The correlation between the growth of body measurements, age, breed and the growth of pelvic sizes of beef cattle in South Africa.

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Summary

Dystocia is a problem in 15-30% of the births in beef cattle. Dystocia has economical losses but also has a negative impact on the health and welfare of the new-born calves. One of the reasons that can cause dystocia is a disproportional fetal-pelvic ratio. In this research we have measured animals of four different South African breeds, Brahman, Bonsmara, Nguni and Hereford. The measurements were done in two rounds with a 5 month interval. The body measurements which performed are body length, shoulder height and hearth girth. The date of birth is also collected from the animals and the pelvis height and growth is measured. All the collected measurements are put in a data set and a Multivariable General Linear Model is analysed. The results showed that for the growth of the pelvis width and area the breed had the best correlation, and for the growth of pelvis height the explanatory variables age, growth of body length and breed had the best correlation. But overall there is no strong correlation between the growth of the pelvis sizes and the growth of the explanatory variables, age or breed. The results also showed that for all three outcome variables (growth of pelvis height, width and area) there is a low R^2 (25.8, 16.5 and 20.1%) with these explanatory variables. Therefore a high percentage of the variation in pelvis growth cannot be explained by the explanatory variables. Based on this study, it is difficult to draw a clear conclusion based on the correlation between growth of the pelvis and the measured variables.

Contents

Introduction

In beef cattle production, dystocia particularly is a problem (Donkersgoed, Ribble, & Townsend, 1990). In dairy cattle the numbers of severe dystocia are internationally between the 2% and 22% and in beef cattle the prevalence ranges from 15-30% (Barrier, et al., 2013) (Donkersgoed, Ribble, & Townsend, 1990). Dystocia's can have far-reaching economic consequences, such as losing the calf, or the dam, or both (Price & Wiltbanks, 1978) (Mee.J.F., 2008). The culling rate in cows after dystocia vary from 2-30% (Meijering, 1984). Besides direct loses, calves which suffered dystocia may be less vital, resulting in higher mortality rate or retarded growing during rearing period (Meijering, 1984). The exact definition of dystocia is calving difficulty, resulting from prolonged spontaneous calving , or prolonged or severe assisted extraction, causes can be pelvic size of the dam, disproportion of the calf or position of the calf (Barrier, et al., 2013) (Mee.J.F., 2008). Experiencing dystocia has both short and long-term effects (Barrier, et al., 2013). Short-term effects can be health and welfare problems in the neonatal period. The long-term effects for the calf can be reduced survival rate until adulthood and reduced milk production when it is a heifer calf. In the research of *Barrier et al.(2013)* they looked at the neonatal physiology, survival, health and subsequent growth of calves following dystocia. They studied the long-term effects of dystocia in dairy calves by observing 455 live born calves. No assistance was needed at the birth of 360 calves(N), 82 calves required farmer assistance but were normally presented(FN) and 13 calves needed farmer assistance and were mispresented(FM). They followed the calves from birth until leaving the farm (the bulls) or until first service (heifers). Parameters they checked in this research are: salivary cortisol, rectal temperatures, survival to weaning, passive immune transfer, health treatments of the calves, and growth of the heifer calves to first service. The results showed that the calves, which needed assistance of the farmer, had higher salivary cortisol concentration in the first 24 hours after birth compared to the calves which not needed assistance. There was no significant effect of dystocia on rectal temperatures. The mortality rates in assisted calves(heifers) were significant higher than non-assisted heifers, for the FN calves the mortality percentage was 9,4% and for the FM calves 40%.

The "in normal position" calves , which needed assistance of the farmer, had a significant lower passive immune transfer. In the first 60 days after birth the calves which needed assistance and were mispresented needed to be treated with medication twice as many days then the other calves, this is significant. There was no significant relation between dystocia or not and growth to first service of heifer calves (Barrier, et al., 2013).

Naazie et al.(1989) showed that the incidence and severity of dystocia is the highest in two-year-old heifers in breeds of beef cattle. The incidence is 36% higher in two-year-old heifers then in three-year-old cows and 45% higher than in four- and five-year-old cows. *Makarechian et al. (1982, 1983)* found that the most influencing factor on the calving difficulty is the weight of the dam at calving. But *Morrison et al.(1985)* and *Johnson et al.(1988)* found that it was not the weight of the dam that has the most influences but the weight of the calf. *Naazie et al.(1989)* found that the calving period also influences the percentage of calving difficulty's, besides the weight of the dam and calf. When the heifers calf later after winter they had better nutrition for a longer time and had less difficulty's with calving. However they concluded that besides the period when the cow give birth to a calf, the ratio of the calf weight to the cows weight is still the most important factor (Naazie et al., 1989).

One of the factors that can cause dystocia is a disproportional fetal-pelvic ratio. This means that the weight of the calf is to big for the pelvic size of the dam or vice versa. It is impossible to measure the weight of the calf before it is born, it is possible to measure the pelvic of the cow before selective breeding is applied.

The best way to know the pelvic size is doing the measurement itself. However, you need different external measurements to "rescale" the actual measurement. An example to explain it; a small pelvic size can be relatively large if this is a young animal. Therefore, age influences the pelvic size, given a specific age you want to deselect animals with a relatively small pelvic size. When the pelvic size is known, the right animals can be selected to produce offspring, this is called selective breeding. Selective breeding in cattle is a process where the human chooses the cow and the bull produce offspring. The heritability of the pelvic area is 61 percent (Deutscher, 2014). Heritability is the degree of variation in a phenotypic trait in a population due to genetic variation between individuals in that population. The 61% is a high heritability therefore selecting breeding bulls and dams with large pelvic sizes can increase pelvic size of their offspring.

In the study of *Gaines, (1993)* they observed that pelvic size developing in Holstein x Hereford heifers, is not linear over time, from birth until 16 months of age the pelvic area growth is higher than after the age of 16 months. The pelvic area of heifers increases slightly faster from 10 to 15 months versus 16 to 24 months (Lane manufacturing inc.)

In the research of *lane manufacturing inc.(date unknown)* they performed pelvic measurements with the Rice Pelvimeter and weighted the calves at birth and observed if assistance was given while heifers giving birth. They collected data for three years on heifers and the same person performed the measurements. They discovered that when the pelvic area was small (less than 140 cm^2) and the calf weight was high(more than 35 kg) 80% of the births were assisted. When the heifer had a large pelvic area and the calf had a high birth weight, the calving difficulty was reduced from 80% to 48%. When the heifer had a small pelvic area and the calf had a low birth weight, the calving difficulty was reduced from 80% to 42%. By selecting the factors pelvic area and calf weight, the calving problems can be decreased with 75% (Lane manufacturing inc.). In the research of *Kolkman et al.(2009)* they looked if the Rice Pelvimeter was a useful tool to measure the pelvic area of cows. They tested this in Belgian Blue cows, before culling and on the carcass. The conclusion of their study is that the Rice Pelvimeter is presumed to be a useful tool to select animals with a larger pelvic area (Kolkman et al., 2009).

The pelvic size is influences by several external body measurements. *Bellows et al.(1971)* studied if there was a correlation between the body length and the pelvic sizes. They studied over a period of three years 251 Hereford heifers and measured the body length among other external body measurements and the pelvic sizes. The conclusion of their study was that the body length had a significant relation with the pelvic area(β= 0.19, $P<0.01$) (Bellows et al., 1971). The literature also described a correlation between shoulder height and pelvis sizes (Coopman, et al., 2003). *Coopman et al.(2003)* studied the correlation between shoulder height and pelvis sizes in double muscled Belgian Blue beef breed. The external body measurements of 666 animals and the internal pelvic measurements of 332 cows were collected, over a period of six years 192 of them had both external and internal body measurements. They found that the shoulder height had a positive low(r between 0,17 to 0,26), but significant ($P<0,01$) adjusted correlation with inner pelvic sizes. This indicated that in the double-muscled Belgian Blue beef breed the taller animals, irrespective of their live weight, tended towards wider pelvic sizes (Coopman, et al., 2003). *Ramin et al.(1995)* also studied the correlation between shoulder height and pelvic area, they measured 108 dairy heifers from five dairy herds. They found a positive correlation between pelvic height and area with shoulder height at 12-15 months of age (Ramin et al., 1995). A third external body measurements, the hearth girth, is studied by *Bellows et al.(1996)*. They studied the correlation between hearth girth and the pelvic size in Brahman-cross heifers. The study involved 666 Brahman-cross heifers over a three years period.

They measured the pelvic width, pelvic height, hip height, hearth girth, condition score, body weight and calf weight. They concluded that there was a significant (P<0.01) positive correlation between hearth girth and pelvic height(r=0.22), pelvic width(0.18) and pelvic area(0.25) (Bellows et al., 1996). Another external body measurements that influences the pelvic sizes and area is age. The growth of the pelvis is not linear, because the pelvis grows faster from 10-16 months of age and slowed down from 16-22 months of age, after 22 months there was almost no growth of the pelvis anymore (Gaines J.D., 1993). *Gaines et al.(1993)* also found in their study that the rate of increase of the pelvic area/day increased significantly (P<0.01) in the month prior to calving, however they observed a high degree of individual variation. Therefore they concluded the pelvic measurements in the month prior to calving to predict dystocia are not usable (Gaines J.D., 1993). The maturation of the different pelvis sizes is different, the pelvic width is slightly slower in maturation than pelvic height (Green, Brinks, & LeFever, 1988). All these literature studied the correlation between an external body measurements and pelvis sizes, however there is no literature that studied the relation between the growth of an external body measurements and the growth of the pelvis sizes. Also the most literature is done in European or American breeds, so we are going to look in South African breeds.

Breeds in South Africa

Popular beef cattle breeds kept in South Africa are Brahmans, Bonsmara's, Nguni's and Herefords. Each breed will be shortly described and the maternal productivity of the four breeds is showed in table 1. It is found that the predictability of pelvic parameters varied between breeds (Ramin, Daniel, Fenwick, & Verrall, 1995).

Brahman

The Brahman is a breed of Zebu cattle*(Bos indicus)*, and finds its origin in India. This breed has an extreme tolerance for heat, but can also handle cold weather. Besides their large thermo-neutral zone they also have a thick skin, which helps protect for insect borne diseases.
Brahman cattle lives longer than the most other breeds, and have a good fertility they often still produces calves at the age of 15 or older. Because this breed is so strong, they are suitable to be kept in rural South Africa (The Cattle Site, 2014).

Bonsmara

The Bonsmara is a breed which is specially bred for the subtropical climate in South Africa and extensive cattle grazing, together with good reproduction. They are a mix of different other breeds, namely Shorthorns, Herefords and Afrikaners (The Cattle Site , 2014). Nowadays the Bonsmara is very popular and it has become strongest beef breed in South Africa in less than 25 years. The cows are fertile and calve easily. The breed is well adapted to the sub-tropical climate and have a calm temperament (The Cattle Site , 2014).

Nguni

Nguni's descend from both the *Bos Taurus* and the *Bos indicus* cattle. The breed entered Africa around 8000 years ago. The cattle breed got their name from the black tribes of Africa. When the tribes migrated South they took their cattle along. Over the years natural selection and environmental interaction evolved the breed into the hardy breed it is today. The Nguni's are smaller in size then most beef breeds. The body weight of bulls are between the 500 kg and 600 kg and that of cows between the 300 kg and 400 kg. Nguni cattle can handle both extreme heat and cold. They also have a natural immunity to tick borne diseases (The cattle site, 2014).

Their fertility is good, they reach maturity early and calve easily. The cows will often produce 10 or more calves. They are less prone to dystocia, this being ascribed to their sloping rumps, small uterus and low birth mass (The cattle site, 2014).

Hereford

The precise origin of the breed has been lost over time, most likely it originated in the early 1600's from the county Herefordshire, a region in England where this breed evolved. The breed goals of this breed are natural aptitude to grow and gain from grass and grain, rustling ability, hardiness, early maturity and prolificacy. The breed is known for their foraging ability, vigour and their longevity. They have a good fertility, many cows produce calves beyond the age of 15 years. The breed can life in all different area's and climates (The cattle site , 2014).

Table 1 - Comparative maternal productivity of the four breeds we used in South Africa (The Brahman cattle breeders' society of South Africa , 2007)

BREED	BRAHMAN	BONSMARA	NGUNI	HEREFORD
COW WEIGHT (KG)	477	466	396	479
AGE AT FIRST CALVING (MONTHS)	37	34	36	35
CALVING INTERVALS (DAYS)	441	434	412	423
CALCULATED CALVING PERCENT	79	81	87	84
BIRTH WEIGHT CALF (KG)	32	35	28	35
WEANING WEIGHT CALF (KG)	197	197	164	183

Aim of the study

In this study we assessed the relationship between pelvic growth and change in other body measurements, body length, shoulder height and hearth girth in four South African beef breeds, Brahman, Bonsmara, Nguni and Hereford. Because age could influence the pelvic size as well we also analyzed this factor. The hypotheses of this study is that there is a correlation between the growth of all the external body measurements and the growth of the pelvic sizes.

Material and methods:

Animals

For this study we visited five different stud beef farms all within in a radius of 250 km of each other. Two of the farms had Bonsmara's, one had Brahmans, one Nguni's and one Herefords.
The farms were selected on their willingness to participate and their availability of adequate numbers of young animals. The study consisted of two measurement rounds with an interval of 5 months.
For round one the farms needed to have more than 29 animals that were at least 10 months of age and did not had given birth to a calf.
We used different criteria to exclude animals so not all available young animals are included in the study. The exclusion criteria determined by prof. Holm are:

- Animals are not originating from this herd.
- Animals that are not typical of the breed.
- Animals with severely stunted growth or chronically sick animals.

Table 2 - The collected data in this study

GENERAL DATA	PELVIC DIMENSIONS AND DETERMINANTS
Farm number/name	Pelvic height (vertical measurement)
Breed	Pelvic width (horizontal measurement)
Animal ID	Body length
Gender	Shoulder Height
Parity	
Date of birth	
Body condition score	
Dam ID	
Sire ID	

In round two, approximately five months after round one, the same animals were measured again. Not all the animals were on the farms because some animals were sold, culled or could not be found. The measurements of the pelvic size and the external body measurements were performed in the same way as in round one. The animals also got a movement score in both measurement rounds. A score from 0 to 5, were 0 means that the animal was standing still and 5 means that the animal jumps out the crusher.

Method

Rice Pelvimeter

The Rice Pelvimeter is a device for taking transrectal pelvic measurements. The Rice Pelvimeter consists of two aluminium arms and a stainless steel scale graduated in 0.5 centimetres. On the inside of the measuring arm you can read the measurement (Lane manufacturing inc.).

For correct measurements there are two measurements needed, one horizontal and one vertical. The pelvic area is defined as the product of the measured pelvis height(vertical measurement) and pelvis width(horizontal measurement). The vertical one is taken by holding the pelvimeter vertical and opening the arms, one arm is placed on the symphysis pubis and the other arm on the sacral vertebrae. It is important not to squeeze the pelvimeter to hard, one of the two arms may slip off, causing an erroneous measurement. The horizontal measurement is taken at the level of the poas tubercles, this is the widest area of the pelvis (Lane manufacturing inc.). Most cattle will have a larger vertical than horizontal measurement (Lane manufacturing inc.). The pelvic height and width was measured six times during one day. Three different operators measured the animal twice by the use of the Rice Pelvimeter. The body length, shoulder height and hearth girth was measured one time. The animals were restrained by a neck crush, one animal at the time. For every farm we used the same form format to written down the data.

Hearth girth

To measure the hearth girth we used a dairy weight tape(brand Farmllc), but only the side with the centimetres on it was used. To have an accurate measurement it is important that the animal stands in a square evenly placed on a horizontal surface. When the animal was standing we put the measurement tape around the chest just behind the elbows. When the tape was around the chest we could read how many centimetres the hearth girth of the animal was (Farmllc).

Shoulder height

To measure the shoulder height we used a wooden pole with a scale in centimetres on it. On the wooden pole we made a wooden stick at 90 degrees angle, which we could move up and down until it reached the correct height, which was the shoulder height.

Body length

The third external body measurements(EBM) we used was the body length. Another name for the body length is the scapulo-ischial length. This means that the measurement starts at the cranial point of the scapula(acromion) and ends at the tuber ischia. It is important that the animal stands in square on a horizontal surface and is standing still. The measurement was done with help of a measuring tape.

Age

The fourth EBM is the age of the animals at the time of the second round measurements. We collected the date of birth of the animals from the farmer.

All the EBM measurements are performed before the pelvic measurements and are written down on a standard form.

Statistics

After taking the measurements the data was entered in a spreadsheet (Excel) and inspected for typos and missing fields. Extreme measurements were checked against the original hand written data if it was a typo, in which case the data set was corrected. There were also two extreme measurements, one Brahman and one Bonsmara cow, which were physically impossible during the timespan of the study. When we compared the data of these animals in the original forms and the Excel sheets there were no typos, however these animals had an high movement score in the crush what means that the animals were not standing still. Due to this high movement score, it is possible that we were dealing with measurement errors. Both these measurements are treated as outlier and removed from the dataset. To overcome the differences in the technical expertise, and because prof. Holm was the constant professor in both measurements round we only used the measurements prof. Holm collected for the pelvis height and width, and calculated the average of the two measurements, the growth is the average of round 2 minus the average of round 1. The growth of the body measurements is also calculated, the measurement of round 2 minus the measurement of round 1.
There were animals that had a negative growth on some external body measurements, for preventing errors in the analyses we set this growth to 0.0 in the data set. This due to the fact that when there is a negative growth, the model will produces errors, and it is also physically impossible for the animals to have a negative growth on shoulder height and body length.
After checking the quality of the data the exploratory statistics were done. The exploratory statistics start with a baseline table. This table shows the number of animals, their gender, their average age and their body measurements with the range and the growth, per breed. Next we need to investigate and start looking at the individual (univariate) relationships between explanatory variable and target variable, this is done in scatterplots. The plots are split per breed as the assumption is that mixing the breeds will obscure any visual relationships. Another performed exploratory statistic is the pairwise correlation. That shows if there is a correlation and if yes in which direction, between two variables. This correlation generates a coefficient called *r.* The value can range from -1.0 (a perfect negative linear relationship) to 1.0 (a perfect positive linear relationship), the value 0 means that there is no relation between the two variables.

After exploratory analysis and visual inspection, the next step is to investigate the relationship between the explanatory variables and the pelvic measurements as outcome variables. These outcome variables, the growth of the pelvic height, the growth of the pelvic width and the growth of the area. The explanatory variables are the growth of body length, shoulder height and hearth girth between the first and second round of measurements, age and breed.
Considering the data looked more or less continues a multivariable general linear model(GLM) was used to investigate the relationship between the explanatory variables and the outcome variables.
A stepwise GLM backwards regression approach is chosen to select the best model. This means that initially the model is fitted with all explanatory variables and then systematically the variables with a non-significant relationship are removed. Every model iteration is called a Run. The removal of variables is stopped when no more reduction can be done without a significant decrease in goodness of fit. The criterion chosen for goodness of fit was the Akaike Information Criterion(AIC). A model with a smaller AIC is considered to be the better model.
The GLM gives a R^2 in percentages. The R^2 means how much of the variation in the outcome variable is explained by the explanatory variables used in the model.
The multivariable models were checked for confounding, which is the case when between the stepwise modelling steps parameter estimates changes above 10% for a EBM occurred.
The validity of the model is evaluated by a visual inspection of the residuals using a normal probability plot and plotting the residuals versus the predicted values. The normal probability plot shows a normality when the open dots of the model follow the diagonal straight line. The linearity is good when the open dots are distributed evenly on both sides of the red line in the residuals plot. The determinants sex and body condition score were not analysed in this study.

Results

Table 3 - Description of the number of animals, gender, the average age and body measurements with the range and the growth(in approximately 5 months) of all the animals per breed.

BREED	BRAHMAN	BONSMARA	NGUNI	HEREFORD
TOTAL NO.	24	41	10	36
FEMALE	17	36	10	36
MALE	7	5	0	0
PELVIS HEIGHT (CM)	15.48 (14.25-18.25)	15.64 (13.5- 17.75)	13.86 (13 - 15)	17.58 (15.5-19.5)
PELVIS HEIGHT GROWTH (CM)	1.33 (0.25-3)	0.85 (0-1.75)	0.77 (0-1.5)	1.1 (0-2)
PELVIS WIDTH (CM)	9.91 (8.5-13.25)	12.20 (9.25-13.75)	10.0 (9.25-11)	15.15 (13.5-16.5)
PELVIS WIDTH GROWTH (CM)	0.78 (0-3.5)	0.49 (-0.5-1.75)	0.47 (0-1)	0.35 (-0.5-1.25)
BODY LENGTH (CM)	116.67 (107-131)	120.60 (106 -170)	104.2 (99-112)	132.19 (119.5-141)
BODY LENGTH GROWTH (CM)	1.43 (-14-24.5)	3.45 (-14.5-39)	-1.4 (-9.5-8)	10.08 (-4.5-25)
SHOULDER HEIGHT (CM)	124.22 (116.5-135)	118.44 (110-133)	110.7 (102.5-117)	126.71 (121-134)
SHOULDER HEIGHT GROWTH (CM)	5.80 (-2-26)	1.32 (-5-8)	2.1 (-4.5-8)	3.74 (-4-17)
HEARTH GIRTH (CM)	168.65 (149-189)	164.82 (117-196)	135.0 (131-139.5)	193.1 (182-208)
HEARTH GIRTH GROWTH	6.46	0.76	-6.3	0.67

(CM)	(-4-20)	(-27-10.5)	(-13- -2.5)	(-11-9)
AGE (MONTHS)	20.13 (12-33)	31.48 (23-41)	28.4 (24-34)	27.31 (25-30)

Table 3 shows a description of the number of animals as well as the average of the measurements with their range. This table gives an indication of the population of animals we used in the second round of the research. What is striking is that the Brahmans have the smallest pelvis width but the largest pelvis height, this indicates that the shape of their pelvis is different than the other breeds. The Bonsmaras are the breed with the largest external body measurements in this study and the Nguni's had the smallest external body measurements.

In the scatterplots (see appendix figures 9-16) the explanatory variables are plotted against the pelvis height and width. It can be observed that none of the explanatory variables carries a very clear correlation with either the pelvis width nor the pelvis height. Also observed is the difference in linearity between breeds and the spread of growth in body dimensions on the one hand and growth of pelvis dimensions, horizontal and vertical, on the other hand. The graphs also shows that there is no linearity assumption, with high rate of spread between the target- and explanatory variables, this indicates a large variance. The linear regression being flat in most cases, a flat linear regression means no linear relation between the target and explanatory variables.

Figure 1 – Pairwise correlation matrices between pelvis width growth (left) and the growth of hearth girth, shoulder height and body length. On the right side the pairwise correlation matrices between pelvis height growth and the growth of hearth girth, shoulder height, body length. The pairwise correlation shows if there is a linear relationship between two variables with coefficient *r*.

Figure 2 - Pairwise correlation matrices between pelvis area growth and the growth of heart girth, shoulder height, and body length. The pairwise correlation shows if there is a linear relationship between two variables with coefficient *r*.

The pairwise correlation of both the pelvis width and height growth tells the same story. It is shown that heart girth growth(0.09) has the best correlation with pelvis width growth, for pelvis height growth body length growth and hearth girth growth has the same *r* (0.19). In the pairwise correlation for pelvis area growth, the body length has the best correlation. All the pairwise correlations show that there is no strong linear relationship between the variables and the pelvis sizes growth, and also not between the explanatory variables. There is not one variable that has a strong correlation, indicating that a multivariable model probably is a better fit.

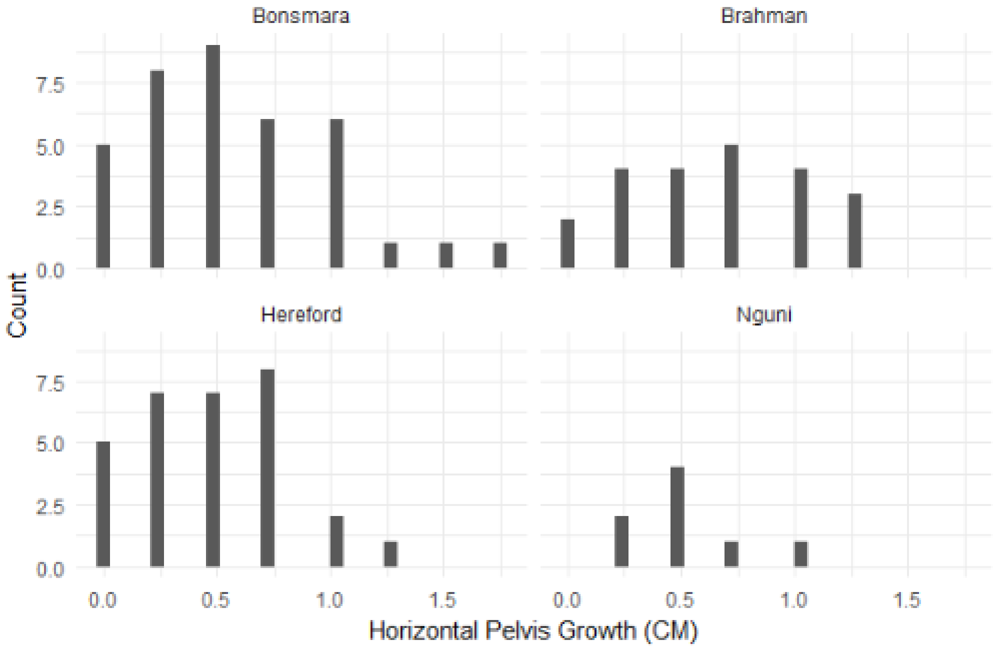

Figure 3 - Histogram of the Pelvis Width Growth per 0.25 centimetres as a function of the number of animals that has experienced this growth, split out per bovine breed.

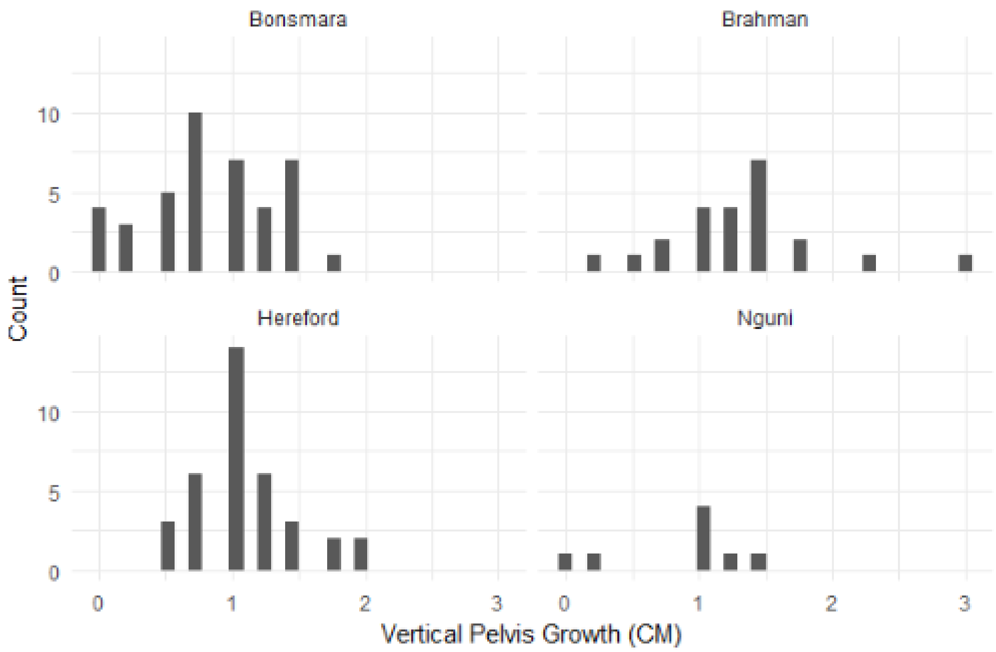

Figure 4 - Histogram of the Pelvis Height Growth per 0.25 centimetres and the number of animals that has experienced this growth, split out per bovine breed.

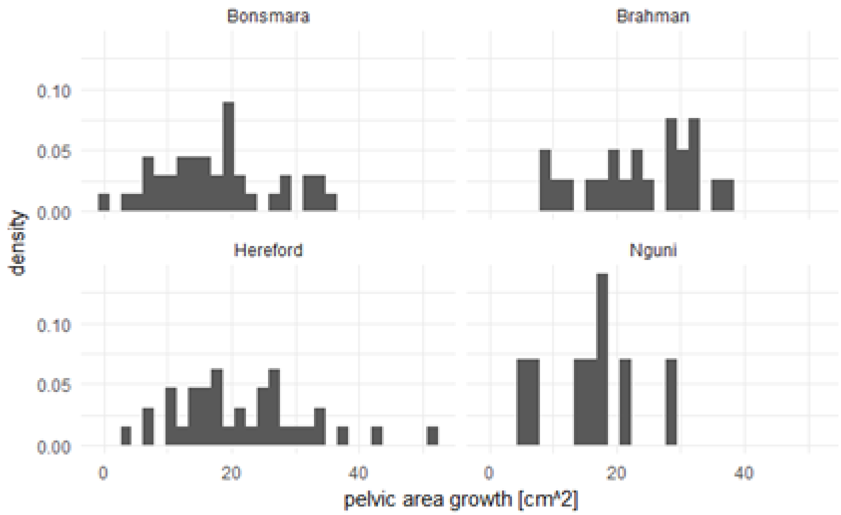

Figure 5 - Histogram of pelvic area growth per 0.25 centimeters and the number of animals that has experienced this growth, split out per bovine breed.

To judge the assumption that the target measurements are normally distributed, a histogram of the pelvic growth variables is made (shown in figure 3-5). The histograms of the pelvis width growth, and pelvis height growth are middling bell shaped and show breed variation.

Table 4 - overview of the pelvis width and height growth of all the animals per bovine breed

BREED	PERCENTAGE OF ANIMALS WITH PELVIS WIDTH GROWTH	PERCENTAGE OF ANIMALS WITH PELVIS HEIGHT GROWTH
BRAHMANS	92	100
BONSMARA	88	91
NGUNI	100	90
HEREFORD	75	100

The histograms alone are not enough to determine if there is normality in the pelvis sizes growth. To achieve this there are multivariable General linear regression models performed to see if the growth of the pelvic sizes (outcome variables) can be explained by the explanatory variables and if there is a correlation between the explanatory variables and outcome variables.

Table 5 - Multivariable parameter estimates for pelvis width growth and their change over GLM backward regressions.

VARIABLE	ESTIMATE	95% CI								
	Run 1		Run 2	Change	Run 3	Change	Run 4	Change	Run 5	Change
HEARTH GIRTH DELTA	-0.001	[-0.127 , 0.491]								
SHOULDER HEIGHT DELTA	-0.009	[-0.123 , 0.104]	-0.010	11%						
BODY LENGTH DELTA	0.021	[-0.105 , 0.147]	0.021	0%	0.019	-10%	0.019	0%		
AGE	-0.013	[-0.143 , 0.117]	-0.013	0%	-0.014	8%				
BREED - BRAHMAN	0.530	[0.133 , 0.928]	0.529	0%	0.520	-2%	0.543	4%	0.543	0%
BREED - HEREFORD	0.079	[-0.238 , 0.394]	0.078	-1%	0.076	-3%	0.085	12%	0.103	21%

BREED - NGUNI	0.288	[-0.113 , 0.689]	0.288	0%	0.287	0%	0.292	2%	0.291	0%
AIC	**141.7**		**139.7**		**137.8**		**135.8**		**133.9**	
FINAL MODEL RUN	**McFadden R^2** = 16.5%									

Table 6 – Multivariable parameter estimates for pelvis height growth and their change over GLM backward regressions.

VARIABLE	**ESTIMATE**	**95% CI**				
	Run 1		**Run 2**	**Change**	**Run 3**	**Change**
HEARTH GIRTH DELTA	0.040	[-0.074 , 0.154]				
SHOULDER HEIGHT DELTA	-0.073	[-0.176 , 0.029]	-0.067	-8%		
BODY LENGTH DELTA	0.122	[0.008 , 0.236]	0.109	-11%	0.093	-15%
AGE	0.094	[-0.024 , 0.212]	0.096	2%	0.091	-5%
BREED - BRAHMAN	0.789	[0.429 , 1.150]	0.837	6%	0.775	-7%
BREED - HEREFORD	0.339	[0.053 , 0.626]	0.377	11%	0.364	-3%
BREED - NGUNI	0.217	[-0.147 , 0.581]	0.219	1%	0.212	-3%
AIC	**123.9**		**122.38**		**122.21**	
FINAL MODEL RUN	**McFadden R^2** = 25.8%					

Table 7 - Multivariable parameter estimates for pelvis area growth and their change over multiple stepwise GLM backward regression.

VARIABLE	**ESTIMATE**	**95% CI**								
	Run 1		**Run 2**	**Change**	**Run 3**	**Change**	**Run 4**	**Change**	**Run 5**	**Change**
HEARTH GIRTH DELTA	-0.042	[-0.278 , 0.194]	-0.043	2%						
SHOULDER HEIGHT DELTA	-0.120	[-0.330 , 0.089]	-0.121	1%	-0.127	5%	-0.138	9%		
BODY LENGTH DELTA	-0.071	[-0.313 , 0.170]	-0.071	0%	-0.056	-21%				
AGE	-0.009	[-0.260 , 0.242]								
BREED - BRAHMAN	1.241	[0.459 , 2.024]	1.258	1%	1.209	-4%	1.225	1%	1.112	-9%
BREED - HEREFORD	1.050	[0.441 , 1.658]	1.056	1%	1.013	-4%	0.965	-5%	0.905	-6%
BREED - NGUNI	0.312	[-0.438 , 1.062]	0.316	1%	0.312	-1%	0.317	2%	0.301	-5%
AIC	**247.2**		**245.2**		**243.4**		**241.6**		**241.5**	
FINAL MODEL RUN	McFadden R^2 = **20.1%**									

The multivariable General Linear stepwise backward regression models show that the breed is the only explanatory variable that is left in the final model, this means that breed has the best correlation with pelvic width growth. The R^2 is 16.5% in the model for pelvis width growth and there is confounding in run 5.

For pelvis height growth the body length growth, age and breed are the explanatory variables that are present in the final model, the R^2 is 25.8%

The model for pelvis area growth showed that the breed is the only explanatory variable in the final model, the R^2 is 20.1% and there is no confounding in this model.

The residuals figures show that the linearity and normality is reasonably good for the pelvic sizes, so the multivariable General Linear stepwise backward regression model is a valid model.

Discussion and conclusion

The results of this study show that, for the pelvis width growth, breed is the explanatory variable with the best correlation. For the pelvis height growth the body length growth, age and the breeds are the best and for the pelvis area growth the best is the explanatory variable breed again. The correlation between these explanatory variables and the pelvis sizes growth is not strong. The R^2 of the final models show this as well, for pelvis width growth the R^2 is 16.5% for pelvis height growth, 25.8% and for pelvis area growth this is 20.1%, this indicates that a high percentage of the variation in pelvis growth cannot be explained by the explanatory variables we observed in this study. We also see that there is breed variation. The fluctuations above 10% in change between the different steps of the stepwise backward logistic regression model indicates that there are confounding variables that are of influence to the pelvis growth, which have not been measured or observed in this study. This was also described in another study that tested the correlation between body measurements and pelvis sizes in different breeds (Bellows et al., 1971).

It cannot be said if these conclusions are in accordance with the literature because the literature does not describe the correlation between the pelvis sizes growth and the growth of the external body measurements we performed in this study. But the literature showed that there is positive significant correlation between the body length, hearth girth and shoulder height and pelvis sizes if this was measured on one moment in time (Bellows et al., 1971, 1996)(Ramin et al., 1995) (Coopman, et al., 2003).

The literature showed that there is no good correlation between pelvis growth and age (Gaines J.D., 1993). In our study we observed no linear relationship between the age of the animals and the growth of the pelvis sizes (see figure 12 & 13 in the appendix) and also a weak correlation between age and pelvis sizes growth. *Gaines,(1993)* described that the pelvis growths faster between 10-16 months of age, slowed downed between 16-22 months of age and almost does not grows after 22 months of age. In our study most of the animals are older than 22 months(see table 3) and this can be a possible explanation for the missing linearity and weak correlation between age and growth of the pelvis sizes in our study. However *Gaines, (1993)* also described that the month prior to calving the rate of increase of the pelvic area/day increased significantly, but there is a high individual variation. This could be a reason that there is also no linearity because some animals (older than 22 months) are 7 or 8 months with young so according to *Gaines, (1993)* their pelvis is possible growing again. This could also be a reason for a lack of linearity between age and pelvis growth. There are several possible explanations for the weak correlation in our study. The first explanation is the number of animals. In the end only 111 of the 229 animals that entered the study could be used to study the growth. This reduction is explained by the reasons that animals were culled, sold or could not be found by the farmer. Due to this significantly smaller sample size the influence of the

individual variation, and any possible measurement errors are bigger. Another explanations could be the age, as mentioned above the animals in this study are mostly older than 22 months in the second round of the study and then the pelvis does not growth anymore, or they are 7 or 8 months with young and the pelvis is growing again, this gives high individual variation.
Another explanation could be that the bulls and cows are not separated for the statistics. In this study there are 13 bulls in total of the breed Brahman or Bonsmara. The literature does not describe if there is difference in the growth of the pelvis between bulls and cows. However we can see in our own results that the external body measurements of bulls are larger than the external body measurements of cows. This could give another correlation between the growth of the external body measurements and the pelvis growth. For this study we analysed this in a model (see appendix table 8) and we determined that the correlation gets weaker. Our data contained only 13 bulls but when the data set content more animals it is useful to separate the bulls and cows.
A fourth explanation could be the high variation in growth in the external body measurements. is a protocol how to do the measurements and every handler follows this protocol. However measurement errors are easily made in a dynamic environment such like field measurements, which can be caused due the difficulties and differences in restraining animals. This due to the fact that not all the farms had proper working neck crushes, and not all the animals were standing still during the measurements. When the animal is not standing still or the animal differences in physical factors such as manure in the rectum, rectal straining and fatigue of the operator, difference in measurements can occur (Van Donkersgoed et al., 1993).
Recommendations for further studies would be to maintain a bigger population of animals per breed. By the use of a a bigger population the influences of individual variation and possible measurement errors gets smaller. When the population is bigger it is also possible to separate the bulls and cows for the statistical analyses.
Another recommendation for further studies would be to Include other variables in the study to see if there is a stronger correlation and higher R^2.
Based on this study, it is difficult to draw a clear conclusion based on the correlation between growth of the pelvis and the measured variables.

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Appendix

The scatterplots below (figure 6-11) are showing the univariate relationships between explanatory variables and target variables. The plots are split per breed as the assumption is that mixing the breeds will obscure any visual relationships. The explanatory variables used in these scatterplots are: body length growth, shoulder height growth, hearth girth growth and age. The target variables are pelvis height growth and pelvis width growth.

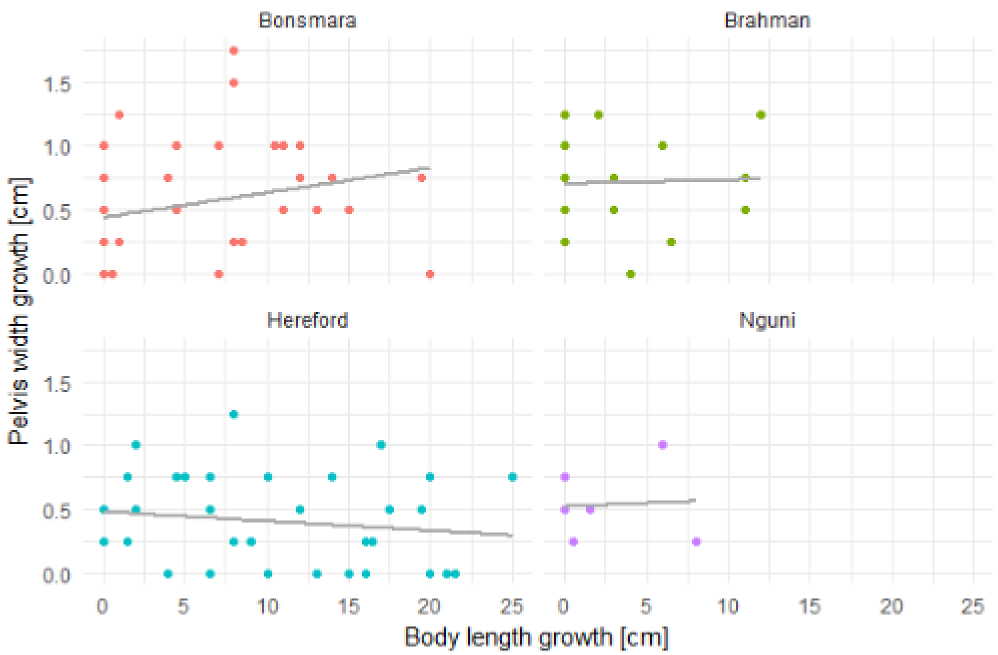

Figure 6 - Pelvis width growth as a function of body length growth, all in centimetres. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis width growth and body length growth.

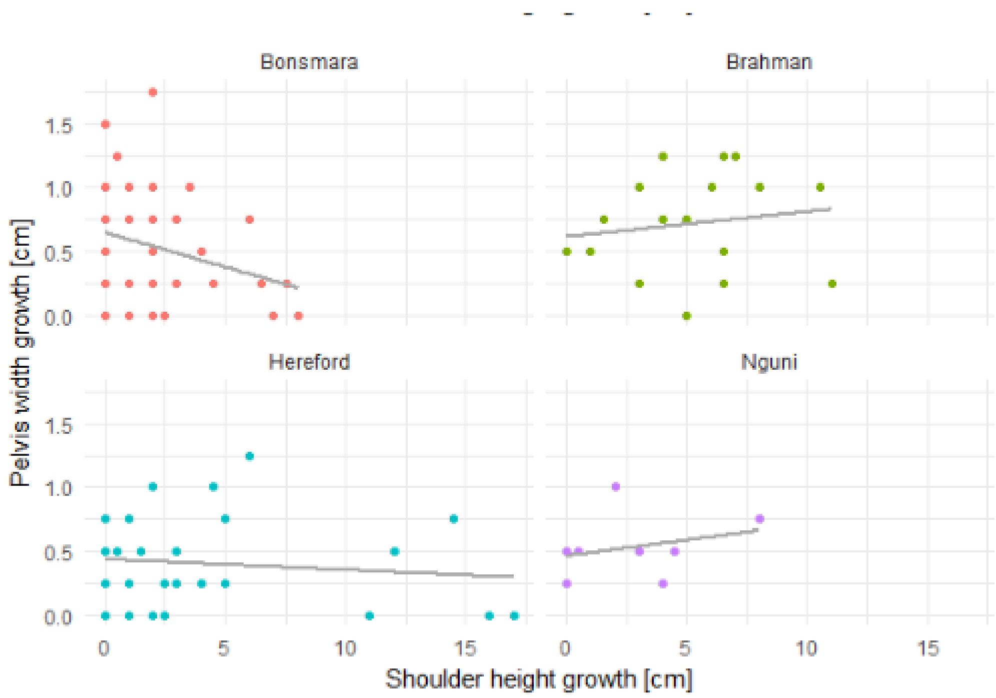

Figure 7 - Pelvis width growth as a function of shoulder height growth, all in centimetres. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis width growth and shoulder height growth.

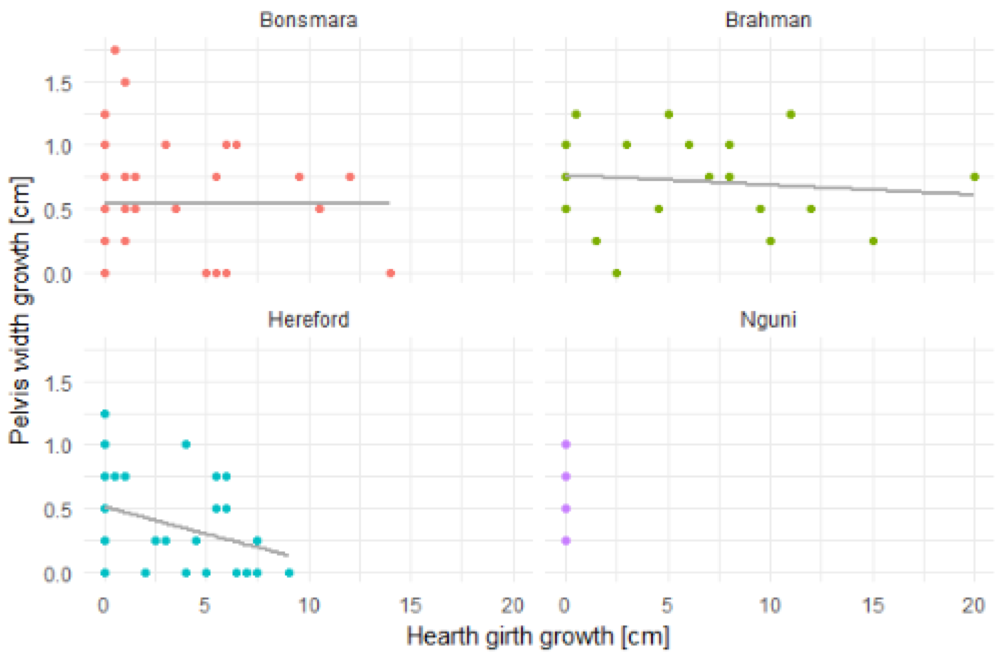

Figure 8 - Pelvis width growth as a function of hearth girth growth, all in centimeters. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis width growth and hearth girth growth.

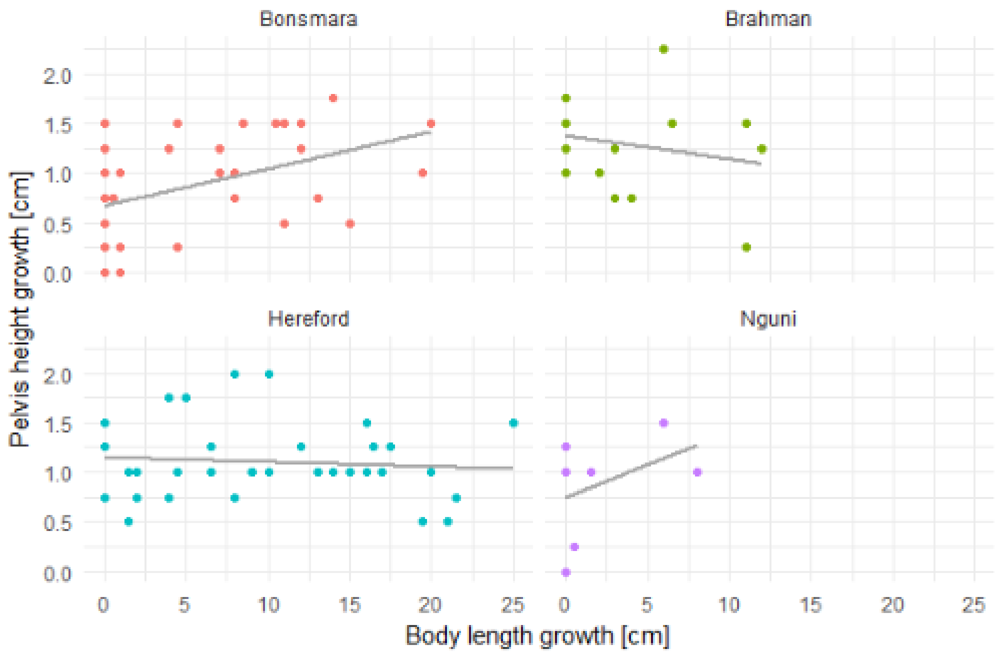

Figure 9 - Pelvis height growth as a function of body length growth, all in centimetres. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis height growth and body length growth.

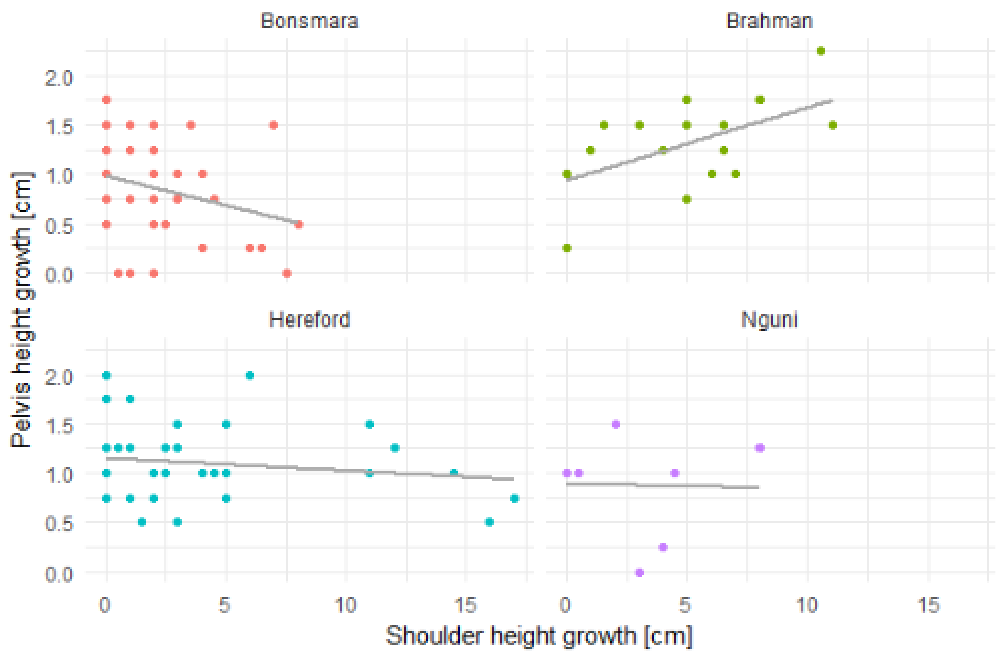

Figure 10 - Pelvis height growth as a function of shoulder height growth , all in centimetres. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis height growth and shoulder height growth.

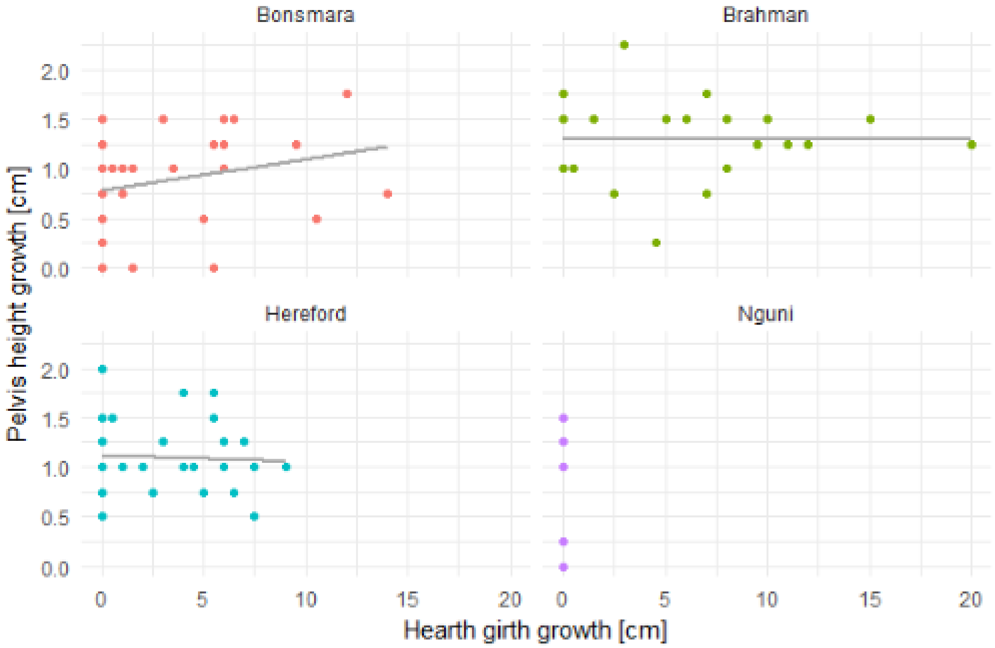

Figure 11 - Pelvis height growth as a function of hearth girth, all in centimetres. Each animal is represented with a coloured dot per bovine breed. The grey line indicates the linear relationship using a linear regression. A flat grey line indicates no linear relation between the pelvis height growth and hearth girth growth.

It was also analysed if there was a trend between the pelvis height growth, the pelvis width growth and the age of the animals. It was found that there is only a weak or no linear relationship (figure 12 and figure 13).

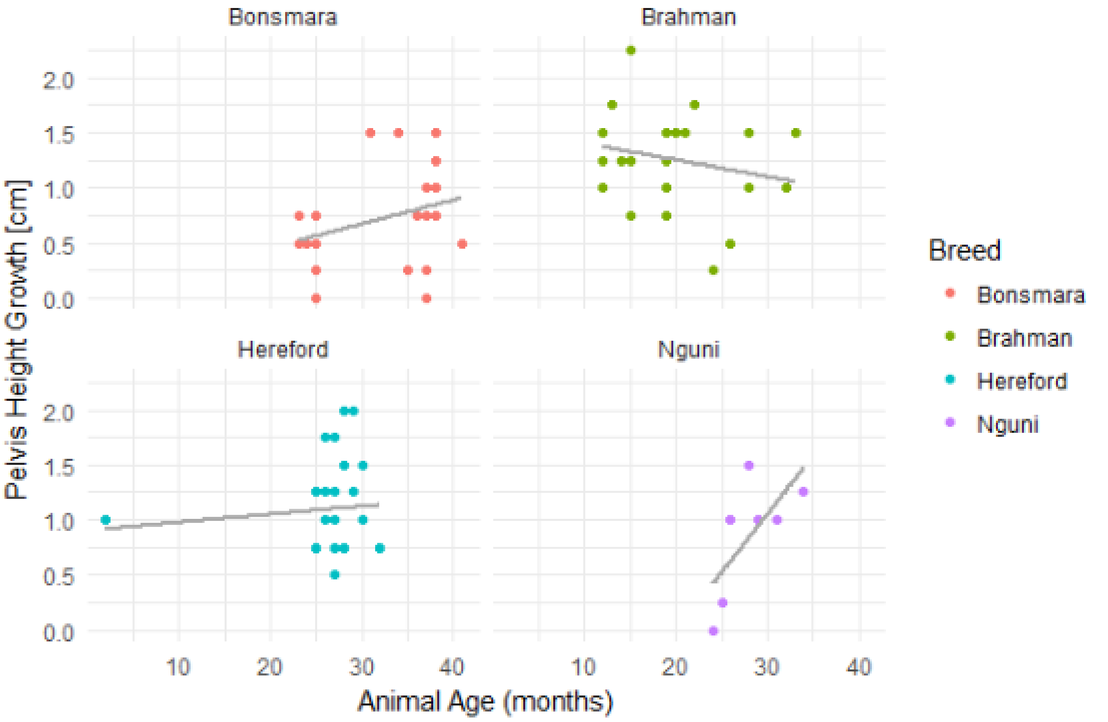

Figure 12 - pelvis height growth (in centimetres) as a function of age (in months) of the animals in the second round of the study, per breed

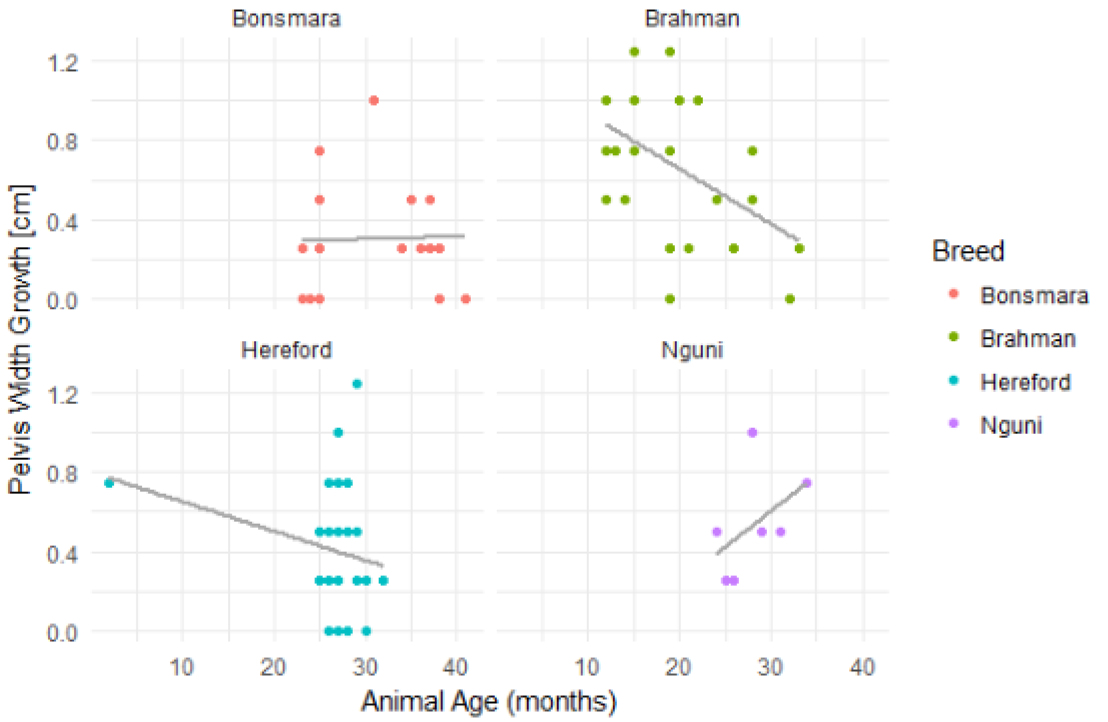

Figure 13 - Pelvis width growth (in centimetres) as function of age (in months) of the animals in the second round of the study, per breed

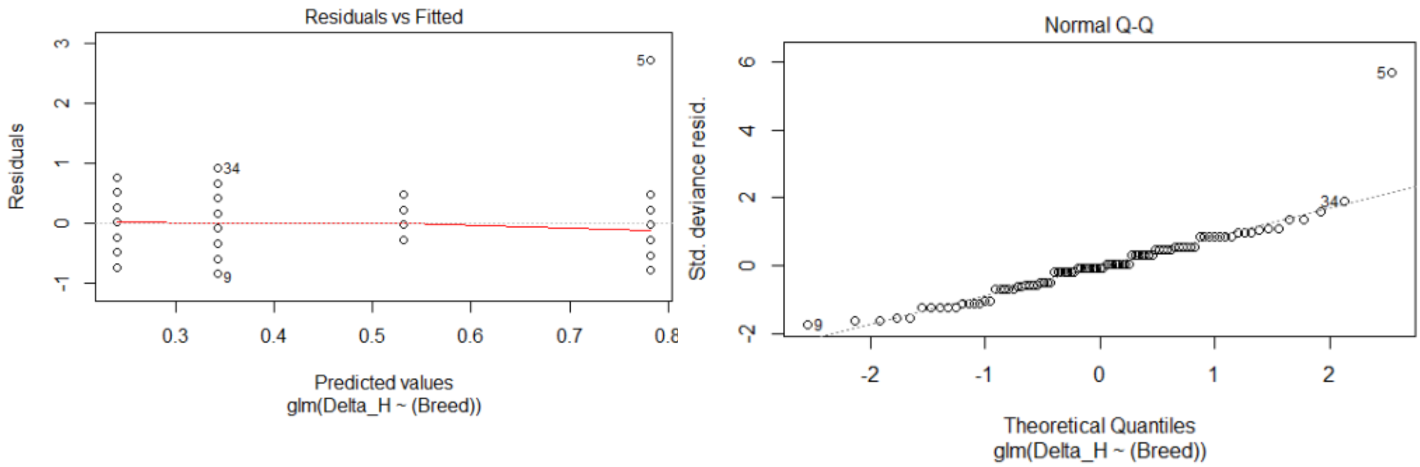

Figure 14 - Residuals and normality plot for the final run of the pelvis width regression model. When on the normality plot the line of individual open points crosses the straight line, there is no normality.

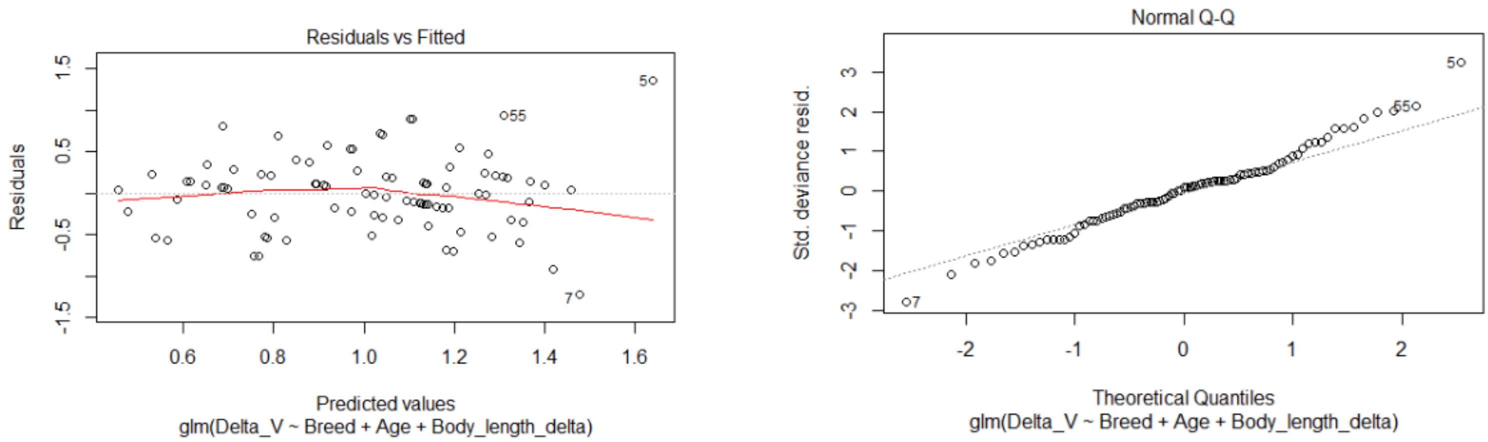

Figure 15 - Residuals and normality plot for the final run of the pelvis height regression model. When on the normality plot the line of individual open points crosses the straight line, there is no normality.

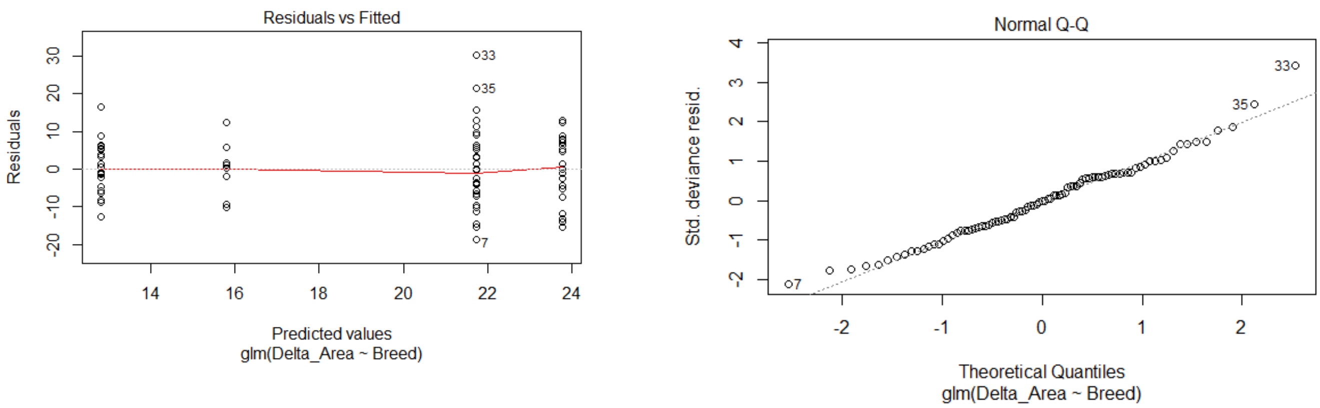

Figure 16 - Residuals and normality plot for the final run of the pelvis area growth regression model. When on the normality plot the line of individual open points crosses the straight line, there is no normality. The left figure shows the linearity and the right figure the normality.

Tabel 8 – the final run of the multivariable GLM stepwise backward regression model without the bulls. Left: pelvis width growth, middle: pelvis height growth and right: pelvis area growth.

VARIABLE	ESTIMATE
	Run 1
HEARTH GIRTH DELTA	
SHOULDER HEIGHT DELTA	
BODY LENGTH DELTA	
AGE	
BREED - BRAHMAN	0.543
BREED - HEREFORD	0.103
BREED - NGUNI	0.291
AIC	**121.3**
FINAL MODEL RUN	McFadden R^2 = 14.0%

VARIABLE	ESTIMATE
	Run 1
HEARTH GIRTH DELTA	
SHOULDER HEIGHT DELTA	
BODY LENGTH DELTA	0.053
AGE	0.080
BREED - BRAHMAN	0.792
BREED - HEREFORD	0.419
BREED - NGUNI	0.240
AIC	**115.3**
FINAL MODEL RUN	McFadden R^2 = 23.6%

VARIABLE	ESTIMATE
	Run 1
HEARTH GIRTH DELTA	
SHOULDER HEIGHT DELTA	
BODY LENGTH DELTA	
AGE	
BREED - BRAHMAN	1.093
BREED - HEREFORD	0.822
BREED - NGUNI	0.227
AIC	**218.1**
FINAL MODEL RUN	McFadden R^2 = 17.5%