Effects of Nutrition and Origin on the Amino Acid, Grease, and Suint Composition and Color of Cashmere and Guard Hairs

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ABSTRACT: Nutritional and environmental effects on the amino acid, wax, and suint contents and color of raw cashmere were investigated. Cashmere was obtained from goats fed with or without dietary protected protein, goats fed different levels of dietary energy and feeds, and goats from Australia, China, and Iran. The determined attributes included the production, diameter, length, fiber curvature, crimp, wax and suint contents, amino acid composition, lightness, and yellowness of cashmere. The content of suint, but not that of wax, was affected by nutrition management. The amino acid composition of cashmere was affected by the energy and protein nutrition, feed type, and country of origin. The amino acid composition of cashmere was different from that of guard hair. The lightness and yellowness of cashmere was affected by the nutrition treatment, grazing, cashmere production, and sum of the wax and suint contents of the raw cashmere. The variation in the amino acid composition of cashmere likely affected both its physical and chemical reactivity. Nutrition manipulation of cashmere goats and the origin of goats have implications with respect to the properties of cashmere as changes in fiber cell biosynthesis can alter the amino acid composition of the fiber. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 117: 409–420, 2010

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INTRODUCTION

Cashmere is a precious animal fiber valued for its softness. Adding cashmere to superfine wool affects the softness, mechanical properties, processing, and wear properties of textiles.[1–4] The softness of processed cashmere is related to its low resistance to compression,[5,6] which in turn is related to the low fiber crimp (curvature) of cashmere.[5–7] Cashmere from some places is softer than cashmere from other places[5,6] because the form of fiber crimping (sinusoidal or helical) differs with the origin of cashmere.[7] Thus, the fiber crimp frequency and the form of fiber crimping affect the most important commercial attribute of cashmere.

The perceived softness of handle of raw cashmere can be affected by changes in the contents and proportions of the nonfiber components of the greasy fiber, such as suint and wool grease (wax). Suint is a mixture of the dried perspiration secreted by the sudoriferous glands and deposited on the fibers as water-soluble salts of various fatty acids and other water-soluble products found in the fleece.[8] Suint is highly hygroscopic: at 65% relative humidity, the moisture content of suint is 40%, whereas the moisture content of wool fibers is 14–16%.[9] By affecting the moisture content of the raw fiber, the absolute level of suint affects the perceived handle of the raw fiber.

It has been known for many years that the crimp frequency of Merino wool affects the amino acid composition of the wool fibers.[10–12] Variations in the nutrition of Merino sheep have been shown to affect the amino acid composition of Merino wool, partly because changes in nutrition lead to changes in the growth rate of wool, which leads to changes in the frequency of fiber crimping (fiber curvature), and partly because of the increase in the high-sulfur protein content.[10,13] However, the response of the amino acid composition to variations in the crimp frequency of wool differs within sheep and between sheep. Within sheep, reduced nutrition leads to a greater crimp frequency and reduced amounts of cystine and high-sulfur proteins. However, between sheep, a greater crimp frequency increases the amount of cystine when sheep are fed unrestricted diets.[10,11]

Variations in the amino acid composition and suint content of wool affect various commercial

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attributes of keratin fibers, including the wool color before, during, and after processing.[14–18] Changes in the nutrition and in the genetic selection of Merino sheep have also been shown to affect the proportions of nonfiber components of the wool.[19] Dietary supplements of methionine have been shown to increase the staple strength of wool grown by Merino sheep losing live weight.[20] Reis[21] reviewed the literature and concluded that there were no clear associations between the proportions of constituent proteins in wool and the strength of wool fibers; however, the content of high-tyrosine proteins in the matrix of weak fibers was frequently reduced. The content of high-sulfur and high-tyrosine proteins may influence some mechanical properties of fibers during compression.[22] The wool fiber strength has been associated with high-sulfur proteins in some but not all studies.[21]

Although there are a number of general reports available on the amino acid composition of cashmere and the nonprotein components of cashmere,[23–28] none can be found that have investigated the impact of environmental, nutritional, or productivity factors on the amino acid composition and nonfiber components of cashmere. Most of the studies reporting differences or a lack of differences in the amino acid composition of cashmere do not provide any statistical evidence to support their claims, and only one has investigated a correlation between any amino acid and fiber physical properties.

Given that the variation in the amino acid composition has important commercial ramifications for Merino wool and given the absence of information on nutritional and environmental effects on the amino acid composition of wax and suint and the color attributes of cashmere, this work was designed to investigate these effects. In particular, some of the tested samples originated from one of the few studies that detected an effect of dietary nutrition manipulation on the growth of cashmere fiber[29] and the only study in which nutrition was shown to affect the cashmere fiber curvature.[30]

EXPERIMENTAL

Materials

There were three sources of cashmere.

White cashmere grown by Australian cashmere goats individually fed in a controlled nutrition experiment conducted indoors for 8 months[30,31]

These goats were shorn at the start (3 December) and at the end (17 June) of the study so only cashmere grown during the nutrition study was tested. Before the experiment was started, most of the indoor pens, which were constructed from galvanized pipes, were thoroughly cleaned with high-pressure steam to remove all traces of grease, soil, and other potential contaminants that may have been present on the pipes. These goats were fed different quantities of the same basal diet to provide three levels of energy intake: (1) a submaintenance live-weight diet that resulted in live-weight loss (0.8M), (2) a live-weight maintenance diet (M), and (3) a greater-than-maintenance diet that resulted in live-weight gain (>M). The basal diet was highly digestible Persian clover hay (*Trifolium resupinatum*) with a crude protein content of 21.45% and a metabolizable energy content of 10.4 MJ/kg of dry matter. Nested within the M diet were three treatments used to assess the influence of additional dietary protein: (1) the goats were fed to maintain their live weight with a base diet of high-quality clover hay (M), (2) the goats were fed to maintain their live weight with 27 g of formaldehyde-treated casein (FTC) per day included in a pellet made with the hay and with the base diet (M + 27 g of FTC), and (3) the goats were fed to maintain their live weight with 54 g of FTC per day included in a pellet made of the base diet and with the base diet (M + 54 g of FTC). Nested within the >M diet were three treatments, of which only two were tested for this study: (1) the goats were fed the base diet *ad libitum* (ADLIB), and (2) the goats were fed the M diet plus 25% of the difference in the mean intake between the M and ADLIB diets (1.25M).

Five Australian cashmere goats that were 1 year and 3 months old were randomly allocated to each of the treatments (the total number housed indoors was 35 from a flock of 90). Only four of the goats from each treatment were used in this study, as these were the goats whose pens had been steam-cleaned. Before the study started, these goats grazed at pasture. Further details are provided elsewhere.[30,31]

White cashmere grown by five Australian goats that grazed at pasture (outside)

These goats were managed in the same cohort described previously, but they were not selected for the main experiment, and they continued to graze on annual pasture until they were shorn on June 17. This pasture was senescent during the summer period and would have resulted in live-weight loss; it was similar to that used in associated studies.[32] The pasture germinated and grew from late autumn to winter.

Cashmere obtained by the authors from other sources

Typical commercially shorn raw white cashmere from Australia (n = 1). This fiber originated from two

bales and four grower lines of cashmere purchased from the Australian Cashmere Marketing Corp. (1997 H pool). This cashmere originated from approximately 12 farms in different regions of Australia and was sampled and dehaired before use in a range of textile experiments.[1–5,7,30]

Iranian cashmere. Samples (n = 4) were collected by the authors from individual goats in the cashmere production areas of Baft (n = 2; brown cashmere) and Birjand (n = 2; white cashmere) during early May 2000.[7]

Chinese cashmere. Samples (n = 7) were collected by the authors from individual goats in five locations, including Inner Mongolia (n = 2; 1 brown and 1 white),[33] Liaoning Province (n = 3; white),[34] and the Xinjiang Uygur Autonomous Region (which includes Kazak and Tajik pastoralists; n = 2; white).[7,35]

Measurements of the fiber attributes

Various tests were undertaken.

Mean fiber diameter, variation in the fiber diameter, and fiber curvature

With the use of an OFDA100 (BSC Electronics, Ardross, Western Australia),[36,37] these attributes were determined via the minicoring of samples or via the guillotining of complete staples taken from the midside site into 2-mm snippets. Snippets were water-scoured with nonionic Lissapol in a sonicating water bath (50–55°C). Samples were gently rinsed twice with ethyl alcohol, excess liquid was removed *in vacuo*, and samples were relaxed for 24 h at a relative humidity of 65 ± 2% and 20 ± 2°C. For each of two samples, two measurements of 8000 counts were made, and the mean results were calculated with a fiber diameter cutoff of 35 μm for cashmere. All the samples were tested on the same machine.

Fiber length

From each individual sample, three random staples were drawn. From each staple, the longest cashmere fibers were drawn. The fibers were gently drawn straight on a velvet board and measured to the nearest millimeter. The length obtained by this method was highly correlated [correlation coefficient (r) = 0.95] to Wool Industries Research Association (WIRA) single-fiber-length measurements.[38]

Cashmere fiber crimp frequency (crimps/cm)

After the measurement of the fiber length, other cashmere fibers were gently removed and allowed to relax on a velvet board. The board was placed on a dissecting microscope, and the frequency of crimping was measured on at least 3 fibers per staple.

Wax and suint content

The samples (each about 5 g of dry weight) were first extracted with redistilled petroleum ether (bp = 40–60°C) for 3 h in a Soxhlet apparatus (24–26 cycles). The petroleum ether was then removed by distillation, and the residue (wax) was then dried to a constant mass in a circulating oven at 110°C.[39] The fiber samples were then conditioned at room temperature, and this was followed by extraction with deionized water for 7 h (24–26 cycles). The water was removed by distillation, and the residue (suint, i.e., the water solubles) was dried to a constant mass at 110°C.[39]

Color attributes of cashmere from the nutrition experiment

The lightness (Y), yellowness (Y–Z), and redness (X–Y) of cashmere were determined with a color machine (B.Y.K. Gardner, Inc., Columbia, MD).[40]

Measurement of amino acids

For each cashmere sample, the guard hair was manually separated from the cashmere with tweezers. All fiber samples were cleaned under nonswelling conditions.[38] For the amino acid analysis, the samples were analyzed in two batches with two different methods.

Batch 1

Samples of a known dry mass (50 mg) were hydrolyzed *in vacuo* with 6*M* hydrochloric acid (HCl) for 18 h at 108°C. After hydrolysis, the solutions were filtered, and the amino acid composition was determined by high-performance liquid chromatography (ion exchange) with a Waters amino acid analyzer (Waters Corp., Milford, MA) with *o*-phthaldehyde for postcolumn detection. The analyzed samples were from goats who underwent the <M, M, ADLIB, and outside treatments (n = 17), and one guard hair sample from individual goats representing each of these treatments was randomly chosen (n = 4).

Batch 2

Samples of a known dry mass (>50 mg) were freeze-dried, and the fiber was hydrolyzed in 6*M* HCl for 24 h under an atmosphere of nitrogen in screw-cap tubes.[41] After hydrolysis, the solution was diluted and filtered, and the HCl was removed under reduced pressure. As this procedure partially destroyed methionine and cystine (plus cysteine), a separate digestion was undertaken for these amino acids. This involved pre-oxidation of the fiber with

performic acid at 0°C for 16 h followed by 6*M* HCl hydrolysis.[42] Under these conditions, methionine was converted to methionine sulfone, and cystine and cysteine were converted to cysteic acid. The resulting solutions of amino acids underwent postcolumn derivatization with ninhydrin after separation with cation-exchange chromatography,[42] and then they were quantified against analytical standards of the corresponding amino acids. The analyzed samples were from goats who underwent the M (n = 1), 1.25M (n = 4), M + 27 g of FTC (n = 3), and M + 54 g of FTC treatments (n = 4), as well as all cashmere obtained by the authors from other sources.

Statistical analysis

The means and standard deviations were determined for the various attributes of raw cashmere and for the amino acid contents.

Data for the influence of nutrition on the amino acid composition and color attributes of cashmere were analyzed by a 2-way analysis of variance using covariate analysis.[43] An extra treatment was added to the original design as the outside treatment. Covariates [the clean cashmere weight, cashmere mean fiber diameter, and total clean fleece weight (hair plus cashmere)] were the characteristics of the fleece harvested in August before allocation of animals to the nutrition experiment. When a significant effect of a covariate was detected ($P < 0.05$), the results were determined after adjustments for the covariate, and they are indicated as such in the tables. For the amino acid analyses, the data were restricted to batch 1, which provided 13 degrees of freedom for the error term without covariates and 12 degrees of freedom for the error term when a covariate was significant. For the analysis of differences between the amino acid compositions of cashmere and guard hair from the same animal sample, a two-way analysis of variance was used without covariates, and this provided 6 degrees of freedom for the error term. For the analysis of color attributes, there were 32 degrees of freedom for the error term as all treatments and replicates were present.

Data for the influence of protected dietary protein were analyzed by a two-way analysis of variance without covariates with the 1.25M, M + 27 g of FTC, and M + 54 g of FTC treatments tested in batch 2. As there were no differences in the amino acid compositions between the two treatments with protected protein, these data were pooled and analyzed as M + PP; this provided 9 degrees of freedom for the error term. Data comparing the effects of the country of origin of cashmere on the amino acid composition were analyzed only for samples tested in batch 2. For the Australian goats, the M + PP samples were excluded, and this provided 14 degrees of freedom for the error term. For all analyses of variance, the determined standard errors of difference between means and the statistical probability of difference between treatments (*P* value) have been provided.

The amino acid composition was modeled as a function of the mean fiber diameter, fiber curvature, crimp frequency, and fiber length with linear and multiple linear regression analyses.[43] Color attributes were modeled as a function of the amino acid, wax, and suint compositions. Mean nutrition treatment data for color attributes were modeled as a function of the mean clean cashmere, hair, and total fleece growth with treatment. Best fit regression lines were plotted with individual data. The residual standard deviations of regression (RSDs), *r* values, and *P* values are provided.

RESULTS

There was a wide range, as indicated by the standard deviation and ranges, of compositions of most amino acids tested (Table I).

Effect of energy nutrition and management on suint and wax

The content of suint, but not that of wax, in the raw fleece was affected by nutrition and management treatment (Table II). The fleeces of goats that grazed outside during the year had significantly more suint than the fleeces of goats fed indoors. With the goats fed indoors, the energy nutrition treatment also affected the suint content of the fleeces, with those goats fed at the highest level of nutrition (ADLIB) having a greater amount of suint than the goats fed below maintenance (0.8M).

Effect of energy nutrition and management on the amino acid composition

Energy nutrition and management affected the amino acid composition of cashmere (Table III). Cashmere from goats that grazed outside had lower alanine, histidine, isoleucine, proline, and valine levels and higher aspartic acid and phenylalanine levels in comparison with some or all of the cashmere grown by goats housed indoors. For the goats fed indoors, energy nutrition had few significant affects. Increasing energy nutrition reduced aspartic acid levels and increased proline levels of cashmere, and cashmere from ADLIB-fed goats had lower phenylalanine contents than cashmere from goats fed the M diet ($P < 0.1$; Table III).

Within the nutrition experiment for housed goats fed the same diet but in various quantities (<M, M, and ADLIB), there were associations between the amino acid composition of cashmere and the physical metrics of cashmere. The mean fiber diameter of cashmere was associated with methionine (P =

TABLE I
Means, Standard Deviations, and Ranges of Greasy Fleece Attributes and Amino Acid Compositions of Cashmere Grown by Wether Goats Fed Different Levels of Energy and Protein Intake

Attribute	Mean	Standard deviation	Minimum	Maximum
Greasy fleece production (g)	574	178	321	855
Clean cashmere production (g)	236	85.1	99	378
Mean fiber diameter (μm)	17.2	0.85	15.4	18.6
Fiber curvature (°/mm)	56.6	12.97	35.4	86.3
Cashmere maximum length (mm)	92	18.5	53	125
Suint (% w/w)	2.80	0.671	1.99	4.06
Wax (% w/w)	3.09	0.873	1.42	4.51
Alanine (μmol/g)	489.1	20.8	425.0	517.0
Ammonia (μmol/g)	893.8	109.3	654.3	1058.0
Arginine (μmol/g)	611.0	38.5	540.4	676.0
Aspartic acid (μmol/g)	482.8	22.4	432.0	542.0
Cystine and cysteine (μmol/g)	398.2	53.1	294	508
Glutamic acid (μmol/g)	1195.9	42.3	1065	1266.5
Glycine (μmol/g)	753.5	136.2	516.4	957.0
Histidine (μmol/g)	92.6	17.47	69.7	121.0
Isoleucine (μmol/g)	271.4	10.4	256.9	293.0
Leucine (μmol/g)	631.3	34.7	549.2	674.0
Lysine (μmol/g)	206.7	23.0	150.0	234.0
Methionine (μmol/g)	17.13	15.40	0	36.19
Phenylalanine (μmol/g)	227.6	14.0	199.0	251.0
Proline (μmol/g)	658.0	67.4	571	841.9
Serine (μmol/g)	976.4	103.9	803	1129
Threonine (μmol/g)	557.2	68.2	440	667
Tyrosine (μmol/g)	247.4	28.5	176	290
Valine (μmol/g)	493.8	45.4	419	547

0.040, $r = -0.54$), valine (0.049, −0.52), and leucine (0.059, 0.49). The fiber curvature of cashmere was associated with arginine (0.019, 0.62) and valine (0.090, 0.44). The staple length of cashmere was associated with alanine (0.030, −0.57) and cystine plus cysteine (0.045, 0.53).

Effect of feeding protected protein on the amino acid composition

There were significant differences between the amino acid compositions of the cashmere grown by goats fed the 1.25M diet and the cashmere grown by goats fed protected protein (Table IV). For the cashmere grown by goats fed protected protein, 13 amino acids had higher concentrations, and one amino acid had a lower concentration, in comparison with the cashmere grown by goats fed the 1.25M diet (Table IV).

Effect of the country of origin on the amino acid composition

The country of origin affected the contents of four amino acids in the cashmere samples (Table V). Glycine, phenylalanine, serine, and tyrosine were higher in cashmere samples from China versus cashmere samples from Australia, with the samples from Iran having intermediate values.

Amino acid compositions of cashmere and guard hair from the same goats

There were significant differences between the amino acid compositions of cashmere and the guard

TABLE II
Effects of the Nutrition Treatment on the Fleece Suint and Wax Contents of Wether Goats Fed at Three Levels of Energy Intake

Treatment	0.8M (n = 4 goats)	M (n = 4 goats)	ADLIB (n = 4 goats)	Outside (n = 5 goats)	Standard error of difference: Between outside and other treatments	Standard error of difference: Between 0.8M, M, and ADLIB treatments	*P* value
Suint (% w/w)	2.18	2.38	2.80	3.64	0.221	0.233	$\mathbf{6.8 \times 10^{-5}}$
Wax (% w/w)	3.08	3.28	2.83	3.15	0.638	0.673	0.92

The *P* value in bold is significant at the 5% level.

TABLE III
Effects of the Nutrition Treatment on the Amino Acid Contents of Cashmere Grown by Wether Goats Fed High-Quality Hay Indoors at Different Levels of Energy Intake or Grazed Outside on Pasture

Treatment	0.8M (n = 4 goats)	M (n = 4 goats)	ADLIB (n = 4 goats)	Outside (n = 5 goats)	Standard error of difference: Between outside and other treatments	Standard error of difference: Between 0.8M, M, and ADLIB treatments	*P* value
Alanine (μmol/g)	510	505	499	471	12.9	13.6	**0.039**
Ammonia(μmol/g)	932	951	942	991	35.7	37.6	0.386
Arginine (μmol/g)	642	640	635	632	18.0	19.0	0.951
Aspartic acid (μmol/g)[a]	492	470	466	507	18.6	19.6	0.092
Cystine and cysteine (μmol/g)	397	357	401	348	39.9	42.0	0.475
Glutamic acid (μmol/g)	1209	1141	1196	1176	28.2	29.7	0.167
Glycine (μmol/g)	878	852	827	874	29.8	31.2	0.363
Histidine (μmol/g)[b]	112	108	111	97	4.9	5.2	0.090
Isoleucine (μmol/g)	278	283	282	270	3.4	3.5	**0.009**
Leucine (μmol/g)[b]	656	658	653	652	7.9	8.3	0.853
Lysine (μmol/g)	211	206	204	192	22.1	23.2	0.856
Methionine (μmol/g)	10.2	7.3	5.5	0	6.5	6.8	0.464
Phenylalanine (μmol/g)[c]	230	239	214	229	8.5	8.9	0.082
Proline (μmol/g)[c]	644	673	690	579	23.2	24.5	**0.005**
Serine (μmol/g)	1071	1043	1049	1046	35.4	37.3	0.866
Threonine (μmol/g)	621	606	617	580	21.2	22.9	0.266
Tyrosine (μmol/g)[b]	236	235	225	242	18.1	19.1	0.829
Valine (μmol/g)	538	540	534	513	7.0	7.4	**0.007**

P values in bold are significant at the 5% level.
[a] Values were adjusted for a significant covariate ($P < 0.05$) allocation cashmere mean fiber diameter.
[b] Values were adjusted for a significant covariate ($P < 0.05$) allocation cashmere weight.
[c] Values were adjusted for a significant covariate ($P < 0.05$) allocation clean fleece weight.

hair grown by the same goats (Table VI). Cashmere had 10 amino acids with higher concentrations and three amino acids with lower concentrations in comparison with the guard hair.

Color of cashmere from the nutrition experiment

For cashmere in the nutrition experiment, the means and standard deviations of the color measurements were as follows: 58.2 ± 3.34 (range = 49.3-65.0) for

TABLE IV
Effects of the Nutrition Treatment on the Amino Acid Content of Cashmere Grown by Wether Goats Fed To Grow (1.25M) or Fed a Maintenance Diet with Protected Protein (M + PP)

Treatment	1.25M (n = 4 goats)	M + PP (n = 7 goats)	Standard error of difference	*P* value
Alanine (μmol/g)	463	490	3.5	$\mathbf{2.4 \times 10^{-5}}$
Ammonia (μmol/g)	668	872	28.1	$\mathbf{4.7 \times 10^{-5}}$
Arginine (μmol/g)	553	581	5.7	**0.00075**
Aspartic acid (μmol/g)	458	489	5.6	**0.00015**
Cystine and cysteine (μmol/g)	418	425	15.2	0.662
Glutamic acid (μmol/g)	1172	1230	8.7	$\mathbf{8.5 \times 10^{-5}}$
Glycine (μmol/g)	549	632	17.3	**0.00098**
Histidine (μmol/g)	70.8	75.0	1.1	**0.003**
Isoleucine (μmol/g)	261	262	2.4	0.581
Leucine (μmol/g)	563	616	9.5	**0.00032**
Lysine (μmol/g)	206	213	1.2	**0.00035**
Methionine (μmol/g)	27.9	34.6	1.6	**0.003**
Phenylalanine (μmol/g)	213	234	7.2	**0.017**
Proline (μmol/g)	741	661	50.7	0.151
Serine (μmol/g)	820	891	11.8	**0.00020**
Threonine (μmol/g)	546	463	9.4	$\mathbf{1.0 \times 10^{-5}}$
Tyrosine (μmol/g)	244	276	11.7	**0.025**
Valine (μmol/g)	427	451	3.8	**0.00013**

P values in bold are significant at the 5% level.

TABLE V
Effects of the Country of Origin on the Amino Acid Content of Cashmere

Country	Australia (n = 6 goats)	China (n = 7 goats)	Iran (n = 4 goats)	Standard error of difference	*P* value
Alanine (μmol/g)	472	482	472	11.9	0.551
Ammonia (μmol/g)	772	837	787	67.6	0.189
Arginine (μmol/g)	562	575	554	12.6	0.256
Aspartic acid (μmol/g)	468	475	468	13.8	0.817
Cystine and cysteine (μmol/g)	411	425	394	15.4	0.161
Glutamic acid (μmol/g)	1189	1207	1183	34.5	0.740
Glycine (μmol/g)	571	696	644	33.4	**0.002**
Histidine (μmol/g)	70	72	68	1.9	0.122
Isoleucine (μmol/g)	261	256	259	5.8	0.609
Leucine (μmol/g)	578	607	583	21.3	0.305
Lysine (μmol/g)	210	219	214	6.5	0.328
Methionine (μmol/g)	30	34	31	2.3	0.183
Phenylalanine (μmol/g)	219	233	223	6.4	0.056
Proline (μmol/g)	715	692	688	35.7	0.693
Serine (μmol/g)	836	903	843	30.0	**0.046**
Threonine (μmol/g)	527	504	503	20.9	0.383
Tyrosine (μmol/g)	255	325	299	19.9	**0.004**
Valine (μmol/g)	433	443	432	9.3	0.409

P values in bold are significant at the 5% level.

lightness, 1.13 ± 0.97 (range = −0.69 to 3.78) for yellowness, and −1.48 ± 0.164 (range = −1.82 to −1.08) for redness. The nutrition treatment affected the lightness, yellowness, and redness attributes of cashmere (Table VII).

The lightness of cashmere was correlated with two amino acids: proline ($P = 0.003$, $r^2 = 0.416$, standard error of observation = 2.73) and valine (0.018, 0.277, 3.03). Only proline was significant when proline and valine were tested in a multiple regression. The yellowness of cashmere was correlated with three amino acids: proline (0.002, 0.456, 0.851), isoleucine (0.013, 0.303, 0.963), and valine (0.040, 0.202, 1.03). Only proline was significant when tested in a multiple regression.

Neither the lightness nor yellowness of cashmere was significantly related to the wax or suint content ($P > 0.1$). However, when the wax and suint contents were summed, there was a weak association with the lightness of cashmere:

TABLE VI
Amino Acid Contents of Cashmere and Guard Hair Obtained from the Same Sample

Country	Cashmere (n = 4 goats)	Guard hair (n = 4 goats)	Standard error of difference	*P* value
Alanine (μmol/g)	500	424	7.1	$\mathbf{4.0 \times 10^{-5}}$
Ammonia (μmol/g)	940	916	40.3	0.573
Arginine (μmol/g)	632	610	7.5	**0.025**
Aspartic acid (μmol/g)	476	488	19.8	0.575
Cystine and cysteine (μmol/g)	374	303	40.5	0.132
Glutamic acid (μmol/g)	1196	1541	39.6	**0.00013**
Glycine (μmol/g)	868	726	11.2	$\mathbf{1.5 \times 10^{-5}}$
Histidine (μmol/g)	105	115	3.4	**0.025**
Isoleucine (μmol/g)	281	254	6.1	**0.004**
Leucine (μmol/g)	654	690	11.7	**0.023**
Lysine (μmol/g)	204	211	17.1	0.707
Methionine (μmol/g)	6	0	5.5	0.356
Phenylalanine (μmol/g)	240	208	4.7	**0.00046**
Proline (μmol/g)	624	519	29.1	**0.011**
Serine (μmol/g)	1032	954	22.9	**0.014**
Threonine (μmol/g)	592	494	22.2	**0.005**
Tyrosine (μmol/g)	253	155	19.2	**0.002**
Valine (μmol/g)	524	448	15.3	**0.002**

P values in bold are significant at the 5% level.

TABLE VII
Effects of the Nutrition Treatment on the Lightness, Yellowness and Redness of Australian Cashmere

Treatment group	n	Lightness (Y)	Yellowness (Y–Z)	Redness (X–Y)
<M	5	55.21	2.12	−1.33
M	15	59.14	0.73	−1.46
>M	15	59.30	0.89	−1.52
O	5	54.50	2.33	−1.44
Standard error of difference: <M, O − other (P value)		1.319 (<**0.001**)	0.371 (<**0.001**)	0.075 (0.091)
Standard error of difference: M − >M (P value)		0.933 (NS)	0.263 (NS)	0.053 (NS)
Treatment within >M	n	Lightness (Y)	Yellowness (Y–Z)	Redness (X–Y)
1.25M	5	56.89	1.50	−1.33
1.50M	5	62.22	0.61	−1.67
ADLIB	5	58.78	0.55	−1.57
Standard error of difference (P value)		1.615 (**0.009**)	0.455 (0.081)	0.092 (**0.003**)

P values in bold are significant at the 5% level. The nutrition treatment groups were as follows: <M, below-live-weight maintenance feeding; M, maintenance of live-weight feeding; >M, above-live-weight maintenance feeding; and O, pasture grazing.

$$\text{Lightness} = 64.3(\pm 4.46) - 0.014(\pm 0.0075) \times (\text{Wax} + \text{Suint}), P = 0.079, \text{RSD} = 3.31, r = 0.37.$$

The mean lightness and yellowness of cashmere with the nutrition treatment were associated with the mean clean cashmere production with the treatment (Fig. 1):

$$\text{Lightness} = 45.38(\pm 2.29) + 0.067(\pm 0.0155) \times (\text{Clean cashmere weight}), P = 0.005, \text{RSD} = 1.52, r = 0.84.$$

$$\text{Yellowness} = 3.96(\pm 1.08) - 0.015(\pm 0.0056) \times (\text{Clean cashmere weight}), P = 0.038, \text{RSD} = 0.549, r = 0.68.$$

Neither the total fleece weight nor the guard hair weight were significant alone or when added to the clean cashmere weight in regressions with lightness or yellowness ($P > 0.30$). There were no significant relationships between the redness and any fleece attribute ($P > 0.15$).

DISCUSSION

The amino acid composition of cashmere is affected by the nutritional management and country of origin. Such variations likely affect both the physical and chemical reactivity of the cashmere fibers and therefore affect textile processing and textile properties. Variations in the suint content of cashmere due to differences in the nutrition and management of goats have implications for cashmere testing and processing.

Wax and suint

In this work, the housing of goats for 8 months did not affect the wax content of cashmere in comparison with that found on naturally grazing goats, and this suggests that these values must represent the genetic potential of the animals with respect to wax production. The mean wax content of these individual fleeces (3.1%) was similar to the content found in commercial lots of Australian cashmere (3.2%).[44]

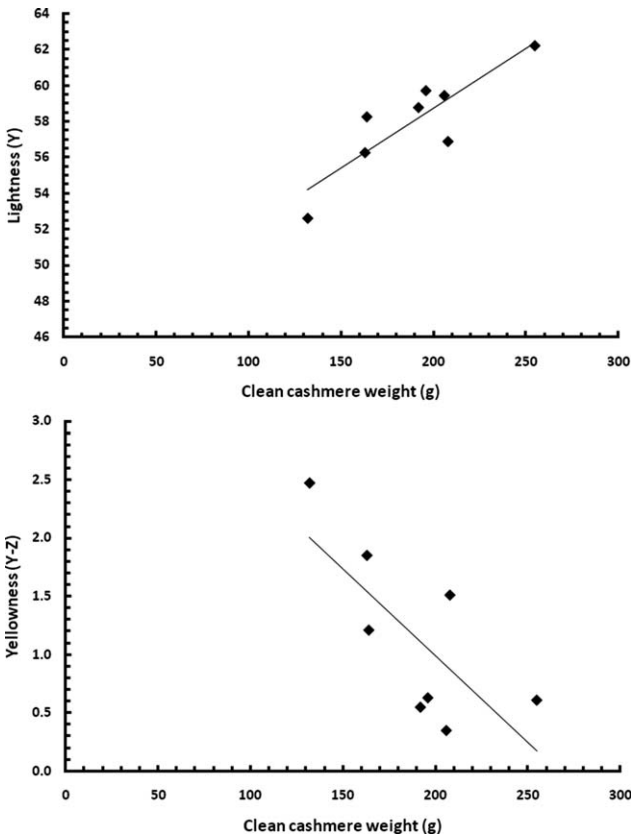

Figure 1 Relationship between the lightness and yellowness of cashmere and clean cashmere growth of Australian cashmere goats subjected to various nutrition treatments including grazing at pasture and being housed indoors. Data points are means for different nutrition treatments.

Both these values were 0.8–1% higher than the mean values reported in individual fleeces of Australian goats in three earlier studies (74 goats: mean = 2.5%, range = 1.1–4.0%;[45] 317 goats: mean = 2.2%, range = 0.1–8.3%;[46] 4 samples: range = 0.7–2.9%[26]). The wax values for Australian cashmere are less than those reported for Merino and crossbred sheep breeds, which range from 5.3 to 25.4% with an average of 10.6–16.1% greasy wool.[47] Wax values up to 54.6% have been found in a selected Merino flock.[16]

Suint (sweat) is the water-soluble component within the fleece and consists mainly of potassium cations, anions of nonvolatile organic acids, and other compounds.[47] The mean value of suint in cashmere grown by housed goats (2.5%) was less than the value for cashmere grown by grazing goats (3.6%), even though the grazing goats were subject to rain that might wash some of the suint from the cashmere. The highest suint content measured in this raw cashmere was 4.1%. The amount of suint in the goats that grazed outdoors was similar to that found in commercial lots of Australian cashmere (mean = 4.0%, range = 3.2–4.6%[44]) but more than 3 times the highest value recorded by Tucker et al.[26] (4 samples: range = 0.3–1.2%). The suint values for Australian cashmere are less than those reported for Merino and crossbred sheep breeds, which range from 2.0 to 13.6% with an average of 6.1–8.2% greasy wool.[47] Suint values up to 15.4% have been detected in a selected Merino flock.[16]

Higher suint contents in raw wool (particularly potassium ions) are associated with increased yellowing of wool, and the reported relationships are linear.[16] The implications of higher suint contents in cashmere are not known.

Clearly, the suint content, but not the wax content, of raw cashmere is affected by nutritional and environmental factors. McGregor[44] observed that the higher values for wax and suint reported in that study, in comparison with the values reported in earlier studies of Australian cashmere, suggested that the husbandry and/or genetics of Australian cashmere goats had changed between the respective sampling dates (ca. 1980–1983 for the earlier studies and 1997 for the latter study). In this work, the goats were born in 1983 and so represented earlier genetics. The suint values for the grazing goats in this work, in comparison with the values obtained for cashmere from commercially grazed goats harvested in 1997, indicate that exposure to greater climatic and environmental variations is the likely cause of increased suint content in cashmere from grazing goats. However, if Australian cashmere breeders have favored goats with softer fiber handle attributes during their selection of breeding goats, they may have indirectly increased the suint content of raw cashmere, as a high suint contents have been shown to increase the perceived softness of handle of Merino wool,[48] perhaps because suint increases the moisture content of the fleece.[9]

The water-soluble contents of the fleece are not completely derived from the sudoriferous glands. Suint includes any water-soluble component in the raw fiber, including material formed by atmospheric and photochemical action on the wool and products of microbiological modification not only of true suint but also of the wool keratin and wool wax.[8] Thus, the precise origin of the suint constituents is somewhat ill defined. This view is strengthened by the demonstration that the sequence of extraction of wax and suint affects the numerical results.[49] The extraction of water solubles first provides higher suint determinations and lower wax determinations. This suggests that the actual level of suint is underreported for cashmere.

The total composition of wax and suint in raw Australian cashmere is not trivial (from 5.9% in this work to 7.2%[44]) and possibly increases over time as a result of animal selection. It is therefore important that, during the evaluation of sires for cashmere production, testing be undertaken to accurately measure the clean cashmere fiber content of harvested fiber. This process involves the measurement of both the clean washing yield of raw fiber and the estimation of the cashmere yield in clean fiber. Ignoring the wax and suint contents in raw Australian cashmere will bias estimates of clean cashmere production upward by approximately 7%.

Amino acids in cashmere

The amino acid composition of cashmere was affected by nutrition and management, including grazing versus the feeding of a high-quality diet, supplementary feeding of protected protein versus the feeding of a high-quality diet, and production in China versus production in Australia. The amino acids that were affected by the country of origin were different from the amino acids affected by energy nutrition and grazing management but were affected by the feeding of protected protein.

With Merino sheep, nutritional manipulation has been shown to affect the cystine and methionine contents of wool.[13] No effects were detected in this work on the cystine content of cashmere, even when supplements of high-quality protected casein were fed or when comparisons were made between countries of origin. However, the feeding of protected protein to cashmere goats had large effects on most of the amino acids measured, including methionine. As reported previously, the addition of dietary protected protein in this study increased the growth of wool in Merino sheep[33] but did not increase cashmere growth. However, this work shows that the

feeding of protected protein in the diet of cashmere goats did affect the amino acid composition of the cashmere. Thus, altered protein nutrition may not have significantly increased the cell proliferation rate, but it did affect cell biosynthesis, as shown by the altered amino acid composition, and almost certainly the physical and chemical composition.

Almost all the absorption of UV light by wool is due to the amino acids tyrosine and tryptophan, which contain chromophores.[15] The energy that tyrosine absorbs is transferred to tryptophan, which then reacts with oxygen to form colored products. As the wool yellows, the tryptophan content gradually decreases. Yellowing has also been associated with the photooxidation of phenylalanine[18] and with products associated with histidine, proline, arginine, and lysine[50,51] and phenazine-based chromophores found in the cuticle.[52] In this work, the tyrosine and phenylalanine contents of Australian cashmere were found to be lower than those of Chinese cashmere samples, and the tyrosine and phenylalanine contents of cashmere were increased by the feeding of protected protein. If the same mechanisms that operate in wool also operate in cashmere, then Chinese cashmere and cashmere grown from goats fed high levels of protected protein may have a greater propensity to yellow when exposed to light. This may explain the finding that the origin of cashmere explains over 50% of the variation in the color of white cashmere and that processed Chinese white cashmere had lower lightness and greater yellowness than Australian white cashmere.[5]

Merino wool with a higher staple crimp frequency had a higher proline content than wool of a similar fiber diameter but with a lower staple crimp frequency.[11] A similar finding was made with the cashmere grown indoors and the cashmere from grazing goats (Table III) but not between cashmere from different countries of origin (Table V).

Amino acids in guard hair

The differences between cashmere and guard hair detected in this work differed to some extent in comparison with those reported for feral goat cashmere and guard hair.[27] This work detected differences between cashmere and guard hair in 13 amino acids, whereas Tucker et al.[27] detected differences in 10 amino acids, 3 of which (aspartic acid, cystine, and lysine) were not detected in this work and 1 of which (isoleucine) was higher in guard hair in feral goats but lower in this study. Thus, when viewed together, the results of these two studies showed differences between the amino acid compositions of cashmere and guard hair for all amino acids examined, with the exception of methionine.

The differences between the two reports may be related to genetic or environmental factors. It is likely that the goats used in this study[31] grew 2 to 4 times the quantity of cashmere grown by feral goats.[27,53] For most cashmere goats, the total annual growth of guard hair is usually 55–80% of the annual fleece growth, so the growth of guard hair is 1.2–4 times that of cashmere fibers. It is not know if productivity differences affect the amino acid composition of guard hairs, but in the samples tested, increasing the energy nutrition of cashmere goats significantly increased the growth of guard hair.[29,31]

It would appear that the different amino acid compositions of cashmere and guard hair reflect different biochemical pathways that operate within the primary and secondary follicles.

Color of cashmere

The lightness and yellowness of cashmere were affected by the amino acid composition, nutrition treatment, and cashmere production. Goats that grazed at pasture produced cashmere that was less bright and more yellow in comparison with cashmere grown by goats fed to grow and housed indoors. Presumably, the greater yellowness of cashmere grown by goats grazing at pasture was a result of UV damage to cashmere fibers accompanied by the degradation of amino acids, as discussed earlier.

As increased cashmere growth was associated with increased lightness and reduced yellowness, these finding imply that more productive cashmere goats produce cashmere with preferred color attributes. Such associations have been reported for Merino wool; genetic selection may reduce yellowness and increase lightness, with the heritability for the latter properties being moderate to high (0.42–0.55).[53] There are several possible mechanisms for this association, including a reduction in the average UV irradiation of cashmere fibers as fleece production increases, the relative dilution of natural chromophores within the fleece as fleece growth increases, and a change in the fiber reflectance properties related to the cuticle scale size or surface properties. The first mechanism is possible as cashmere goats grow guard hair, which is usually longer[33,34] and present in quantities 2–5 five times greater than the quantity of cashmere.[44,53] Furthermore, guard hair is responsive to improved nutrition.[29] Thus, better fed goats produce more fleece,[29] and greater protection is afforded to the shorter cashmere proportion, which is growing further from the extremity exposed to UV light. This mechanism is illustrated in Merino sheep, in which the densely packed staple tip is exposed to high levels of UV light degradation, but the wool growing further from the staple tip is not.[54] However, the evidence in this work to support

this mechanism is solely the quantity of cashmere, as the amount of guard hair did not improve prediction equations, possibly because the goats were housed indoors during the experiment. The second mechanism is similar to the inverse response in the sulfur content of wool detected within Merino sheep selected for increased wool production.[55] As detected within this work, increasing the nutrition of cashmere goats resulted in reduced phenylalanine content, which has been positively associated with photooxidation of wool.[18] Thus, improved nutrition leads to increased cashmere production and reduced relative concentrations of chromophores. The third mechanism may arise as increased cashmere production is positively associated with increases in the cashmere mean fiber diameter.[29,31,32] Changes in the fiber diameter change the circumference of the fiber, and if the cuticle scale numbers are fixed, then the cuticle scale metrics must change. It is unknown if such changes occur.

Earlier reports that Australian-grown white cashmere had higher lightness and lower yellowness than Chinese white cashmere[5] may be related to differences in the productivity of the goats that contributed to the analyzed samples. These differences in the color attributes of cashmere grown in different countries may also reflect differences in the exposure to sunlight during the summer half of the year related to differences in the altitude at which the goats were grazed. These differences may, however, reflect only the influence that different processing conditions (particularly the application of heat) have on yellowness as reported for wool,[50,51] as McGregor[5] reported significant effects of the processor on the lightness and yellowness of cashmere. Further investigations into factors affecting the color attributes of white cashmere are warranted as lightness of cashmere is a desirable attribute because it increases the potential range of pastel shades available by dyeing.

CONCLUSIONS

The amino acid composition and suint content of raw cashmere were affected by nutrition manipulation, energy intake, grazing, supplementary feeding of protected protein, and the country of origin. The lightness and yellowness of cashmere were associated with changes in the amino acid composition, nutrition treatment, grazing, and productivity of cashmere goats. Changes to both the physical and chemical reactivity of cashmere were likely results of changes in the amino acid composition of the fiber.

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