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IMPACT OF ENVIRONMENTAL FACTORS ON MILLET QUALITY IN THE EASTERN AND WESTERN REGIONS ON THE LYULIANG MOUNTAINS

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Abstract

This study aims to examine the influence of categories of environmental factors-climatic, soil and topographic conditions, on millet quality in the eastern and western regions of the Lyuliang Mountains. Ten millet varieties were assessed across 15 quality indices, including protein, fat, and essential amino acids, at five locations on the eastern and western slopes of the Lyuliang Mountains. Comprehensive environmental data related to each sample site were collected. Principal component analysis (PCA) and correlation analysis were employed to explore the relationships between ecological factors and the nutritional composition of the millet. The results showed that certain nutrients in the millet were significantly correlated with specific environmental factors. Millet from Xingxian County exhibited the highest quality, with nutrient composition variation remaining below 10%. Environmental factors played a more substantial role in determining millet quality than genetic varieties. Average daily temperature showed a significant negative correlation ($P < 0.01$) with protein and yellow pigment content, while demonstrating a positive correlation with branched-chain starch and phosphorus levels in millet. It was significantly ($P < 0.01$) correlated with the content of flavonoids in millet by precipitation, significantly correlated with the content of methionine, isoleucine, leucine, and essential amino acids at the average daily temperature, and significantly ($P < 0.01$) correlated with the content of threonine, isoleucine, leucine, and essential amino acids at the average daily temperature. Altitude had a significant negative correlation ($P < 0.01$) with threonine content. The results of this study offer valuable guidance for selecting the finest varieties of millet and planting methods.

Introduction

To address climate challenges, sustainable agriculture requires diverse genetic resources. Resilient millet offers great potential for arid regions (Abrouk *et al.* 2020). Climate-adapted millet in the Lyuliang Mountains provides nutritional value (Lima *et al.* 2022, Shi *et al.* 2022, Tiwari *et al.* 2023), but the environmental impacts on their nutrient composition need further study. This work investigated these effects in the Lyuliang region to provide support for agricultural adaptation and crop improvement.

Ecological conditions have a significant impact on millet quality, and poor planting choices can hinder its potential. Research (Huang *et al.* 2023, Ma *et al.* 2023) indicated that latitude, climate, and soil significantly affect nutritional content. Temperature, rainfall, diurnal variation, and soil nutrients all determine millet quality, emphasizing the need for optimal cultivation sites. The complex interaction of these factors highlights the importance of site selection aligned with production goals.

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Material and Methods

The millet samples were provided by Shanxi Academy of Agricultural Sciences, with collection sites and varities shown in Fig. 1. Millet size and color (L, a, b*) were measured following Ramashia *et al.* (2018) with modifications. Twenty grains per variety were analyzed, reporting mean ± SD. Protein (GB 5009.5), fat (GB 5009.6), starch (GB/T 15683), amino acids (GB 5009.124), calcium (GB 5009.92), phosphorus (GB 5009.87), vitamin A (GB 5009.82), and B2 (GB 5009.85) were quantified. Minerals, polyphenols, flavonoids, and yellow pigments were analyzed using adapted methods (Bhatia *et al.* 1974, Zhang *et al.* 2022, Deng *et al.* 2024), with HPLC for pigments.

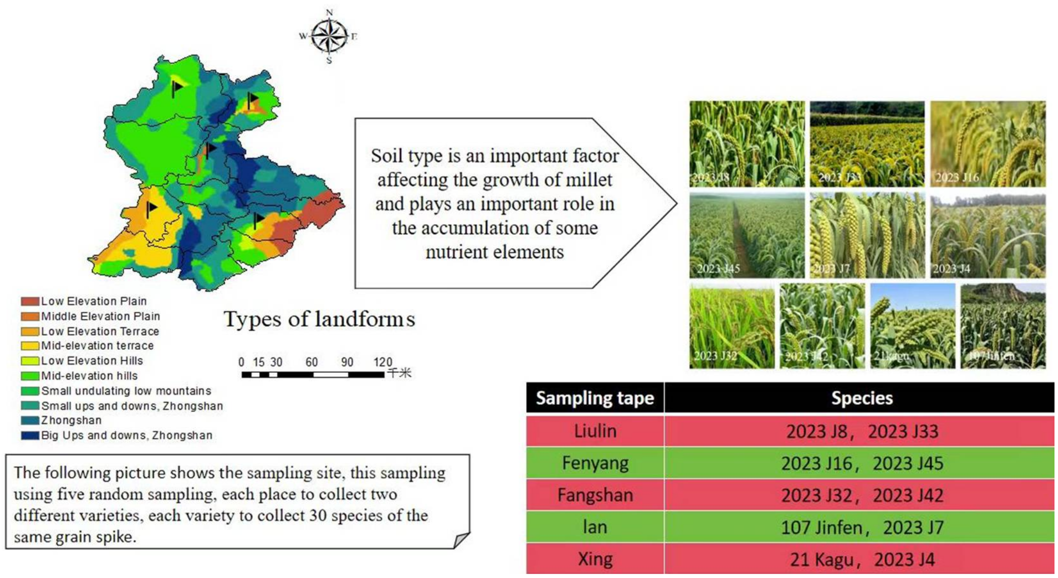


Fig. 1. Collection sites and species.

Ecological factors were evaluated using real-time temperature, precipitation, and sunshine data from sowing to harvest, collected from local meteorological stations and China Weather Network (CNWN). Geographic parameters (elevation, soil type, climate data) for Lyuliang were sourced from the Chinese Resource and Environment Science Data Platform. Data were processed in Microsoft Excel 2019. PCA and cluster analyses were conducted using R, while remote sensing data were analyzed with ArcMap 10.8.1.

Results and Discussion

Millet size was evaluated across 10 varieties from five sampling zones. Fig. 2 shows 2023 Pin J7 had the largest size, while Jinfen 107 was smallest. Size is influenced by soil and environmental factors (Ning *et al*. 2017). Yields were higher in red clay than brown loam (Hou *et al.* 2022). Millet colour (L, a, b*) varies due to nutrients (amino acids, proteins, vitamins) and environmental factors like precipitation and temperature. Nutrient differences depend on soil and climate, linking appearance to regional growing conditions.

Fig. 3 shows Jingu 21 had the highest protein content ($P < 0.05$ vs others), followed by Jinfen 107. Xingxian's 'Jingu 21' and '2023 Pin J4' contained the highest flavonoids, polyphenols, pigments, proteins and fats, but the lowest amylose. Protein increased with altitude, while oil content rose at lower elevations (Capelin *et al.* 2022). Fangshan's 2023 J32/J42 had the highest vitamins A/B2, while Fenyang's 2023 J16/J45 showed elevated calcium/phosphorus levels, reflecting soil influences.

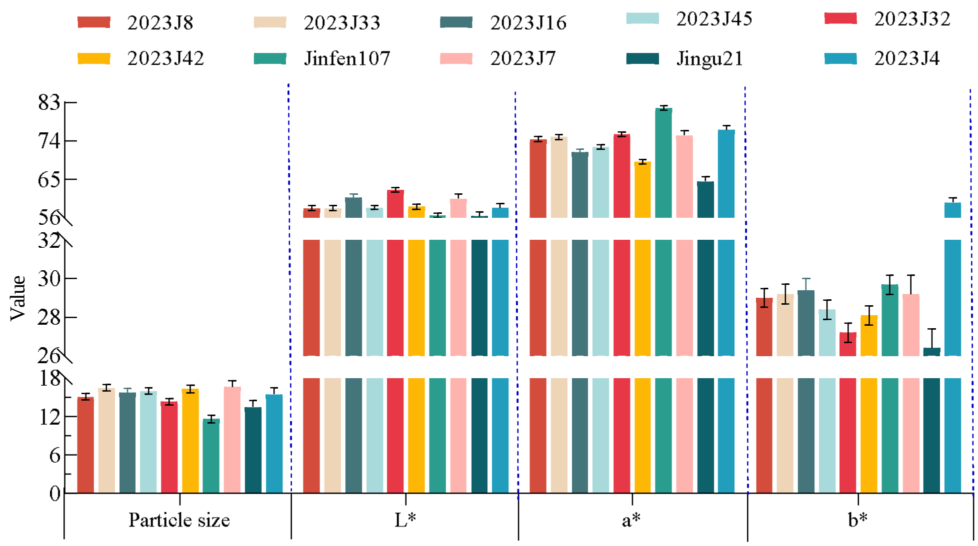


Fig. 2. Appearance quality index content of millet.

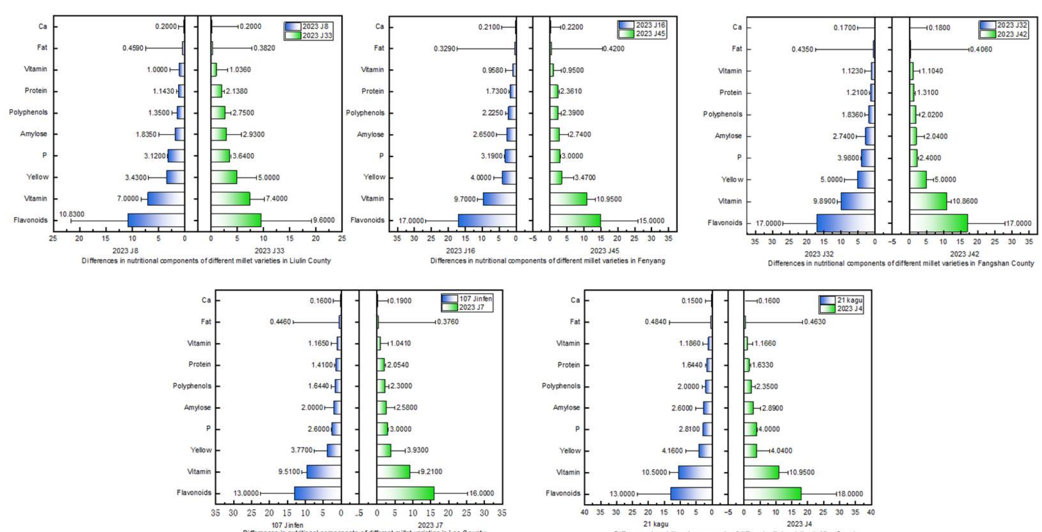


Fig. 3. Conventional nutrient index content of millet.

Fig. 4 reveals that among 10 millet varieties across 5 regions, Jingu 21 and 2023 J4 (Xingxian) contained the highest essential amino acids, whereas 2023 J16 and 2023 J45 (Fenyang) showed the lowest levels. With variation coefficients under 20%, essential amino acids demonstrated consistent distribution. As millet's secondary nutrient after starch, free amino acids - mainly glutamic acid, proline, leucine, and alanine - contribute significantly to human health as protein building blocks. Swaminaidu *et al.* (2015) demonstrated that methionine- and cystine-rich millet offers superior nutritional quality.

Correlation and PCA analyses of 15 millet quality traits revealed: protein positively correlated with fat/EAA (P <0.01) but negatively with starch/Ca; fat inversely linked to starch/Ca; yellow pigment associated with polyphenols (positively) and vitamin A (negatively) (Figs 5 and 6). Essential amino acids demonstrated synergistic interactions. While consistent with Kudapa *et al.* (2023), geographic/ methodological variations may explain some disparities (Tharifkhan *et al.* 2021). These findings elucidate nutrient interactions for quality enhancement.

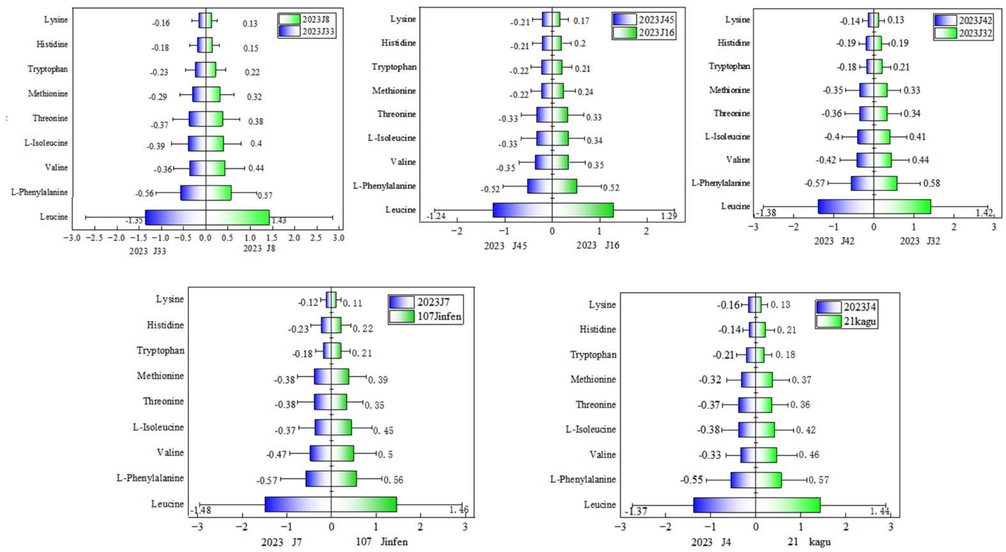


Fig. 4. Content of essential amino acids in millet.

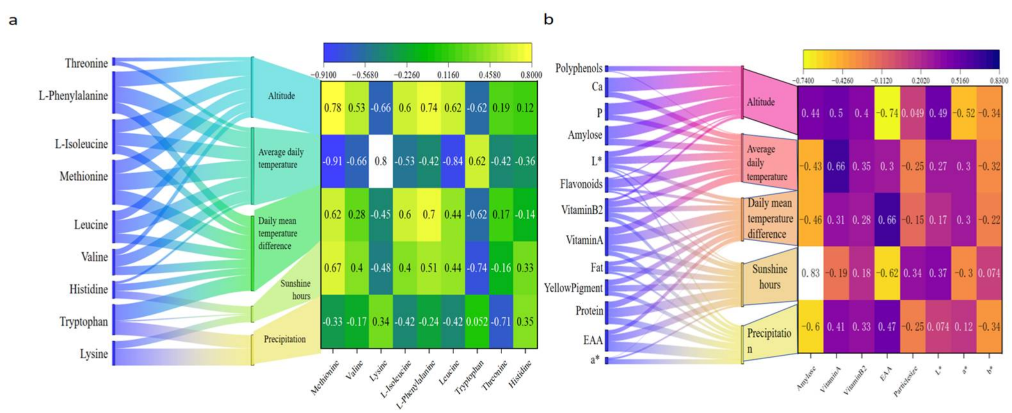


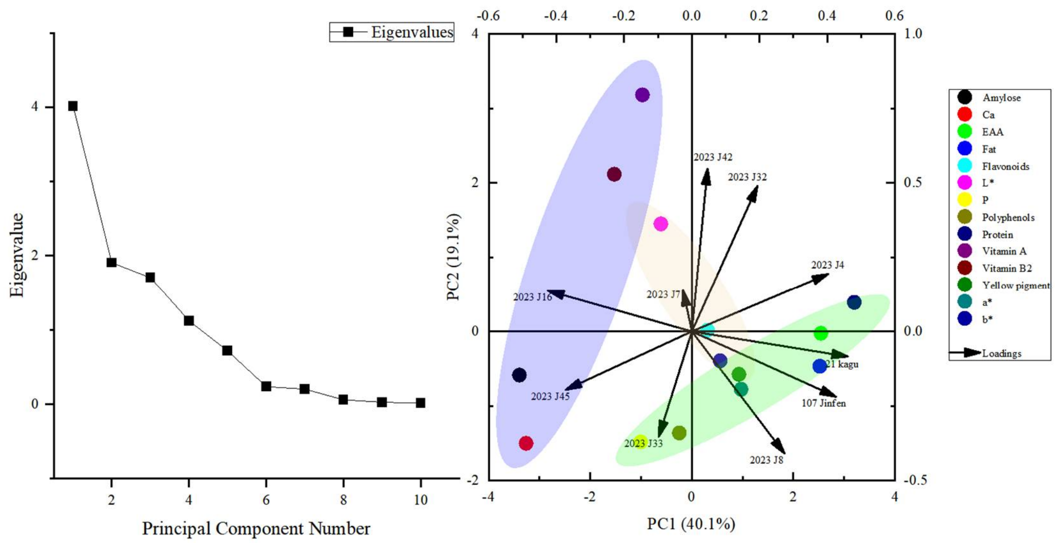
Fig. 5. Correlation analysis of the quality of millet. a. Correlation analyses of essential amino acids with environmental factors. b. Correlation analyses of nutrients with environmental factors.

Table 1 showed the first five principal components (cumulative 82.977% variance, eigenvalues >1) captured most information from 14 quality indices. PCA revealed protein, fat, EAA, straight-chain starch, Ca, and yellow pigment as key quality determinants (Fig. 6). The first

PC (35.871%) favored high protein/EAA/fat and low starch/Ca varieties, while the second PC (19.339%) preferred high yellow pigment/a* and low vitamin A. Together (55.21% variance), these PCs critically defined millet quality.

Table 1. PCA initial eigenvalues and contributions.

Principal component	Initialize values	Variance contribution/percent	Variance contribution/percent
1	5.022	35.871	35.871
2	2.707	19.339	55.21
3	1.789	12.775	67.985
4	1.091	7.791	75.776
5	1.008	7.201	82.977



PCA lithograph and PCA loading diagram

Fig. 6. Plot of principal component analysis.

According to the principal component loading matrix (Table 2), a Scoring model was constructed for five principal components. F1~F5 denote each principal component's score of different millet varieties, X1 to X14 represent 14 quality indexes, and F stands for the composite score.

In the comprehensive evaluation model, the quality of different varieties of millets was assessed by weighted summation of the scores of each principal component ($F= 0.359F_1 + 0.193F_2 + 0.128F_3 + 0.078F_4 + 0.072F_5$). The results indicated that 'Jin millet 21' from the Xingxian sampling zone had the highest quality, while 'Pin 2023 J16' from Fenyang exhibited the lowest quality. Millet quality was affected by environmental factors such as rainfall, soil fertility, altitude, and type of fertilizer application, among which fat content playing a significant role in millet quality.

Ning *et al.* (2017) demonstrated that altitude, precipitation, and temperature all had an effect on millet quality, with altitude having the most significant effect on millet quality. Fangshan

County recorded the longest sunshine hrs and the greatest daily temperature variation. Daylight hours serve as a 'biological clock' for millet maturation, and extended photoperiods significantly delayed tasselling in barnyard millets, positively affecting relative growth rates and biomass (Muldoon 1985). Extended photoperiods significantly boosted dry matter production and leaf area, especially under low-temperature conditions (Hay 1990).

Table 2. Principal Component Loadings Matrix.

Serial No.	Norm	PC1	PC2	PC3	PC4	PC5
X_1	Carbohydrate	0.971	0.047	0.041	-0.043	-0.074
X_2	Fat	0.936	0.047	-0.076	-0.04	0.11
X_3	Amylum	-0.964	-0.104	-0.125	0.014	0.118
X_4	Flavonoid	0.266	-0.201	-0.358	-0.005	0.761
x5	Polyphenol	-0.076	0.589	-0.237	0.497	0.317
X_6	Yellow pigment	0.064	0.926	-0.046	0.03	-0.015
X_7	Vitamin A	0.098	-0.53	0.554	0.369	0.154
X_8	Vitamin B2	-0.514	0.003	0.154	0.635	-0.277
X_9	Ca	-0.906	-0.054	-0.144	-0.217	0.176
X_{10}	P	-0.176	-0.044	-0.661	-0.241	-0.345
X_{11}	L^*	-0.279	0.087	0.648	-0.254	0.044
X_{12}	a^*	-0.106	0.928	-0.032	0.065	-0.023
X_{13}	b^*	-0.183	0.537	0.605	-0.349	0.174
X_{14}	EAA	0.972	0.068	0.058	0.054	-0.115

Table 3. Environmental factors in different sampling zones.

Sampling tape	Height above sea level/m	Height above sea level/°C	Height above sea level/°C	Height above sea level/h	Height above sea level/mm
Liulin	1372	22.1	12.4	937.5	356.3
Fenyang	1246	23.4	11.8	957.4	462
Fangshan	1532	21.5	14.2	1077.0	406.7
Xingxian	1446	20.7	12.9	995.6	366.9
Lanxian	1415	21.3	13.3	986.0	350.4

The soils in Liulin and Lanxian counties are primarily loess, characterized by low cation exchange and poor water and fertilizer retention capacity. Fangshan County's soils are predominantly chestnut brown, brown soil, and brown loam, featuring humification and calcification, which promote calcium absorption through strong leaching. The environmental factors in different sampling areas are shown in Table 3, and the effects of environmental factors on the growth period of cereals is shown in Fig. 7.

The correlation analysis of regional ecological factors with the nutrients and amino acid species of millet in corresponding sampling areas is presented in Tables 4 and 5. The most significant effect of mean daily temperature was significantly negatively correlated with protein, yellowness, and some amino acids, and significantly positively correlated with branched-chain starch and phosphorus ($P < 0.01$), in agreement with Lima *et al.* (2022). Precipitation affected nutrients and altitude was negatively correlated with threonine content.

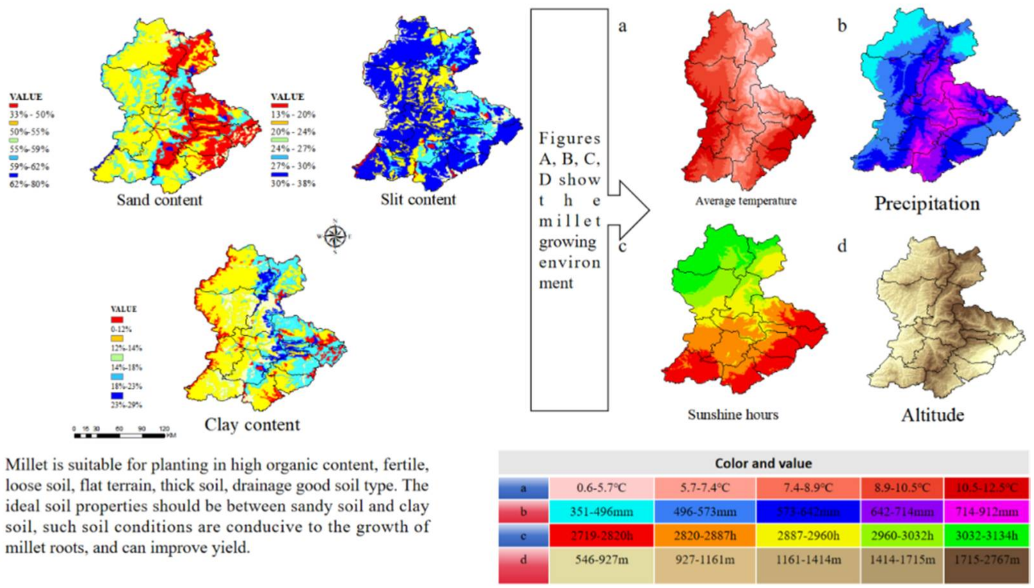


Fig. 7. Effects of environmental factors on the growth period of cereals.

Table 4. Correlation between nutrients and environmental factors in millet.

Environmental factor	Nutrient									
	Carbohydrate (g/100g)	Fat (g/100g)	Amylum (g/100g)	Vitamin A (g/100g)	Vitamin B2 (g/100g)	flavonoid (mg/g)	Polyphenol (mg/g)	Yellow pigment (mg/g)	Calcium (mg/g)	Phosphorus (mg/g)
height above sea level/m	-0.266	-0.367	0.162	0.572	0.649	-0.602	0.280	0.175	-0.408	-0.425
temperature/°C	-0.935*	-0.910*	0.971**	0.318	0.336	0.040	-0.055	-0.882*	0.873	0.903*
temperature difference/°C	0.572	0.508	-0.584	0.057	0.263	-0.018	-0.022	0.853	-0.736	-0.728
daylight hrs/h	0.234	0.190	-0.277	0.499	0.644	-0.406	-0.226	0.563	-0.537	-0.580
quantity of rain/mm	-0.484	-0.425	0.392	0.815	0.565	-0.937*	-0.419	-0.529	0.258	0.116

Table 5. Correlation between amino acid species and environmental factors in millet.

Environmental factor	Amino acid type								
	Met	Aal	Lys	Ile	Phe	Leu	Trp	Thr	His	EAA
height above sea level/m	-0.005	-0.072	0.104	0.013	-0.204	-0.223	-0.224	-0.900*	0.774	-0.081
temperature/°C	-0.932*	-0.870	0.824	-0.882*	-0.811	-0.891*	0.579	-0.393	-0.298	-0.886*
temperature difference/°C	0.608	0.616	-0.658	0.671	0.762	0.631	-0.083	-0.089	0.210	0.665
daylight hrs/h	0.278	0.239	-0.264	0.316	0.513	0.256	-0.209	-0.424	0.303	0.294
quantity of rainfall/mm	-0.475	-0.630	0.718	-0.597	-0.444	-0.623	-0.625	-0.571	0.329	-0.629

Note: * indicates significant correlation; ** indicates highly significant correlation.

Geographical differences significantly affect cereal nutrients, especially protein, fat, starch, Ca, EAA, and yellow pigment. Temperature and altitude drive nutritional variations, while precipitation and sunlight mainly affect growth stages. Environmental factors had a greater impact on regionally grown cereals than genetic differences.

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