Multiple regression analyses of traits contributing to the skin value of South African ostriches

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Abstract

The contribution of various skin traits to determining skin value was investigated in South African slaughter ostriches. Processed skins (n = 747) from the South African Black ostrich breed slaughtered between 2003 and 2019 and aged 282–588 d were used. Tannery data (skin size, skin grade, and quill value) were used to calculate individual skin price based on the prices paid to producers in October 2020. The PROC REG model of the SAS statistical package was used for stepwise multiple regression analyses to investigate the influence of various skin traits on skin price. Traits included skin size, skin grade, quill value, nodule size score, nodule shape score, hair follicle score, and pitting score. Pearson correlations coefficient (r) among variables were calculated using Minitab software. Skin grade accounted for most of the variation in the monetary value of individual skins at 76.66%, followed by skin size and quill value with respective contributions of 5.12% and 1.42% to the cumulative R^2 of the final model. When quill value was omitted from the model, nodule shape contributed 0.26% to the variance in skin value. When skin grade was not modelled, skin size accounted for most of the variation in skin price; pitting score contributed only 0.62% to the cumulative R^2. Pearson correlations confirmed that skin grade was the dominant regression variable for skin value (r = -0.88); quill value and skin size were significant, but less important. No strong correlations were observed between skin grade and quill value. Therefore, it seems that skin grade is the dominant force determining the price currently paid to ostrich farmers in South Africa.

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Introduction

The South African ostrich industry contributes substantially to the national economy, generating income from the three main products, *viz.* the feathers, skin, and meat (Viviers, 2015). Currently, ostrich skins contribute up to 40% of industry revenue produced at slaughter (DAFF, 2019). Due to its distinctive quill pattern, durability, and suppleness, ostrich skin can be processed into exquisite leather products that are in high demand (Al-Khalifa & Al-Naser, 2014) and compete in the exotic leather market, which makes it a luxury commodity.

Leather quality is consequently of utmost importance in determining the value of ostrich skins. The quality of the ostrich skin is determined by visible defects (including pitting, physical damage, and

hair follicles) and nodule appearance (Engelbrecht *et al.*, 2005). Although skin quality influences the value of the leather, the actual price paid to producers is determined collectively by the grade of the skin (based on the presence and quantity of visible defects and lesions), the quill value (an indicator of nodule acceptability), as well as the size of the skin as a quantitative trait. Skins that are bigger than 140 dm^2, have the least damage and therefore the best grade (premium grade), and have acceptable nodules (a quill value of 1–3) and fetch the best price per dm^2 according to the price structure used in the South African ostrich industry (Table 1; based on the price structure used by Cape Karoo International).

The extent to which each skin trait influences the price of ostrich leather has not yet been studied in detail. Therefore, the aim of this study was to investigate the influence of each of these traits on the monetary value of individual ostrich skins, by using stepwise multiple regression techniques. Secondly, the study investigated whether the traits recorded on processed skins could be considered proxies for data recorded at tanneries.

Material and methods

Skin data of the South African Black (SAB) ostrich breed were obtained from the ostrich flock at the Oudtshoorn Research Farm of the Western Cape Department of Agriculture, South Africa. A total of 747 processed skins from ostriches slaughtered between 2003 and 2019, aged 282–588 d of age, were used. This is comparable with the age range at which birds are slaughtered in the industry, as there is large variation due to factors such as different feeding regimes and feather harvesting practices. Traits known to have an influence on the skin's value were included as independent variables for analyses. These included skin size (SSZ) as a quantitative trait, as well as skin grade (SG) and quill value (QV), as recorded at the tannery. Additionally, nodule size score (NSZ), nodule shape score (NS), hair follicle score (HF), and pitting score (PIT) were recorded afterwards on the processed chrome-crusted skins. It was surmised that the traits associated with defects (HF and PIT) would pick up variation from SG, whereas nodule traits would pick up variation from QV. The skin quality traits considered were defined in the review by Engelbrecht *et al.* (2009b).

Information obtained from the tannery (skin size, grade, and quill value) was used to calculate a monetary value in South African Rand (ZAR) for each skin, based on the price structure used by the ostrich industry for October 2020 (Cape Karoo International; Table 1). The relative unit prices for this period, expressed as a percentage of the best unit price achievable, are provided in Table 1.

The price category was derived by considering skin grade (1–6, with 1 indicating premium skins with no damage, 2 indicating grade 1, and so forth; Table 1), quill value (QV), and skin size category. A QV of 1–3 is considered acceptable, whereas a QV of 4 or 5 indicates that the nodules are considered to be small. This measure is based on the appearance (size and shape) of the nodules on the individual skins. Large, rounded nodules are preferred. The unit prices (ZAR per dm^2) used by Cape Karoo International during October 2020 for the different categories was then multiplied by the actual size of the skin (in dm^2) to obtain a skin value in ZAR for each skin.

The descriptive statistics, including the mean, standard deviation, and coefficient of variation (CV%) of price as the dependent variable, as well as all of the independent variables, were calculated using the Descriptive Statistics module in the Excel Data Analysis tool pack. The PROC REG module of the SAS statistical package (SAS, 2009) was used for the subsequent multiple regression analyses. The stepwise selection method was applied to identify the independent variables that significantly ($P <$ 0.05) contributed to skin value. The following multiple regression models were fitted:

Model 1 included the three independent variables used for determining the pricing of the skin in ZAR:

$$\text{Skin value} = QV + SG + SSZ \qquad (1)$$

Model 2 included additional, subjectively-scored independent variables (NSZ and NS) as proxies for nodule acceptability (or QV), as well as HF and PIT, which contribute to SG:

$$\text{Skin value} = QV + SG + SSZ + NSZ + NS + HF + PIT \qquad (2)$$

Model 3 included all the independent variables in Model 2, except for QV, to observe how the related traits would influence the value of the skin in the absence of QV:

$$\text{Skin value} = SG + SSZ + NSZ + NS + HF + PIT \qquad (3)$$

Model 4 included all traits in Model 2, except for SG, which was left out to observe how the related traits would influence the value of the skin when SG was not modelled explicitly:

$$\text{Skin value} = QV + SSZ + NSZ + NS + HF + PIT \qquad (4)$$

Table 1 Relative unit prices paid to ostrich farmers for ostrich skins, based on grading, quill value, and skin size (dm^2), expressed as a percentage of the best unit price achievable

Grade	Skin size (dm^2)	Acceptable nodules (Quill value 1–3) Relative price/dm^2	Small nodules (Quill value 4–5) Relative price/dm^2
Premium	≥ 140	100	50
1	≥ 140	58	32
2	≥ 140	32	18
3	≥ 140	19	11
4	≥ 140	12	6
5	≥ 140	3	1
1	130-139	52	32
2	130-139	29	18
3	130-139	17	11
4	130-139	10	6
5	130-139	3	1
1	115-129	16	7
2	115-129	11	6
3	115-129	7	4
4	115-129	4	3
5	115-129	2	1
1	<115	6	5
2	<115	5	4
3	<115	3	2
4	<115	2	1
5	<115	1	1

The multiple linear regression models are described as:
$$Y = a + b_1X_1 + b_2X_2 \ldots + b_nX_n, \tag{5}$$
Where:
  Y = the dependent variable (skin value in ZAR),
  a = the intercept,
  $b_1 - b_n$ = regression coefficients for skin value on the respective independent variables from 1 to n, with n ranging from 3 for Model 1 to 7 for Model 2, and
  $X_1 - X_n$ = the modelled independent variables ranging from n = 3 to n = 7, as described above.

    Furthermore, Pearson correlations between skin value (as the dependent variable) and skin size, as well as the skin quality traits, were calculated using Minitab software (Minitab 18 Statistical Software, 2017).

Results and discussion
    Descriptive statistics for traits analysed in this study are presented in Table 2. The coefficients of variation (CV%) of the traits ranged from as low as 5% for SSZ to a maximum of 65% for skin value. The higher CV% for SG compared to SSZ and QV indicates that SG could have a more pronounced effect on skin value compared to the other less variable traits. Any visible defect or damage to ostrich skins markedly affect the grade of the skin and therefore the price of the skin (Table 1).

Table 2 Descriptive statistics: Number of records (N), mean, standard deviation (SD), coefficient of variation (CV%), and range (minimum/maximum value) for skin traits of 747 South African Black ostriches

Trait (unit of measurement)	N	Mean	SD	CV%	Minimum	Maximum
Skin value (ZAR)	747	1156.71	747.95	65	68.62	5357.88
Skin grade (1–6)	747	4.0	1.0	24	1	6
Quill value (1–5)	747	3.0	0.5	16	1	5
Skin size (dm^2)	747	142	7	5	106	170
Nodule size score (1–9)	747	4.7	1.0	21	1	9
Nodule shape score (1–9)	747	4.4	1.3	30	1	9
Hair follicle score (1–9)	747	3.4	1.7	50	1	9
Pitting score (1–9)	747	1.6	1.0	63	1	7

Results of the analysis of Model 1 are given in Table 3. Analysis with Model 1 included only QV, SG, and SSZ. At 76.8% of the variation accounted for, SG was by far the dominant factor in determining the monetary yield of ostrich skins (Table 3). The negative sign for the regression on SG indicate that better grades (lower values indicate better quality skins) resulted in higher monetary yield. SSZ accounted for 5.12% of the variation in skin value, indicating that larger skins resulted in higher skin values. Previous studies have reported an increase in skin size with an increase in age (Van Schalkwyk, 2008; Engelbrecht, 2013) and Brand *et al.* (2018) reported that both live weight and skin yield of ostriches increased with an increase in age at slaughter. The addition of QV added another 1.42% to the cumulative R^2. The negative regression coefficient in this case indicated that a higher QV, which translates to smaller nodules, compromised skin value. All three independent variables combined to result in a cumulative R² of 83.3% for the full model fitted (Table 3).

Table 3 Results from the multiple regression analysis depicting the effect of quill value (QV), skin grading (SG), and skin size (SSZ) on the monetary yield of 747 ostrich skins (Model 1)

Regression parameters	SG	SSZ	QV
Coefficient (B)	-681.60	20.66	-194.47
SE	11.55	1.54	24.46
P-value	<0.0001	<0.0001	<0.0001
Cumulative R^2	0.7677	0.8189	0.8331
Intercept (a) = 1530.01			

Model 2 included the additional four traits (NSZ, NS, HF, and PIT) recorded on processed skins. The stepwise regression model indicated that the additional traits did not significantly impact skin value when QV, SG and SSZ were also modeled. The output of Model 2 was similar to that of Model 1 (Table 3), where only QV, SG and SSZ were included. This output is thus not provided.

Results of the analysis of Model 3 are given in Table 4. Model 3 included SG, SSZ, NSZ, and NS to determine the extent to which the subjectively-scored nodule traits (NSZ and NS) would influence skin price in the absence of QV. In the absence of QV, 76.8% of the variation in skin value was still accounted for by SG, whereas NS (0.26%) picked up part of the variation previously associated with QV (Table 4). It thus seems that this qualitative, subjectively-scored skin trait does explain some of the variation accounted for by QV, but not all. The full model accounted for 82.2% of the variation in skin value, marginally down from Model 1. Both Mellett *et al.* (1996) and Meyer *et al.* (2004) contended that the size and shape of the nodules were important in determining the value or quality of the skin, with bigger, rounded nodules being preferred (Engelbrecht *et al.*, 2009b). Smaller nodules tend to be elongated and poorly shaped compared to bigger nodules. These results suggest that the shape of the nodule explained more of the variation in skin value than the size of the nodule.

Table 4 Results from the multiple regression analysis depicting the effect of skin grading (SG), skin size (SSZ), and nodule size (NS) on the monetary yield of 747 ostrich skins (Model 3)

Regression parameters	SG	SSZ	NS
Coefficient (B)	−680.96	21.02	21.51
SE	11.96	1.67	10.72
P-value	<0.0001	<0.0001	0.0452
Cumulative (R^2)	0.7677	0.8189	0.8215
Intercept (a) = 682.91			

Results of the analysis of Model 4 are given in Table 5. Model 4 included SSZ, QV, PIT, and HF to determine the extent to which PIT and HF influenced skin monetary yield in the absence of SG. Only 3.5% of the variation in monetary yield was accounted for by SSZ. QV contributed another 1.6% to the cumulative R^2. In the absence of SG, PIT contributed only 0.62% to the variation accounted for. A negative regression coefficient (-60.24) for PIT indicated that more pitting on the skins would reduce monetary yield. HF did not contribute to the observed R^2 (*P* >0.10) and is therefore not shown in Table 5.

Table 5 Results from the multiple regression analysis depicting the effect of skin size (SSZ), quill value (QV), and pitting (PIT) on the monetary yield of 747 ostrich skins (Model 4)

Regression parameters	SSZ	QV	PIT
Coefficient (B)	15.82	-165.97	-60.24
SE	3.68	61.33	27.94
P-value	<0.0001	<0.0070	0.0314
Cumulative (R^2)	0.0350	0.0510	0.0572
Intercept (a) = -673.22			

It was evident that when SG was removed from the model, the remaining variables only accounted for a cumulative R^2 of <6% (Table 5). The fact that PIT accounted for <1% of the variation in skin value, and that HF did not contribute substantially, is unexpected. Van Schalkwyk (2008) stated that pitting damage (scored as PIT) was an important skin defect, whereas pinholes (scored as HF) were also seen as an important contributor to the downgrading of ostrich leather (Engelbrecht *et al.*, 2005). The results of the current study lend support to earlier reports that the most common cause of downgrading is visible scars due to healed wounds caused by scratches and kick marks (Meyer, 2003; Meyer *et al.*, 2003). Furthermore, it is contended that fine damage or defects, such as those scored as PIT and HF, would be masked by the importance and size of healed wounds and other types of damage, such as sunburn (associated with feather pecking) that can cover large areas of the skin.

The importance of SG in predicting skin value is perhaps not surprising, given the dominant role of SG in unit price determination (Table 1). A study by Urge *et al.* (2020) on cattle similarly reported that downgrading of skins and hides due to cockle and other lesions affected the market price. Defects such as visible skin damage are very important when grading leather, as reported by Engelbrecht *et al.* (2009b) on ostriches and Ebrahiem *et al.* (2015) on cattle, goats, snakes, and lizards.

The Pearson's correlations among the traits are reported in Table 6. Positive, significant correlations ranged from lowest at 0.08 between SSZ and HF and between SG and PIT, to moderate at 0.51 between NSZ and NS. Strong negative correlations were also observed, ranging from -0.08 between SSZ and HF to -0.88 between skin value and SG. This table confirms that SG is the dominant regression variable for determining skin value, as indicated by the high correlation coefficient of r = -0.88, with QV and SSZ being of lesser importance at -0.16 and 0.19, respectively (*P* <0.001).

Table 6 Pearson's correlation coefficients (r) between ostrich skin value, skin size (SSZ), skin grade (SG), quill value (QV), nodule size score (NSZ), nodule shape score (NS), hair follicle score (HF), and pitting score (PIT)

	Skin value	SSZ	SG	QV	NSZ	NS	HF
SSZ	0.19**						
SG	-0.88**	0.04					
QV	-0.16**	-0.18**	0.00				
NSZ	0.11*	0.36**	0.02	-0.37**			
NS	0.13**	0.17**	-0.05	-0.34**	0.51**		
HF	0.01	0.08*	0.03	-0.11*	0.12**	0.02	
PIT	-0.09*	-0.01	0.08*	-0.05	-0.06	-0.04	0.01

*$P <0.05$, **$P <0.001$

The strong negative correlation of skin value with QV indicates that a decrease in QV score will result in an increase in skin value. A lower QV indicates improved nodule development and since nodule development is believed to depend on nodule size and shape, it could be argued that NSZ and NS would be proxies for QV. Only NS seemed to account for some of the variation explained by QV in Table 4, however. This could indicate that the shape of the nodules is actually more important than the size of the nodules in determining nodule acceptability. Pearson's correlation coefficients of skin value with NSZ, NS, and PIT were also significant, but the absolute correlation coefficients were low at 0.09 to 0.13. SSZ, on the other hand had strong correlation coefficients with QV, NSZ, NS, and HF, although the latter correlation was low (0.08). The positive correlation with HF was considered unfavourable as high scores are indicative of the excessive expression of HF. Conversely, the positive correlation of skin size (SSZ) with nodule size score (NSZ) and nodule shape score (NS) is favourable.

The non-existing correlation of SG with QV was expected, as these two qualitative traits reflect different aspects of product quality, namely skin damage and nodule development, respectively.

The skin traits reported here were all measured post-slaughter. This implies that farmers cannot predict the potential value of the skin on live birds. However, various skin traits were previously found to be heritable and correlated to slaughter weight (Cloete *et al.*, 2004; Engelbrecht *et al.*, 2009a; Nemutandani *et al.*, 2019; Nemutandani *et al.*, 2023). The high genetic correlation between skin size and slaughter weight (Nemutandani *et al.*, 2019), which can be easily measured on-farm, allows for indirect selection for larger skins.

Skin size and nodule size were shown to also increase with age (Cloete *et al.*, 2004; Engelbrecht *et al.*, 2005, 2007; Meyer *et al.*, 2002; 2004; Van Schalkwyk *et al.*, 2005), whereas nodule shape also improves with age (Engelbrecht *et al.*, 2005; Meyer *et al.*, 2002, 2004; Van Schalkwyk *et al.*, 2005). Unfortunately, skin damage also increases with age, resulting in poorer skin grading (Meyer, 2003; Meyer *et al.*, 2002). Predicting skin value therefore remains a challenge due to the importance of skin grading in price determination.

Scoring the prevalence of filoplumes on live birds is a more recent breakthrough towards predicting skin quality, since filoplume scores on live birds were reported to be genetically correlated to the presence of hair follicles (HF) on processed ostrich skins (Engelbrecht & Cloete, 2021; 2023). It was also suggested that the high heritability of scores on live birds and on skins will allow for selection against this trait.

Conclusion

Skin grading (SG) was by far the dominant trait in the price determination of ostrich skins. The lack of substantial contributions from the other traits touted to reflect skin damage or defects (HF and PIT) is concerning and should be studied further. According to the present analyses, a highly heritable and industry-valued trait such as HF was of limited importance in determining skin value. The grading system currently in use could partly explain this though, since only the main reasons for downgrading are recorded, which could mask the importance of finer damage, such as these defects, whereas recording all defects would provide more accurate information regarding the actual importance and prevalence of the various defects. However, it is also reasoned that HF will probably emerge as a more important contributor to skin value when physical damage such as scratches and kick marks, which are the main reasons for downgrading of ostrich skins, can be markedly reduced. Nonetheless, it is clear that managerial and breeding strategies to limit skin damage and improve SG should be prioritized.

Conversely, whereas SSZ and QV also contribute to the price-fixing mechanism determining the profitability of skins, it was seemingly less important with regards to skin value. However, the price

structure is not fixed and changes according to market conditions and trends. Skin size and the appearance of the nodules will always remain important, however, since the nodules set ostrich leather apart from other leather types and the size determines the cutting value for making leather products. Breeding as an intervention to promote monetary gain can therefore also be pursued, since skin size and nodule traits are known to be highly heritable, with substantial phenotypic variation, which facilitates genetic improvement of these traits. HF have also been reported to be highly heritable and this aspect of skin grading could therefore also be improved though selection.

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Authors' contributions
        Project idea, design and study execution were contributed by KRN, AE, SWPC, KD, and OT. KR and PTM were responsible for the analysis of the data and AE and SWPC oversaw supervision of the manuscript. KR was responsible for writing of the manuscript. All authors have read and approved the finalized manuscript.

Conflict of interest
        Authors declare that no conflict of interest was encountered concerning publication of this manuscript.

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