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Correlation among serum biochemical indices and slaughter traits, texture characteristics and water-holding capacity of Tan sheep

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ABSTRACT

This study was conducted to determine the correlation among serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity in Tan sheep. Eighty Tan sheep aged 4–6 months were selected. Blood samples were collected from live animals to analyse serum biochemical indices. The slaughter traits, texture characteristics and water-holding capacity of meat were assessed after slaughter. There were highly significant correlations ($p<.01$) and high linear regression R values among serum biochemical indices, slaughter traits, meat texture characteristics and water-holding capacity in Tan sheep. Therefore, this study has demonstrated that the meat qualities of Tan mutton may be evaluated by the serum biochemical indices of live Tan sheep.

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KEYWORDS
Tan sheep; serum biochemical indices; slaughter traits; meat texture characteristics; water-holding capacity; correlation

HIGHLIGHTS

- This study was conducted to determine the correlation among serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity in Tan sheep.
- This study has demonstrated that meat qualities of Tan mutton may be assessed by the serum biochemical indices of live Tan sheep.
- It is necessary to determine slaughter traits, meat texture characteristics and water-holding capacity of meat, which are major indicators for assessing meat and meat products by consumers.

Introduction

Tan sheep are a breed of sheep in China for which there are geographical indications for agricultural products from Yanchi, Ningxia Hui Autonomous Region, China. The meat from Tan sheep is characterised by good quality traits, including tenderness and low fat and high protein contents (Liu et al. 2018; Shi and Zhao 2018). It has been previously reported that serum biochemical indices are significantly correlated with meat quality, since they not only determine the strength of the animal's resistance and oxygen transport, but also have a significant impact on the growth performance, genetic characteristics and specificity of metabolism (Anassori et al. 2015; Muttarin et al. 2016). Furthermore, it is necessary to determine slaughter traits, meat texture characteristics and the water-holding capacity of meat, which are major indicators for assessing meat and meat products by consumers.

Correlations between serum biochemical indices and meat quality traits based on pH, meat colour and marbling have been recently reported. A correlation study evaluating meat quality and serum biochemical indices in Qinghai yak found that serum lactate dehydrogenase (LDH) activity and marble score were significantly and negatively correlated, whereas a significant positive correlation was found between LDH activity and cooking yield (Deng et al. 2013). Yuan et al. (2009) also reported that serum albumin and water-holding capacity, serum somatropin and pH 1 (45–60 min after slaughter) were significantly and positively increased in silky fowl. In summary, some serum biochemical indices were significantly related to growth performance and meat traits in livestock. Consequently, it is essential to clarify the correlation between serum biochemical indices in live animals and meat quality traits of Tan mutton.

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The aim of this study was to determine the serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity and analyse the relationship between serum biochemical indices and meat quality characteristics of Tan mutton. This study provides a theoretical basis for the early breeding and feeding management of Tan sheep.

Materials and methods

The animals were raised according to the Chinese Standards for the Use and Care of Research Animals and the Chinese National Standards of Human Food Animal Harvesting and Processing (Chinese Ministry of Agriculture 2001; Laboratory Animals Management and Use Guidelines 2016).

Serum sample collection and analysis

Before the experiment, eighty ram Tan sheep aged 4–6 months were randomly selected for serum sample collection. After overnight fasting, 30 mL of blood was collected from the precaval veins of Tan sheep by vacuum tubes, and the serum was centrifuged at 5,000 g for 20 min and stored at −20 °C until further analyses. The contents of alanine aminotransferase (ALT), aspartate aminotransferase (AST), glutamyl transpeptidase (GT), total bile acid (TBA), acetylcholinesterase (CHE), prealbumin (PA), total protein (TP), albumin, globulin, total bilirubin (TBIL), direct bilirubin (DBIL), indirect bilirubin (IBIL), glucose, triglyceride (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C) and alkaline phosphatase (ALP) in serum were determined with commercial kits (Nanjing Jiancheng Bioengineering Institute, Jiangsu, China) following the manufacturer's instructions (Paryad and Mahmoudi 2008; He et al. 2015; Peng et al. 2016).

Determination of slaughter traits

Eighty Tan sheep were slaughtered, and then carcases, hind leg, lean meat, fat, *longissimus lumborum* and bones were weighed and calculated according to the standard methods of China National Standards-Fresh and frozen mutton carcase (GB/T9961-2008) and China Agriculture Business Standards-Evaluation Specification of sheep/goat carcase grades (NY/T2781-2015).

Determination of texture characteristics

The hardness, resilience, springiness, cohesiveness, gumminess, chewiness and adhesiveness of the *longissimus lumborum* from Tan mutton were determined by using a texture analyser (TA.XT Plus, SMS, Godalming, Surrey, UK). The P35 detector, 30% strain and 5 s residence time were used in the study. The pre-test velocity, mid-test velocity and posttest velocity were 3 mm/s, 1 mm/s and 5 mm/s, respectively (U- Chupaj et al. 2017; Felix and Aberham Hailu 2018). The assay was performed in triplicate for each sample.

Measurement of water-holding capacity

The *longissimus lumborum* muscle was cut into 2 cm × 3 cm × 4 cm rectangular block samples, which were hung up for 24 h in a sealed plastic bag under refrigerated conditions at 4 °C to determine the drip loss (Zhao et al. 2019). The drip loss was calculated by the following formula:

$$Drip\ loss\ (\%) = \frac{m_0 - m_1}{m_0} \times 100\% \tag{1}$$

where m_0 is the weight (g) of the sample before refrigeration and m_1 is the weight (g) of the sample after refrigeration.

The samples were heated in a water bath at 90 °C for 30 min to measure the cooking loss (Doaa et al. 2019). The cooking loss was calculated using the following formula:

$$Cooking\ loss\ (\%) = \frac{m_2 - m_3}{m_2} \times 100\% \tag{2}$$

where m_2 is the weight (g) of the sample before heating and m_3 is the weight (g) of the sample after heating.

Statistical analysis

Results are expressed as means ± SD. The coefficient of variation (CV) is the ratio of the standard deviation of the original data to the mean of the original data. All data were analysed in a completed random design by SPSS (Version 24.0, IBM Company, USA). Differences among means of treatments were detected by Duncan's multiple range tests with significance at $p<.01$. The correlation between serum biochemical indices and slaughter traits, texture characteristics and water-holding capacity of Tan sheep was examined by Pearson's two-sided test, followed by the establishment of linear regression equations by regression analysis.

Results and discussion

Serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity

As shown in Table 1, there were significant differences in the standard deviation (SD) and coefficient of variation (CV) from the values of serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity in Tan sheep. Serum biochemical indicators not only reflect changes in certain organs and tissues and important metabolic characteristics in animals, but also show the physiological disposition of animal nutrition according to their internal and external environments (Wang et al. 2009). TBIL, DBIL, IBIL, TG, TC, HDL-C, LDL-C and SD were compared with other serum biochemical indices. Moreover, crucial parameters of meat quality are intramuscular fat, tenderness and water-holding capacity (Yin and Li 2014). Among the values of slaughter traits, texture characteristics and water-holding capacity, lean meat rate, fat percentage, bone rate, cohesiveness, drip loss and cooking loss SD were improved compared with others. Among serum biochemical indices, slaughter traits, texture characteristics and water-holding capacity showed significant differences which could be explained by different lairage conditions (Chai et al. 2009), animal populations and ages (Zenon et al. 2017), and diet types (Hou et al. 2018).

The correlation between serum biochemical indices and slaughter traits

As shown in Table 2, the contents of ALT, AST, TBA, IBIL and TC were significantly positively correlated ($p<.05$) with lipid content, while TP, ALB, TG and HDL-C were extremely significantly positively correlated ($p<.01$). In particular, ALT played an important role in amino acid metabolism and the mutual transformation of protein, fat and sugar. The levels of CHE, PA and TG were significantly positively correlated ($p<.05$) with

Table 1. The composition of serum biochemical indices, slaughter performance, texture characteristics and water holding capacity of eighty Tan sheep.

Serum biochemical indices	Acronym	Mean	SD	Max	Min	CV (%)
Alanine aminotransferase (U/L)	ALT	15.53	14.27	111.50	2.50	91.89
Aspartate aminotransferase (U/L)	AST	213.34	511.03	3407.00	58.90	239.54
Glutamyl Transpeptidase (U/L)	GT	75.02	34.43	225.60	41.50	45.89
Total Bile Acid (umol/L)	TBA	28.96	37.43	286.80	2.10	129.25
Acetylcholinesterase (U/L)	CHE	101.75	45.03	155.00	17.00	44.26
Prealbumin (mg/L)	PA	43.05	14.82	71.50	18.00	34.43
Total Protein (g/L)	TP	63.93	7.16	81.80	46.60	11.20
Albumin (g/L)	ALB	34.87	5.18	43.80	21.80	14.86
Globulin (g/L)	GLB	28.94	4.39	41.50	20.40	15.17
Total Bilirubin (umol/L)	TBIL	2.00	1.75	12.38	0.02	87.50
Direct Bilirubin (umol/L)	DBIL	0.48	0.62	4.35	−0.15	129.17
Indirect Bilirubin (umol/L)	IBIL	1.54	1.40	8.03	−1.47	90.91
Glucose (mmol/L)	GLU	6.53	2.83	15.95	1.29	43.34
Triglyceride (mmol/L)	TG	0.22	0.11	0.60	0.07	50.00
Total Cholesterol (mmol/L)	TC	1.75	0.56	4.27	0.44	32.00
High-density Lipoprotein Cholesterol (mmol/L)	HDL-C	0.67	0.18	1.03	0.06	26.87
Low-density Lipoprotein Cholesterol (mmol/L)	LDL-C	0.38	0.18	1.16	0.14	47.37
Alkaline Phosphatase (U/L)	ALP	150.61	184.78	912.40	0.10	122.69

Indices of meat qualities	Units	Means	SD	Max	Min	CV (%)
Slaughter performance						
Carcase body weight	Kg	17.99	1.96	22.90	13.70	10.89
Hind leg weight	G	293.65	85.82	495.60	45.60	29.23
Lean meat rate	%	0.40	0.05	0.62	0.25	12.50
Fat percentage	%	0.25	0.06	0.43	0.07	24.00
Bone rate	%	0.25	0.05	0.40	0.03	20.00
Longissimus dorsi weight	G	205.50	38.39	305.70	110.00	18.68
Texture characteristics						
Hardness	G	4,563.56	3,140.65	1,9057.34	309.28	68.82
Resilience (%)	%	24.81	8.23	59.60	11.37	33.17
Springiness (%)	%	65.02	8.73	81.87	49.04	13.43
Cohesiveness (%)	%	0.48	0.07	0.67	0.22	14.58
Gumminess	–	2,270.69	1,718.48	9,449.71	148.27	75.68
Chewiness	–	1,531.00	1,275.14	7,506.47	96.25	83.29
Adhesiveness	–	−129.16	51.08	3.63	−264.00	−39.55
Water holding capacity						
Drip loss	%	0.019	0.022	0.167	0.001	115.789
Cooking loss	%	0.283	0.052	0.382	0.136	18.375

Table 2. The correlation and regression analysis between serum biochemical indices and slaughter performance of eighty Tan sheep.

Serum indices	Lipid content	Lean meat rate	Carcase body weight	Hind leg weight	Bone rate	Longissimus dorsi weight
ALT (U/L)						
Pearson	0.266[a]	0.023	−0.065	−0.204	−0.063	0.217
Sig. (T)	0.017	0.841	0.565	0.070	0.580	0.053
AST (U/L)						
Pearson	0.227[a]	−0.010	−0.155	−0.173	0.005	0.047
Sig. (T)	0.043	0.930	0.171	0.124	0.964	0.681
GT (U/L)						
Pearson	0.124	−0.119	−0.171	−0.320[b]	0.097	−0.057
Sig. (T)	0.274	0.291	0.129	0.004	0.393	0.615
TBA (umol/L)						
Pearson	0.265[a]	−0.110	−0.034	−0.107	−0.067	−0.010
Sig. (T)	0.018	0.332	0.764	0.345	0.552	0.930
CHE (U/L)						
Pearson	−0.180	0.257[a]	0.204	0.656[b]	−0.037	−0.049
Sig. (T)	0.110	0.022	0.069	0	0.747	0.664
PA (mg/L)						
Pearson	−0.140	0.221[a]	0.181	0.561[b]	−0.042	−0.056
Sig. (T)	0.215	0.049	0.108	0	0.712	0.621
TP (g/L)						
Pearson	0.345[b]	−0.052	0.011	−0.362[b]	−0.031	0.192
Sig. (T)	0.002	0.649	0.924	0.001	0.785	0.088
ALB (g/L)						
Pearson	0.355[b]	0.019	0.177	−0.213	−0.127	0.496[b]
Sig. (T)	0.001	0.868	0.117	0.057	0.263	0
GLB (g/L)						
Pearson	0.088	−0.079	−0.254[a]	−0.345[b]	0.128	−0.269[a]
Sig. (T)	0.439	0.488	0.023	0.002	0.258	0.016
A / G						
Pearson	0.219	0.024	0.374[b]	0.100	−0.200	0.587[b]
Sig. (T)	0.051	0.830	0.001	0.377	0.076	0
TBIL (umol/L)						
Pearson	−0.149	−0.103	−0.298[b]	−0.020	0.270[a]	−0.383[b]
Sig. (T)	0.186	0.362	0.007	0.858	0.015	0
IBIL (umol/L)						
Pearson	−0.284[a]	−0.069	−0.321[b]	0.046	0.302[b]	−0.459[b]
Sig. (T)	0.011	0.546	0.004	0.684	0.007	0
GLU (mmol/L)						
Pearson	0.069	0.117	0.154	0.113	−0.048	0.229[a]
Sig. (T)	0.544	0.301	0.172	0.320	0.676	0.041
TG (mmol/L)						
Pearson	−0.403[b]	0.226[a]	−0.251[a]	0.211	0.022	−0.187
Sig. (T)	0	0.044	0.025	0.061	0.846	0.097
TC (mmol/L)						
Pearson	0.251[a]	−0.104	0.129	−0.293[b]	−0.107	0.303[b]
Sig. (T)	0.025	0.357	0.253	0.008	0.345	0.006
HDL-C (mmol/L)						
Pearson	0.361[b]	−0.084	0.304[b]	−0.106	−0.293[b]	0.381[b]
Sig. (T)	0.001	0.458	0.006	0.351	0.008	0
LDL-C (mmol/L)						
Pearson	0.184	−0.096	−0.038	−0.430[b]	−0.037	0.204
Sig. (T)	0.102	0.398	0.740	0	0.743	0.070

Slaughter performance	R	F	Sig	Regression equations
Lipidid content	0.588	4.119	0.000	$Y_1 = 0.18 + 0.001X_1 - 1.814\times10^{-5}X_2 + 0.001X_4 + 0.001X_7 - 1.876\times10^{-5}X_8 - 0.01X_{12} - 0.137X_{14} - 0.014X_{15} + 0.054X_{16}$
Lean meat rate	0.272	2.030	1.117	$Y_2 = 0.372 + 0.057X_{14}$
Carcase body weight	0.540	5.017	0.000	$Y_3 = 17.688 - 0.065X_9 - 0.807X_{10} + 0.851X_{12} - 5.136X_{14} + 1.976X_{16} + 1.859X_{19}$
Hind leg weight	0.684	9.065	0.000	$Y_4 = 216.233 - 0.133X_3 + 1.593X_5 - 1.741X_6 + 1.308X_7 - 2.415X_9 + 15.909X_{15} - 108.578X_{17}$
Bone rate	0.364	3.859	0.013	$Y_5 = 0.28 + 0.005X_{10} + 0.002X_{12} - 0.067X_{16}$
Longissimus dorsi weight	0.671	7.271	0.000	$Y_6 = 105.916 + 1.329X_8 - 0.671X_9 - 6.451X_{10} + 1.086X_{12} - 0.289X_{13} + 15.546X_{15} - 8.001X_{16} + 51.883X_{19}$

[a]represents the confidence (T) is 0.05, and the correlation is significant.
[b]represents the confidence (T) is 0.01, and the correlation is extremely significant.
Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6 are lipid content, lean meat rate, carcase body weight, hind leg weight, bone rate and longissimus dorsi weight, respectively; X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17} and X_{19} are ALT, AST, GT, TBA, CHE, PA, TP, ALB, GLB, TBIL, IBIL, GLU, TG, TC, HDL-C, LDL-C and A/G, respectively.

the lean meat rate. Moreover, Liu et al. (1999) found that ALT was positively correlated with slaughter rate, chest muscle rate, leg muscle rate, lean meat rate and abdominal fat rate of mulard ducks. In addition, serum total protein (consisting of ALB and GLB) plays an important role in maintaining the normal immune function of the body and regulating tissue fluid balance. Generally, ALB is the carrier of nutrient transport, GLB mainly exerts an immunological action, and A/G reflects the resistance of the body (Wang et al. 2019). The levels of A/G, TBIL, IBIL and HDL-C were extremely significantly correlated ($p<.01$) with carcase body weight, while GLB and TG contents were significantly negatively correlated ($p<.05$). The content of blood lipids, including TG, TC and HDL-C, could reflect the metabolism of lipids in the body, being reported to be related to fat percentage and longissimus dorsi weight (Xing et al. 2018). As also indicated by Choe et al. (2009), the blood glucose level was not significantly correlated with carcase weight, while it was significantly correlated with longissimus dorsi weight in piglets. Glucose is an indispensable substance in life activities and could directly participate in energy metabolism processes in animals. The levels of GT, CHE, PA, TP, GLB, TC and LDL-C were all extremely significantly correlated ($p<.01$) with hind leg weight, and only the IBIL and HDL-C contents were extremely significantly correlated ($p<.01$) with bone rate. ALP in animal serum is mainly derived from bones and produced by osteoblasts. It promotes the storage of calcium phosphate in bones and participates in the process of bone calcification (Zhang et al. 2015). Nevertheless, Wang et al. (2004) reported that the serum alkaline phosphatase level reflected the growth of chickens, and its activity could reflect the growth rate and production performance. The levels of ALB, A/G, TBIL, IBIL, TC and HDL-C were extremely significantly correlated with longissimus dorsi weight ($p<.01$), while GLB was significantly negatively correlated ($p<.05$).

As shown in Table 2, the R value for the hind leg weight and longissimus dorsi weight in the linear regression were higher than those of other slaughter traits and had a better degree of fit with linear equations. In other words, the R values of the lean meat rate and bone rate in the linear regression were low. The results indicated that serum biochemical indices and slaughter traits of Tan sheep were correlated.

The correlation between serum biochemical indices and texture characteristics

Texture characteristics are among the most fundamental factors of meat quality and are influenced by the breed of Zebu cattle (Ana et al. 2019). As shown in Table 3, the levels of CHE and PA were extremely significantly negatively correlated with hardness ($p<.01$), while GT and LDL-C contents were significantly positively correlated ($p<.05$). AST, CHE, PA, TP, ALB, A/G, IBIL and LDL-C were extremely significantly correlated ($p<.01$) with springiness, and the levels of ALP, TBIL, DBIL, TG, TC and HDL-C were significantly correlated ($p<.05$). In summary, hardness and springiness are predominant elements of the acceptability and quality of meat products (Imen et al. 2019). The contents of AST, ALP, ALB and HDL-C were extremely significantly correlated ($p<.01$) with gumminess, while the ALT, CHE, TP and TC levels were significantly correlated ($p<.05$). The levels of CHE, PA and LDL-C were extremely significantly correlated ($p<.01$) with chewiness, while the GT, TP, ALB, TG and TC contents were significantly correlated ($p<.05$). CHE, PA and LDL-C were extremely significantly correlated ($p<.01$) with adhesiveness, resilience and cohesiveness. Additionally, Pavlík et al. (2008) found that there was a significant correlation between the levels of glucose and urea in the blood serum and the tenderness of beef cattle. In fact, Nowak et al. (2007) reported that cohesiveness and adhesiveness were important for sliced meat in accord with our study results.

Among the texture characteristics, the adhesiveness R value in the linear regression was the lowest (Table 3). The springiness and cohesiveness R values in the linear regression were higher than 0.600, suggesting that some serum biochemical indices might be used to evaluate the quality of Tan mutton in the future.

The correlation between serum biochemical indices and water-holding capacity

The water-holding capacity is mainly from bound water in muscles combined with the surface of myofibrillar protein molecules. Additionally, bound water is not easily dissociated and evaporated (Choe et al. 2015). Thus, water-holding capacity is an important meat quality indicator that significantly affects consumers' desire to buy. The ability of muscles to restrain water after slaughter has been studied (Huff-Lonergan and Lonergan 2005). With the loss of muscle water, protein and soluble flavour substances in the muscle are lost, which also affects the quality of pork (Savage et al. 1990). As shown in Table 4, only TG levels were significantly positively correlated ($p<.05$) with drip loss, while GT, CHE, PA, TP, ALB, GLB and DBIL levels were extremely significantly correlated ($p<.01$) with cooking loss. TG, TC and LDL-C were significantly correlated ($p<.05$) with cooking loss. It was

Table 3. The correlation and regression analysis between serum biochemical indices and texture characteristics of eighty Tan sheep.

Serum indices	Hardness	Springiness	Gumminess	Chewiness	Adhesiveness	Resilience	Cohesiveness
ALT (U/L)							
Pearson	0.023	0.171	−0.237[a]	0.102	0.075	0.006	0.175
Sig. (T)	0.839	0.13	0.034	0.369	0.506	0.959	0.121
AST (U/L)							
Pearson	−0.004	0.336[b]	−0.334[b]	0.138	0.064	0.119	0.346[b]
Sig. (T)	0.97	0.002	0.002	0.224	0.571	0.295	0.002
ALP (U/L)							
Pearson	0.047	−0.285[a]	0.363[b]	−0.026	0.029	−0.005	−0.134
Sig. (T)	0.681	0.01	0.001	0.818	0.796	0.968	0.237
GT (U/L)							
Pearson	0.231[a]	0.213	−0.1	0.267[a]	0.237[a]	0.359[b]	0.271[a]
Sig. (T)	0.039	0.058	0.379	0.017	0.034	0.001	0.015
CHE (U/L)							
Pearson	−0.442[b]	−0.343[b]	0.229[a]	−0.462[b]	−0.447[b]	−0.436[b]	−0.418[b]
Sig. (T)	0	0.002	0.041	0	0	0	0
PA (mg/L)							
Pearson	−0.390[b]	−0.327[b]	0.104	−0.419[b]	−0.394[b]	−0.397[b]	−0.334[b]
Sig. (T)	0	0.003	0.358	0	0	0	0.003
TP (g/L)							
Pearson	0.149	0.485[b]	−0.282[a]	0.275[a]	0.214	0.287[b]	0.497[b]
Sig. (T)	0.189	0	0.011	0.013	0.057	0.01	0
ALB (g/L)							
Pearson	0.114	0.532[b]	−0.293[b]	0.240[a]	0.179	0.256[a]	0.502[b]
Sig. (T)	0.313	0	0.008	0.032	0.113	0.022	0
A / G							
Pearson	−0.133	0.308[b]	−0.098	−0.041	−0.095	−0.009	0.222[a]
Sig. (T)	0.24	0.005	0.389	0.719	0.401	0.934	0.048
TBIL (umol/L)							
Pearson	−0.036	−0.230*	−0.042	−0.089	−0.038	−0.092	−0.155
Sig. (T)	0.751	0.04	0.712	0.433	0.738	0.415	0.171
DBIL (umol/L)							
Pearson	0.174	0.249[a]	−0.15	0.208	0.209	0.255[a]	0.312[b]
Sig. (T)	0.124	0.026	0.184	0.064	0.063	0.023	0.005
IBIL (umol/L)							
Pearson	−0.124	−0.321[b]	0.034	−0.202	−0.137	−0.196	−0.290[b]
Sig. (T)	0.275	0.004	0.769	0.074	0.228	0.084	0.01
TG (mmol/L)							
Pearson	−0.191	−0.225[a]	0.054	−0.261[a]	−0.223[a]	−0.257[a]	−0.322[b]
Sig. (T)	0.09	0.045	0.634	0.019	0.046	0.022	0.004
TC (mmol/L)							
Pearson	0.185	0.244[a]	−0.272[a]	0.254[a]	0.222[a]	0.213	0.311[b]
Sig. (T)	0.101	0.029	0.015	0.023	0.048	0.058	0.005
HDL-C (mmol/L)							
Pearson	0.107	0.268[a]	−0.301[b]	0.186	0.138	0.138	0.264[a]
Sig. (T)	0.345	0.016	0.007	0.099	0.223	0.222	0.018
LDL-C (mmol/L)							
Pearson	0.263[a]	0.299[b]	−0.207	0.333[b]	0.309[b]	0.295[b]	0.408[b]
Sig. (T)	0.018	0.007	0.066	0.003	0.005	0.008	0

Texture characteristics	R	F	Sig	Regression equations
Hardness	0.479	5.583	0.001	$Y_7 = 6670.155 - 1.28X_3 - 37.991X_5 + 27.928X_6 + 1716.222X_{17}$
Springiness	0.681	4.026	0.000	$Y_8 = 49.601 - 0.001X_2 - 0.021X_5 - 0.136X_6 - 0.064X_7 + 0.734X_8 - 0.55X_{10} + 3.759X_{11} + 0.211X_{12} + 8.262X_{14} - 4.099X_{15} + 10.123X_{16} - 0.39X_{17} - 0.01X_{18} + 1.149X_{19}$
Gumminess	0.409	1.785	0.094	$Y_9 = -1362.337 + 27.794X_1 - 1.188X_2 + 10.706X_3 + 13.065X_7 + 21.358X_8 + 1065.646X_{15} - 1223.934X_{16} + 0.174X_{18}$
Chewiness	0.557	3.996	0.001	$Y_{10} = 3481.269 - 0.485X_3 - 16.383X_5 + 9.479X_6 - 32.896X_7 + 32.111X_8 - 976.741X_{14} + 220.985X_{15} + 405.655X_{17}$
Adhesiveness	0.292	1.135	0.351	$Y_{11} = -119.415 - 0.132X_3 + 0.389X_5 - 0.441X_6 - 25.599X_{14} - 12.192X_{15} + 16.892X_{17}$
Resilience	0.491	2.812	0.009	$Y_{12} = 33.246 - 0.005X_3 - 0.089X_5 + 0.078X_6 - 0.178X_7 + 0.205X_8 + 0.731X_{11} - 5.916X_{14} + 7.603X_{17}$
Cohesiveness	0.633	3.387	0.001	$Y_{13} = 0.42 - 6.334 \times 10^{-6}X_2 - 7.639 \times 10^{-6}X_3 - 0.001X_5 + 0.002X_6 - 0.002X_7 + 0.008X_8 + 0.015X_{11} - 5.96410^{-5}X_{12} - 0.029X_{14} + 0.045X_{15} - 0.108X_{16} - 0.058X_{17} - 0.016X_{19}$

[a]represents the confidence (T) is 0.05, and the correlation is significant.
[b]represents the confidence (T) is 0.01, and the correlation is extremely significant.
Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{12} and Y_{13} are hardness, springiness, gumminess, chewiness, adhesiveness, resilience and cohesiveness, respectively; X_1, X_2, X_3, X_5, X_6, X_7, X_8, X_{10}, X_{11}, X_{12}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18} and X_{19} are ALT, AST, GT, CHE, PA, TP, ALB, TBIL, DBIL, IBIL, TG, TC, HDL-C, LDL-C, ALP and A/G, respectively.

Table 4. The correlation and regression analysis between serum biochemical indices and water holding capacity of eighty Tan sheep.

serum indices	Drip loss	Cooking loss
GT (U/L)		
Pearson	0.072	−0.387[b]
Sig. (T)	0.526	0.000
CHE (U/L)		
Pearson	−0.111	0.544[b]
Sig. (T)	0.327	0.000
PA (mg/L)		
Pearson	−0.045	0.443[b]
Sig. (T)	0.690	0.000
TP (g/L)		
Pearson	−0.205	−0.426[b]
Sig. (T)	0.068	0.000
ALB (g/L)		
Pearson	−0.204	−0.291[b]
Sig. (T)	0.070	0.009
GLB (g/L)		
Pearson	−0.058	−0.358[b]
Sig. (T)	0.609	0.001
DBIL (umol/L)		
Pearson	−0.090	−0.302[b]
Sig. (T)	0.429	0.006
TG (mmol/L)		
Pearson	0.088[a]	0.260[a]
Sig. (T)	0.438	0.020
TC (mmol/L)		
Pearson	−0.030	−0.235[a]
Sig. (T)	0.793	0.035
LDL-C (mmol/L)		
Pearson	−0.058	−0.285[a]
Sig. (T)	0.611	0.010

Water holding capacity	R	F	Sig	Regression equations
Drip loss	0.079	0.494	0.484	$Y_{14}=0.015+0.016X_{14}$
Cooking loss	0.640	4.798	0.000	$Y_{15}=0.357-8.94\times10^{-5}X_3+0.001X_5-0.002X_6+0.004X_7-0.005X_8-0.006X_9-0.025X_{11}-0.044X_{14}-0.005X_{15}+0.049X_{17}$

[a]represents the confidence (T) is 0.05, and the correlation is significant.
[b]represents the confidence (T) is 0.01, and the correlation is extremely significant.
Y_{14} and Y_{15} are drip loss and cooking loss, respectively; X_3, X_5, X_6, X_7, X_8, X_9, X_{11}, X_{14}, X_{15} and X_{17} are GT, CHE, PA, TP, ALB, GLB, DBIL, TG, TC and LDL-C, respectively.

also reported that blood parameters were significantly correlated with the rate of early post-mortem glycolysis and water-holding capacity of silky fowl (Yuan 2009). Furthermore, water-holding capacity is an important meat quality index that directly affects the meat flavour, meat texture, nutrients, meat colour and other qualities. In addition, a higher water binding capacity was reported to be associated with a lower water loss rate in porcine longissimus dorsi muscle (Lars 2003).

As shown in Table 4, cooking loss had a good effect, with an R value in the linear regression of 0.640, but drip loss had little correlation ($p>.05$). Briefly, cooking loss could be used as one of the indices to predict the water-holding capacity of Tan mutton.

The correlation among slaughter traits, texture characteristics and water-holding capacity

As shown in Table 5, the hind leg weight was extremely significantly correlated ($p<.01$) with cooking loss, hardness, resilience, cohesion, gumminess and chewiness. The fat percentage was significantly correlated ($p<.05$) with adhesiveness and springiness. The cooking loss was extremely significantly negatively correlated ($p<0.01$) with hardness, resilience, cohesion, gumminess and chewiness, while it was significantly negatively correlated ($p<.05$) with springiness. Generally, moisture loss often makes meat products dry and tough during cooking and processing (John et al. 2000). In other words, water-holding capacity affects the texture characteristics of meat, while texture characteristics also affect the slaughter traits of meat. Therefore, slaughter traits, texture characteristics and water-holding capacity are closely correlated.

Conclusions

In conclusion, the results of this study showed that the serum biochemical indices and slaughter traits, texture characteristics and water-holding capacity of

Table 5. The correlation among slaughter performance, texture characteristics and water binding capacity of eighty Tan sheep.

	Hind leg weight	Carcase body weight	Lean meat rate	Fat percentage	Bone rate	Longissimus dorsi weight	Cooking loss	Hardness	Adhesiveness	Resilience	Cohesion	Springiness	Gumminess	Chewiness
Hind leg weight														
Pearson	1	0.356[b]	0.199	0.029	−0.12	0.161	0.386[b]	−0.387[b]	0.096	−0.433[b]	−0.341[b]	−0.224[a]	−0.386[b]	−0.382[b]
Sig. (T)	0	0.001	0.076	0.8	0.29	0.153	0	0	0.395	0	0.002	0.046	0	0
Carcase body weight														
Pearson	0.356[b]	1	−0.151	0.467[b]	−0.428[b]	0.547[b]	0.158	−0.143	−0.002	−0.215	−0.08	−0.097	−0.126	−0.103
Sig. (T)	0.001	0	0.182	0	0	0	0.162	0.207	0.988	0.055	0.48	0.394	0.264	0.363
Lean meat rate														
Pearson	0.199	−0.151	1	−0.264[a]	0.038	0.279[a]	0.219	−0.053	0.173	−0.109	−0.056	−0.043	−0.047	−0.06
Sig. (T)	0.076	0.182	0	0.018	0.739	0.012	0.051	0.641	0.126	0.335	0.621	0.704	0.679	0.599
Fat percentage														
Pearson	0.029	0.467[b]	−0.264[a]	1	−0.477[b]	0.360[b]	−0.015	−0.119	−0.273[a]	−0.099	0.073	0.226[a]	−0.07	−0.024
Sig. (T)	0.8	0	0.018	0	0	0.001	0.896	0.292	0.014	0.383	0.522	0.044	0.538	0.831
Bone rate														
Pearson	−0.12	−0.428[b]	0.038	−0.477[b]	1	−0.318[b]	−0.218	0.164	0.066	0.158	0.061	−0.118	0.146	0.106
Sig. (T)	0.29	0	0.739	0	0	0.004	0.053	0.146	0.563	0.16	0.59	0.295	0.197	0.348
Longissimus dorsi weight														
Pearson	0.161	0.547[b]	0.279[a]	0.360[b]	−0.318[b]	1	0.042	−0.028	−0.103	−0.062	0.199	0.304[b]	0.052	0.097
Sig. (T)	0.153	0	0.012	0.001	0.004	0	0.715	0.808	0.365	0.587	0.077	0.006	0.649	0.39
Cooking loss														
Pearson	0.386[b]	0.158	0.219	−0.015	−0.218	0.042	1	−0.366[b]	0.095	−0.375[b]	−0.365[b]	−0.271[a]	−0.380[b]	−0.401[b]
Sig. (T)	0	0.162	0.051	0.896	0.053	0.715	0	0.001	0.404	0.001	0.001	0.015	0.001	0
Hardness														
Pearson	−0.387[b]	−0.143	−0.053	−0.119	0.164	−0.028	−0.366[b]	1	0.082	0.662[b]	0.395[b]	0.139	0.977[b]	0.962[b]
Sig. (T)	0	0.207	0.641	0.292	0.146	0.808	0.001	0	0.471	0	0	0.219	0	0
Adhesiveness														
Pearson	0.096	−0.002	0.173	−0.273[a]	0.066	−0.103	0.095	0.082	1	0.214	−0.077	−0.462[b]	0.041	−0.016
Sig. (T)	0.395	0.988	0.126	0.014	0.563	0.365	0.404	0.471	0	0.057	0.496	0	0.72	0.887
Resilience														
Pearson	−0.433[b]	−0.215	−0.109	−0.099	0.158	−0.062	−0.375[b]	0.662[b]	0.214	1	0.701[b]	0.199	0.728[b]	0.714[b]
Sig. (T)	0	0.055	0.335	0.383	0.16	0.587	0.001	0	0.057	0	0	0.077	0	0
Cohesion														
Pearson	−0.341[b]	−0.08	−0.056	0.073	0.061	0.199	−0.365[b]	0.395[b]	−0.077	0.701[b]	1	0.455[b]	0.526[b]	0.538[b]
Sig. (T)	0.002	0.48	0.621	0.522	0.59	0.077	0.001	0	0.496	0	0	0	0	0
Springiness														
Pearson	−0.224[a]	−0.097	−0.043	0.226[a]	−0.118	0.304[b]	−0.271[a]	0.139	−0.462[b]	0.199	0.455[b]	1	0.196	0.305[b]
Sig. (T)	0.046	0.394	0.704	0.044	0.295	0.006	0.015	0.219	0	0.077	0	0	0.082	0.006
Gumminess														
Pearson	−0.386[b]	−0.126	−0.047	−0.07	0.146	0.052	−0.380[b]	0.977[b]	0.041	0.728[b]	0.526[b]	0.196	1	0.987[b]
Sig. (T)	0	0.264	0.679	0.538	0.197	0.649	0.001	0	0.72	0	0	0.082	0	0
Chewiness														
Pearson	−0.382[b]	−0.103	−0.06	−0.024	0.106	0.097	−0.401[b]	0.962[b]	−0.016	0.714[b]	0.538[b]	0.305[b]	0.987[b]	1
Sig. (T)	0	0.363	0.599	0.831	0.348	0.39	0	0	0.887	0	0	0.006	0	0

[a]represents the confidence (T) is 0.05, and the correlation is significant.
[b]represents the confidence (T) is 0.01, and the correlation is extremely significant.

Tan sheep were significantly correlated ($p<.01$). The levels of TP, ALB, TG and HDL-C were extremely significantly correlated ($p<.01$) with the lipid content. The CHE, PA and LDL-C were extremely significantly correlated ($p<.01$) with resilience, cohesiveness, springiness and adhesiveness. The contents of GT, CHE, PA, TP, ALB, GLB and DBIL were extremely significantly correlated ($p<.01$) with cooking loss. Simultaneously, meat traits were related to slaughter traits, texture characteristics and water-holding capacity. Therefore, there is great potential for the use of serum biochemical indices as markers to predict the growth performance and assess the meat quality traits of Tan sheep in the future.

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Data availability statement

The data that supports the findings of this study are available in all tables of this article.

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