feed efficiency could be conducted indirectly using correlated traits.

The residual traits (RFI and RWG) are important indicators of feed efficiency [5, 7, 11]. The RFI is a good measure of feed efficiency and it is independent of weight gain and mature size. However, the correlation of this trait with all investigated traits except for DMI was found to be non-significant. This result is partly agreed with the report of Arthur et al. [5] in bulls. The RWG was highly correlated with GE, KR, AGR, and IWT of goats. Thus, this result suggests that using these growth-related traits as a selection criterion would results in favorable correlated responses in RWG without adverse effects on other traits.

The phenotypic correlation among AGR and RGR observed in this study is lower than the value (0.65) reported by Ghafouri-Kesbi and Gholizadeh [10]. Likewise, the higher correlations for RGR-GE (r=0.57) and RGR-KR (r=0.61) than the current study were noted by the same author. However, the phenotypic correlation for GE-KR in this study is higher than the value (r=0.76) reported by Ghafouri-Kesbi and Gholizadeh [10] for sheep and the value (r=0.88) noted by Mokhtari et al. (2019) for goat. These indicate that selection for any one of these traits would result in improvement in the other traits. A relatively higher relationship (-0.90) among FCR and FE was noted by Talebi et al. [4] in sheep than in the present study.

Prediction of feed efficiency from growth-related traits

The regression analysis of feed efficiency traits on different growth-related traits is presented in Table 5. Knowledge for dry matter intake has enormous advantages in goat production. FWT was the single variable of utmost importance in the prediction of DMI of goats with a moderate coefficient of determination (0.47). The GE, RGR, and KR appeared to be more useful growth-related traits in the prediction of the feed efficiency of Central Highland goat (Table 5).

Table 5. Regression of feed efficiency traits on growth-related traits

Trait	Model	Parameters				R^2	R^2 change
		α	β_1	β_2	β_3		
DMI (g/day)	FWT	0.133	0.025			0.47	0.00
FCR (g I/ g gain)	KR	37.0	-4.10			0.66	0.00
	KR + GE	47.2	-17.1	2.33		0.77	0.11
	KR + GE + RGR	-47.7	-23.5	3.38	0.32	0.86	0.09
FE (g gain /g I)	GE	0.01	0.002			0.94	0.00
RWG (kg/day)	GE	-0.04	0.002			0.90	0.00
	GE + IWT	0.006	0.0016	-0.002		0.95	0.05

DMI=dry matter intake; I=intake, FCR=feed conversion ratio; FE=feed efficiency; RGR=relative growth rate; KR=Kleiber ratio; GE=growth efficiency; RWG=residual weight gain; IWT=initial weight; α=intercept; β=regression coefficient; R^2=coefficient of determination

When Kleiber ratio was the first variable, the feed conversion ratio was predicted with better accuracy (R^2=0.66). The addition of other growth-related traits to KR resulted in significant improvements in the accuracy of prediction (from 66 to 86 %). Therefore, the prediction of feed conversion ratio could be based on regression equation:

Y(FCR)=-47.7–23.5*KR+3.38*GE+0.32*RGR

About 92% and 94% of the variation in feed efficiency was explained by Kleiber ratio and growth efficiency, respectively (Figure 3).

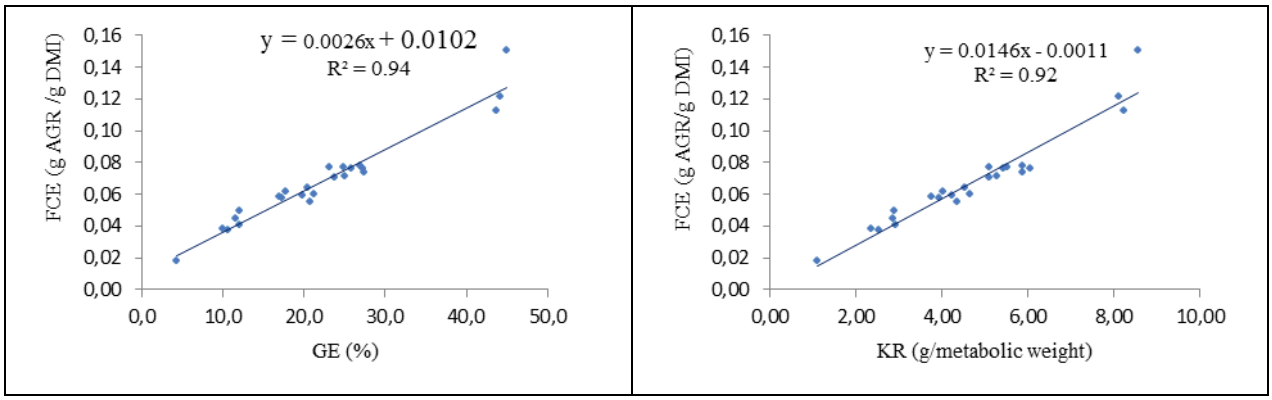

Figure 3. Regression of feed efficiency (FE) on growth efficiency (GE) and Kleiber ration (KR)

The GE and IWT were the most important traits used to predict the RWG with higher accuracy (R^2=0.95). This higher accuracy of prediction implies that the feed efficiency of the goat would be measured indirectly using the available growth data without recording feed intake. Moreover, these prediction equations could be applicable in developing countries in which there is no recording system for the intake of goats.

4. Conclusions

In conclusion, the feed utilization efficiency of Central Highland goats can be estimated with a high accuracy using some feed intake independent growth-related traits. The feed efficiency of the goat would be improved and the cost of production would be reduced through indirect selection for growth-related traits. Therefore, prediction equations could be applicable in developing countries where there is no recording system for the feed intake of goats in place. However, further research using enough sample size is imperative to ensure reliability and to enhance the accuracy of prediction.

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