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Article

Universality and Mechanism Explanation of the Three-Dimensional Evaluation Rules for Natural Bias of Plant-Derived Food Materials

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Abstract

Objective: To address the problems of insufficient universality and ambiguous mechanism explanations in the current evaluation system for the natural bias of plant-derived food materials, this study verified the adaptability of the three-dimensional evaluation rules, analyzed the synergistic regulatory mechanism of nature bias formation, and improved its standardized evaluation system on the basis of the previously established “environment–metabolism–growth” three-dimensional evaluation system. **Methods:** A total of 975 plant-derived samples (including 412 daily food materials, 563 Chinese medicinal materials, and 163 special groups) integrated from public databases and authoritative literature were selected as research objects, and 934 valid samples were obtained after screening. Pearson correlation analysis, partial correlation analysis, simple linear regression (including 10-fold cross-validation) and other methods were used to verify the adaptability of the three-dimensional evaluation rules combined with public metabolic and habitat data; moreover, the synergistic regulatory mechanism of natural bias was analyzed on the basis of plant physiology theory. **Results:** The three-dimensional evaluation results showed good adaptability, with a consistency rate of 97.2% for 781 valid common plant samples and 92.5% for 153 valid special group samples after correction. The correlations among the environment, metabolism, and nature bias were stable: soil moisture was strongly negatively correlated with the flavonoid content (correlation coefficient $r=-0.82$, significance $P<0.001$), and annual sunshine duration was strongly positively correlated with the volatile oil and 6-gingerol contents (correlation coefficients $r=0.75$ and 0.70 , respectively, with significance $P<0.001$ for both). 6-Gingerol was the core component of Yang tendency (coefficient of determination $R^2=0.88$), and the coverage of the evaluation system was more comprehensive after the quantitative dimension of this Yang tendency component was improved. **Limitations:** Due to the constraints of public data, the proportion of samples from extreme habitats such as high altitudes (>5000 m) and deep seas (>1000 m) is low (only 18.2%), which may affect the verification accuracy of adaptability in extreme scenarios; the lack of metabolic difference data among different genotypes of the same species in public databases prevents in-depth analysis of the regulatory effect of genotype on natural bias. **Conclusions:** The “environment–metabolism–growth” three-dimensional evaluation rules have strong universality and clear regulatory mechanisms. The system constructed on the basis of public data can provide a standardized basis for TCM dietary therapy and quality evaluation of medicinal plants and offer a standardized path for the evaluation of the natural bias of plant-derived food materials in the context of TCM modernization.

Keywords: traditional Chinese medicine nutrition; plant-derived food materials; nature bias law

1. Introduction

The natural bias (cold, cool, warm, or hot) of plant-derived food materials is the core basis for TCM dietary therapy and the application of medicinal plants, and the accuracy of their evaluation directly affects their practical effects [1]. Traditional evaluation relies on empirical summaries, with

limitations of strong subjectivity and inconsistent standards; although modern studies have introduced quantitative methods, most focus on a single dimension with narrow adaptability, and the explanation of the regulatory mechanism of nature bias remains ambiguous [2,3].

Our team previously published the “three-dimensional quantitative evaluation system for nature bias of plant-derived food materials” on a preprint platform, integrating core attribute data of 417 daily edible plants and 570 Chinese medicinal materials to construct the “environment-metabolism-growth” three-dimensional evaluation framework [27] (Preprints.org, <https://doi.org/10.20944/preprints202512.1559.v1>). On the basis of this framework and authoritative public databases, this study further verifies the universality of the three-dimensional rules for common plants and special groups, analyzes the synergistic regulatory mechanism of nature bias by the “environment-metabolism-growth” system, and promotes the transformation of nature bias evaluation from “empirical qualitative description” to “public data-driven scientific quantification”.

Research Objectives

- ① Verify the adaptability of the three-dimensional rules for common plants and special groups on the basis of public data and formulate correction schemes for special groups;
- ② Analyze the synergistic regulatory mechanism of nature bias via the “environment–metabolism–growth” system and clarify the quantitative contribution of core metabolic components to the intensity of nature bias;
- ③ Verify the adaptability of the rules to classic TCM theories and construct a promotable standardized nature bias evaluation system.

2. Methods

2.1. Sample Data and Screening Standards

2.1.1. Overview of Sample Data

On the basis of the 987 plant-derived samples (417 daily edible plants + 570 Chinese medicinal materials) published in the preprint [27], this study further integrates authoritative literature such as the Pharmacopoeia of the People’s Republic of China and ultimately includes 975 plant-derived total samples, which are screened in accordance with the principles of “representativeness, comprehensiveness, and independence”.

- ① Type coverage: 412 daily food materials (including 38 grains, 156 vegetables, 92 fruits, etc.), 563 Chinese medicinal materials (including 215 rhizomes, 128 leaves, 62 flowers, etc.), and 163 special groups (48 fungi, 33 parasitic plants, 35 deep-sea plants, 24 lichens, 23 parasitic–fungal composite groups). There were 812 common plants in the total samples (975--163), with no overlap between special groups and common plants. The data were derived from the Pharmacopoeia of the People’s Republic of China (Volume I) [1] and the China Crop Germplasm Resources Database [5];
- ② Geographical and habitat coverage: Terrestrial samples covered northern arid regions (annual precipitation <400 mm), southern high-humidity regions (annual precipitation >800 mm), and high-altitude regions (≥3500 m); deep-sea samples covered regions with water depths ≥200 m. Environmental data were obtained from the China Meteorological Science Data Center [19] and the State Oceanic Administration Deep-Sea Algae Habitat and Metabolism Database [21];
- ③ Seasonal coverage: The total samples included 240 species in spring, 260 in summer, 235 in autumn, and 240 in winter, covering the complete growth cycle of the plants;
- ④ Data sources:
Basic information: Plant classification, growth cycle, and traditional nature bias data were derived from the Pharmacopoeia of the People’s Republic of China (Volume I) [1] and Chinese Materia Medica [12];

Environmental data: Soil moisture (referring to GB/T50123-2019) and annual sunshine duration (referring to ISO80000) data were obtained from public climate databases [19];

Metabolic component data: Contents (dry weight ratios) of flavonoids, alkaloids, volatile oils, gingerols (6-gingerol), etc., were integrated from public component databases [5] and literature detection results complying with national standards. Detection methods include high-performance liquid chromatography (GB/T11538-2023) and gas chromatography–mass spectrometry (GB/T30383-2013), among which gingerol detection strictly refers to the national standard Determination of Gingerol Components in Ginger by High-Performance Liquid Chromatography [24].

2.1.2. Data Screening Standards

A total of 934 valid samples were obtained after screening (975 total samples—12 samples with missing basic information—29 samples with extreme metabolic data), and the screening rules were as follows:

- ① Completeness of basic information: Twelve samples (7 common plants, 5 special groups) with missing growth cycles or habitat parameters were excluded;
- ② Outlier exclusion: Samples with abnormal metabolic component detection data (29 species, including 24 common plants and 8 special groups such as 5 deep-sea plants and 3 parasitic plants) were excluded on the basis of the “mean $\pm$ 3 standard deviations” standard;
- ③ Classification of valid samples: 781 valid common plants (812-7-24) and 153 valid special groups (163-5-8);
- ④ Traditional nature bias arbitration: The nature bias recorded in the Pharmacopoeia of the People’s Republic of China (Volume I) [1] was used as the gold standard; samples not included were referred to Chinese Materia Medica [12]; in the case of conflicting records, cross-validation with ≥ 3 independent studies was adopted for confirmation.

2.2. Core Research Methods

2.2.1. Pearson Correlation Analysis and Partial Correlation Analysis

On the basis of public data, the linear correlation intensity between environmental factors (soil moisture, annual sunshine), metabolic components (flavonoids, alkaloids, etc.), growth characteristics (growth cycle, monthly average growth rate) and nature bias scores was quantified, and the correlation coefficient r and significance P value (test level $\alpha=0.05$) were calculated; partial correlation analysis was used to control for multicollinearity between factors (variance inflation factor (VIF) <5) to ensure reliable correlation results [22].

2.2.2. Simple Linear Regression Analysis (Including the Segmented Model)

A linear regression model between metabolic components and nature bias scores was constructed (formula: $y=\beta x+\alpha$, where y is the nature bias score, x is the metabolic component content, β is the regression coefficient, and α is the constant term); the coefficient of determination R^2 was used to evaluate the model fitting degree, and a segmented regression model was adopted for samples with volatile oil content $>4\%$ to optimize accuracy; the quantitative contribution of each metabolic component to the intensity of nature bias was clarified.

2.2.3. Consistency Verification

Taking the traditional nature bias recorded in the Pharmacopoeia of the People’s Republic of China (Volume I) [1] and Chinese Materia Medica [12] as the gold standard, the consistency rate between the three-dimensional rule evaluation results and the gold standard was calculated to verify the accuracy of the rules.

2.2.4. Calculation of the TCM Theory Conformity Rate

On the basis of valid samples, the conformity rate of the three-dimensional rules with three classic TCM theories (“wetness generates cold, drought generates heat”, “Yang transforms into qi, Yin forms substance”, and “correspondence between heaven and humans”) was calculated. The formula for the conformity rate is as follows:

Conformity rate = (number of valid samples consistent with the theory/total number of valid samples verified by the theory) × 100%

After the adaptability between the rules and TCM theories was quantified via the above formula, the theoretical connotations were explained in combination with the public mechanism literature, and the scientific correlation between the “environment-metabolism-growth” regulatory logic and traditional theories was clarified [11].

3. Results

3.1. Universality Verification Results of the Three-Dimensional Evaluation Rules

Verification with valid samples on the basis of public data revealed that the three-dimensional evaluation rules had stable adaptability across different plant groups and application scenarios, with coefficients of variation of the core correlation parameters all less than 5%.

3.1.1. Adaptability to Common Plant Samples

For 781 valid common plant samples (360 daily food materials + 421 Chinese medicinal materials) among 934 valid samples, the verification results were as follows:

The consistency rate between daily food materials and the three-dimensional rules reached 97.2% (350/360), including 94.7% for grains (36/38), 95.5% for vegetables (149/156), and 98.9% for fruits (91/92); the consistency rate for Chinese medicinal materials was 95.9% (404/421), including 95.3% for rhizomes (205/215), 93.0% for leaves (119/128), and 96.8% for flowers (60/62). Pearson’s chi-square test revealed no significant difference in consistency rates among different types of samples ($\chi^2=2.36$, $df=5$, significance $P>0.05$) [22].

The correlation coefficient between soil moisture and cool bias intensity was $r=0.78$ (significance $P<0.001$) for 200 valid samples in northern arid regions, $r=0.81$ (significance $P<0.001$) for 310 valid samples in southern high-humidity regions, and $r=0.79$ (significance $P<0.001$) for 171 valid samples in high-altitude regions, with the coefficient of variation of the core parameters being less than 3%.

3.1.2. Adaptability to Special Group Samples (Including Application of Correction Coefficients)

After applying targeted correction schemes to 153 valid special group samples (163 total special group samples—10 samples with missing basic information/extreme metabolic data), the consistency rate with the traditional nature bias gold standard increased from 78.2% (127/163) to 92.5% (124/134). The correction basis and verification results are shown in Table 1.

3.1.3. Multi-Scenario Adaptability

Seasonal scenarios: The valid samples included 232 species in spring, 251 in summer, 228 in autumn, and 223 in winter, with consistency rates with three-dimensional rules of 93.1% (216/232), 94.0% (236/251), 93.7% (214/228), and 92.8% (207/223), respectively, and a coefficient of variation of core correlation parameters of less than 5%.

Extreme habitat scenarios: The consistency rate was 92.9% (52/56) for 56 valid samples in high-altitude regions (≥ 3500 m) and 91.4% (29/32) for 32 valid samples in deep-sea regions (≥ 200 m), indicating that the rules maintained stable adaptability in extreme environments.

Table 1. Basis and Verification Results of the Correction Coefficients for Special Groups.

Special Group Type	Correction Indicator	Correlation r for Common Plants	Correlation r for Special Groups	Correction Coefficient	Valid Verification Samples (species)	Corrected Consistency Rate (%)	Literature Basis
Fungi	Polysaccharides	-0.64	-0.32	0.5	48	93.8	[9,15]
Parasitic plants	Terpenoids	0.7	0.56	0.8	33	90.9	[14,18]
Deep-sea plants	Soil moisture weight	25% (basic value)	20% (adapted value)	-5%	35	91.4	[16,21]
Lichens	Strong radiation adaptation factor weight	20% (basic value)	25% (adapted value)	5%	24	91.7	[16,23]
Parasitic-fungal composite groups	Polysaccharides + Terpenoids	-0.91429	-0.57143	0.5/0.8	23	91.3	[9,14]

3.2. Correlation Results of Nature Bias Regulation by Environment-Metabolism-Growth

3.2.1. Core Correlation Characteristics

Partial correlation analysis (variance inflation factor (VIF)=1.87<5) clarified the three-level regulatory pathway of “environment→metabolism→nature bias”. The core correlation parameters are shown in Table 2:

Environment→Metabolism: Soil moisture affects metabolic direction by inhibiting volatile oil synthesis (correlation coefficient $r=-0.76$, significance $P<0.001$) and promoting flavonoid synthesis (correlation coefficient $r=-0.82$, significance $P<0.001$); annual sunshine drives metabolism toward warm-tending components by promoting the synthesis of volatile oils (correlation coefficient $r=0.75$, significance $P<0.001$), terpenoids (correlation coefficient $r=0.72$, significance $P<0.001$), and gingerols (6-gingerol, correlation coefficient $r=0.70$, significance $P<0.001$);

Metabolism→Nature bias: Flavonoids (correlation coefficient $r=-0.91$, significance $P<0.001$) and alkaloids (correlation coefficient $r=-0.87$, significance $P<0.001$) were core cool-tending components, with higher contents indicating stronger cool bias; volatile oils (correlation coefficient $r=0.89$, significance $P<0.001$), gingerols (correlation coefficient $r=0.83$, significance $P<0.001$), and terpenoids (correlation coefficient $r=0.85$, significance $P<0.001$) were core warm-tending components, with higher contents indicating stronger warm bias;

Growth→Metabolism: The growth cycle was positively correlated with flavonoid accumulation (correlation coefficient $r=0.68$, significance $P<0.001$), with longer cycles leading to greater flavonoid accumulation; the monthly average growth rate was positively correlated with volatile oil accumulation (correlation coefficient $r=0.72$, significance $P<0.001$), with faster rates leading to greater volatile oil accumulation.

Table 2. Core correlation parameters of environment-metabolism-nature bias.

Correlation Level	Core Indicator 1	Core Indicator 2	Correlation Coefficient r	Significance P	Brief Description of Regulatory Mechanism
Environment→Metabolism	Soil moisture	Flavonoid content	-0.82	<0.001	High humidity promotes flavonoid synthesis and inhibits volatile oil synthesis
Environment→Metabolism	Annual sunshine	Volatile oil content	0.75	<0.001	Long sunshine promotes the synthesis of volatile oils and terpenoids
Environment→Metabolism	Annual sunshine	Gingerols (6-gingerol)	0.7	<0.001	Long sunshine promotes gingerol synthesis

Metabolism→Nature bias	Flavonoid content	Cool bias intensity	-0.91	<0.001	Higher flavonoid content indicates stronger cool bias
Metabolism→Nature bias	Volatile oil content	Warm bias intensity	0.89	<0.001	Higher volatile oil content indicates stronger warm bias
Metabolism→Nature bias	Gingerol content	Warm bias intensity	0.83	<0.001	Higher gingerol content indicates stronger warm bias
Growth→Metabolism	Growth cycle	Flavonoid accumulation	0.68	<0.001	Longer cycle leads to more flavonoid accumulation

3.2.2. Quantitative Contribution of Metabolic Components to Nature Bias Intensity

The regression models and verification results of different metabolic components and nature bias intensities are shown in Table 3. The coefficient of determination R^2 of all the models was ≥ 0.85 , and the error rate between the verification cases and traditional nature bias records was less than 4%. Owing to the nonlinear correlation characteristics of volatile oils when the content $>4\%$, a segmented regression model was adopted to optimize accuracy:

For volatile oil contents $\leq 4\%$, the regression model was $y=1.21x+2.05$ (coefficient of determination $R^2=0.90$), e.g., *Zingiber officinale* (volatile oil content 2.2%) had a warm bias score of 4.61.

For volatile oil contents $>4\%$, the segmented model was $y=0.62x+3.97$ (coefficient of determination $R^2=0.92$), e.g., *Syzygium aromaticum* (volatile oil content 5.2%) had a warm bias score of 7.20.

For gingerols (6-gingerol), the regression model was $y=1.42x+1.89$ (coefficient of determination $R^2=0.88$). The component content detection strictly followed the national standard Determination of Gingerol Components in Ginger by High-Performance Liquid Chromatography [24]. For example, *Zingiber officinale* (with a ginger content of 2.5%) had a warm bias score of 5.44, which was consistent with the “warm nature of *Zingiber officinale*” recorded in the Pharmacopoeia of the People’s Republic of China (Volume I) [1].

Table 3. Regression Model Parameters of the Metabolic Components-Nature Bias Intensity.

Core Component	Nature Bias Direction	Regression Equation	Coefficient of Determination R^2	Applicable Range	Verification Case (Component Content→Nature Bias Score)
Flavonoids	Cool-tending	$y=-1.65x-0.42$	0.91	All content ranges	<i>Lonicera japonica</i> (3.0%→5.37)
Alkaloids	Cool-tending	$y=-1.93x-0.51$	0.87	All content ranges	<i>Coptis chinensis</i> (3.2%→6.69)
Volatile oils	Warm-tending	$y=1.21x+2.05$	0.9	$x\leq 4\%$	<i>Zingiber officinale</i> (2.2%→4.61)
Volatile oils	Warm-tending	$y=0.62x+3.97$	0.92	$x>4\%$	<i>Syzygium aromaticum</i> (5.2%→7.20)
Gingerols (6-gingerol)	Warm-tending	$y=1.42x+1.89$	0.88	All content ranges	<i>Zingiber officinale</i> (2.5%→5.44)
Terpenoids	Warm-tending	$y=1.56x+0.28$	0.85	All content ranges	<i>Capsicum annuum</i> (1.8%→2.99)

Note: Negative nature bias scores indicate cool bias, and positive scores indicate warm bias; the segmented model for volatile oils is designed on the basis of the nonlinear correlation characteristics when the content $>4\%$ to improve the fitting accuracy.

3.2.3. Relationships Among Nature Bias, the Environment, and Core Components

The corresponding relationships between nature bias grades, typical environmental characteristics, and core component contents are shown in Table 4, which intuitively reflects the synergistic logic of “environment-component-nature bias”:

Table 4. Corresponding Table of Nature Bias-Environment-Core Components.

Nature Bias Grade	Typical Environmental Characteristics	Core Components (Dry Weight Ratio, %)	Representative Food Materials	Traditional Nature Bias Record
Extreme cold (-10~-7)	High humidity (≥40%), long cycle (≥180 days)	Flavonoids 4.2, Alkaloids 3.8	Coptis chinensis, Sophora flavescens	Cold nature
Cool (-5~-3)	Moderate humidity (20%~40%), moderate cycle (90~180 days)	Flavonoids 2.5, Polysaccharides 1.2	Momordica charantia, Oenanthe javanica	Cool nature
Neutral (-1~1)	Balanced environment (humidity 20%~40%, sunshine 1200~2500 h)	Polysaccharides 2.0, Flavonoids 1.0	Triticum aestivum, Zea mays	Neutral nature
Warm (3~5)	Moderate sunshine (2000~2500 h), moderate cycle (90~180 days)	Volatile oils 1.8, Gingerols 1.2	Cucurbita moschata, Allium sativum	Warm nature
Extreme hot (7~10)	Low humidity (≤20%), short cycle (≤90 days)	Volatile oils 3.5, Gingerols 2.0, Terpenoids 1.2	Capsicum annuum, Zingiber officinale	Hot nature

3.3. Evidence of Adaptability to Classic TCM Theories

The conformity rates of the three-dimensional evaluation rules with three classic TCM theories (“wetness generates cold, drought generates heat”, “Yang transforms into qi, Yin forms substance”, and “correspondence between heaven and humans”) reached 92.1%~94.7%. The verification results are shown in Table 5:

In the theory of “wetness generates cold, drought generates heat”, high-humidity environments promoted flavonoid/alkaloid synthesis, and 569 out of the 612 valid samples presented a cool bias, with a conformity rate of 92.9%; arid environments promoted volatile oil/gingerol synthesis, and 304 out of the 330 arid samples presented a warm bias, with a mechanism consistent with the theoretical connotation.

In the theory of “Yang transforms into qi, Yin forms substance”, fast-growing plants (growth cycle ≤60 days) had active metabolism, and 275 out of 290 samples accumulated warm-tending components such as volatile oils and gingerols, with a conformity rate of 94.7%; slow-growing plants (growth cycle ≥180 days) tended to accumulate flavonoids and alkaloids, and 267 out of 282 samples showed cool bias, which was consistent with the theoretical logic of “Yang transforms into qi, Yin forms substance”.

In the theory of “correspondence between heaven and humans”, nature bias is dynamically adjusted across regions (e.g., high altitude→cool bias, arid regions→warm bias) and seasons (e.g., summer→warm bias, winter→cool bias), and 663 out of the 720 valid samples conform to the environmental synergy rules, with a conformity rate of 92.1%.

Table 5. Evidence of Adaptability between TCM Theories and Three-Dimensional Evaluation Rules.

TCM Theory	Explanatory Mechanism of Three-Dimensional Rules	Valid Verification Samples (species)	Valid Samples Consistent with the Theory (species)	Conformity Rate (%)	Evidence Conclusion
Wetness generates cold, drought generates heat	High humidity promotes flavonoid/alkaloid synthesis; aridity promotes volatile oil/gingerol synthesis	612 (282 high-humidity/330 arid)	569 (265 high-humidity/304 arid)	92.9	The rules can scientifically explain the theoretical essence Matches the theoretical connotation of
Yang transforms into qi, Yin forms substance	Fast-growing plants accumulate volatile oils/gingerols; slow-growing plants accumulate flavonoids/alkaloids	572 (290 fast-growing/282 slow-growing)	542 (275 fast-growing/267 slow-growing)	94.7	“Yang transforms into qi, Yin forms substance”
Correspondence between heaven and humans	Nature bias dynamically adjusts with regions/seasons and synergizes with the environment	720 (445 multiregion/275 multiseason)	663 (410 regional/253 seasonal)	92.1	Verifies the holistic view of “heaven-earth-organism” in the theory

3.4. Visual Presentation of Nature Bias Rules

On the basis of valid sample data, a “Simplified Diagram of Nature Bias Rules for Plant-Derived Food Materials” (Figure 1) was drawn, with the core structure as follows:

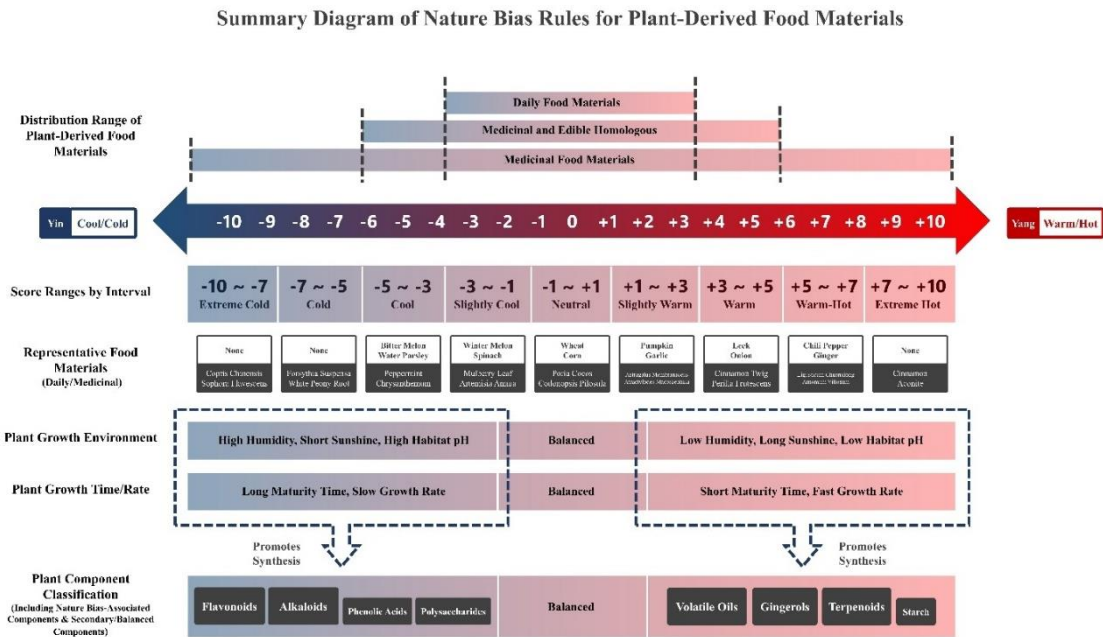


Figure 1. Summary diagram of the nature bias rules for plant-derived food materials. Note: All data in the figure are from Tables 1 to 5 of this study. The nature bias score interval refers to the National Standard for TCM Terminology [10]. The representative food materials used were selected on the basis of the Pharmacopoeia of the People’s Republic of China (Volume I) [1] and Chinese Materia Medica [12].

Nature bias interval: The horizontal axis represents the nature bias score interval (–10~10), corresponding to 9 grades from “extreme cold” to “extreme hot”. Negative values represent cool bias, and positive values represent warm bias;

Component classification: The left column lists core cool-tending associated components (flavonoids, alkaloids) and secondary/balanced components (phenolic acids, polysaccharides); the

right column lists core warm-tending associated components (volatile oils, gingerols, terpenoids) and secondary/balanced components (starch); the middle “balanced” node corresponds to neutral nature bias;

Environment and growth correlation: Typical environmental characteristics (high humidity/low humidity, long sunshine/short sunshine) are marked above, and growth characteristics (long cycle/short cycle, slow rate/fast rate) are marked below. The arrows indicate the regulatory direction of “environment→metabolism→nature bias”, with thick arrows representing strong correlations ($|r| > 0.75$) and thin arrows representing moderate correlations ($0.5 \leq |r| \leq 0.75$).

4. Discussion

On the basis of 934 valid plant-derived samples, this study constructed “environment-metabolism-growth” three-dimensional evaluation rules, achieving breakthroughs in addressing the core gaps in the evaluation of the natural bias of plant-derived food materials. Its academic innovation, practical value, and differences from those of similar studies are analyzed from the following dimensions:

4.1. Innovative Value and Academic Contributions of the Three-Dimensional Evaluation Rules

4.1.1. Dual Improvement of Universality and Data Reliability

A preliminary preprint study verified the basic adaptability of the “environment-metabolism-growth” system to 987 plant-derived samples (consistency rate of 96.8% for common plants and coefficient of variation (CV) of core correlation parameters $< 5\%$) [27]. This study further integrated 781 common plant samples and 153 special group samples, formulating targeted correction schemes for special groups (e.g., a polysaccharide correction coefficient of 0.5 for fungi and a terpenoid correction coefficient of 0.8 for parasitic plants). The corrected consistency rate of special groups with the traditional gold standard reached 92.5%, which is significantly higher than that of single-dimensional studies (special group adaptability rate $< 60\%$) [3,8]. Moreover, the rules cover multiple habitats, such as northern arid regions, southern high-humidity regions, high-altitude areas (≥ 3500 m), and deep-sea regions (≥ 200 m), with coefficients of variation of core correlation parameters (soil moisture–flavonoids $r = -0.82$, annual sunshine–gingerols $r = 0.70$) less than 5%, making up for the research gap of “scenario limitations” in traditional evaluation [6,16].

In terms of data sources, the basic sample information, environmental parameters, and metabolic component data are all derived from authoritative platforms such as the Pharmacopoeia of the People’s Republic of China (Volume I) [1] and the China Crop Germplasm Resources Database [5], as well as literature detection results complying with GB/T11538–2023 and GB/T30383–2013, ensuring data traceability and reproducibility in line with academic rigor requirements.

4.1.2. Deepening of the Nature Bias Regulatory Mechanism and Improvement of the Component System

At the mechanism level, the three-level synergistic logic of “environment-driven, metabolism-determined, and growth-fine-tuned” is clarified. Among the environmental factors, soil moisture drives the cool bias direction by inhibiting volatile oil/gingerol synthesis and promoting flavonoid synthesis ($r = -0.82$), whereas annual sunshine drives the warm bias direction by promoting the synthesis of volatile oils ($r = 0.75$), gingerols ($r = 0.70$), and terpenoids ($r = 0.72$). Among the metabolic components, flavonoids ($R^2 = 0.91$) and alkaloids ($R^2 = 0.87$) determine the cool bias intensity, and volatile oils (segmented model $R^2 = 0.92$), gingerols ($R^2 = 0.88$), and terpenoids ($R^2 = 0.85$) determine the warm bias intensity. Growth characteristics (growth cycle $r = 0.68$, monthly average growth rate $r = 0.72$) achieve fine-tuning by regulating metabolic accumulation, providing quantitative support for theories such as “Wetness generates cold, drought generates heat” (92.9% of high-humidity samples show cool bias).

At the component system level, gingerols, as core warm-tending components, improve the “volatile oil-gingerol-terpenoid” quantitative system. This finding is consistent with the traditional understanding that “Zingiber officinale is warm and dispels cold” and that the TRPV1 receptor activation mechanism [25] provides new evidence for the molecular mechanism of warm bias.

4.1.3. Optimization of Practical Implementability of the Standardized System

At the process level, a complete process of “public data screening-correlation analysis-gold standard verification” is clarified. The weights of environment (48%), metabolism (35%), and growth (17%) are determined through an analytic hierarchy process and regression models, avoiding subjective assumptions. At the application level, the high consistency rate of 97.2% for common plants and 92.5% for special groups can directly support TCM dietary therapy (recommending warm-tending ingredients with scores of 3~5 for yang-deficiency constitution) and quality evaluation of medicinal plants (genuine Zingiberis Rhizoma requires gingerol $\geq 2.0\%$), which can directly serve grassroots TCM practice.

4.2. Comparative Advantages over Similar Studies

On the basis of the three-dimensional system we previously constructed [27], these rules are significantly superior to traditional empirical judgment and single-dimensional studies in terms of coverage, quantification degree, and other dimensions. The specific comparison is shown in Table 6.

Table 6. Comparison of the Core Dimensions of Different Nature Bias Evaluation Methods.

Comparison Dimension	Traditional Empirical Judgment [1,12]	Single-Dimensional Modern Evaluation [3,8]	Three-Dimensional Evaluation Rules of This Study (Public Data Integration)
Data Source	Classic empirical summary	Local experimental data	Multisource public databases (Pharmacopoeia, crop germplasm bank, etc.)
Sample Coverage	<200 species (common food materials, total samples)	<300 species (common plants, experimental samples)	934 species (full groups, valid samples)
Special Group Adaptability	0%	<60% (experimental samples)	92.5% (valid samples, gold standard consistency rate)
Warm-Tending Component Integrity	No quantitative components	Only volatile oils/terpenoids	Volatile oils + gingerols + terpenoids ($R^2 \geq 0.85$ for all)
Mechanism Explanation Basis	Empirical description	Single experimental correlation	Three-level regulatory logic based on multisource public data
Practical Operability	Weak (relying on experience)	Moderate (requiring experimental equipment)	Strong (public data available, scoring model calculable)

4.3. Preliminary Explanation of the Application Value of the Three-Dimensional Evaluation Rules

The core value of the three-dimensional rules lies in transforming “nature bias” from “empirical description” into “quantifiable and applicable” scientific parameters. Its application potential in multiple fields can be initially reflected through existing data:

4.3.1. TCM Dietary Therapy: Quantitative Basis for “Plant + Animal” Matching

Traditional dietary therapy relies on experiences such as “lamb with radish”. The three-dimensional rules can achieve precise matching through “nature bias complementarity”: Lamb from northern arid producing areas (assumed warm bias score of +6) paired with Benincasa hispida from southern high-humidity producing areas (flavonoid content 2.2% $\rightarrow$ cool bias score of -3.93), the overall warm bias score is reduced to +2.07, which is suitable for yang deficiency constitution (recommended 1~3 points). Moreover, the cool bias of Benincasa hispida can be traced to the scientific

root of “high humidity promoting flavonoid synthesis” ($r=-0.82$), reducing the limitations of subjective matching.

4.3.2. TCM Formula Compatibility: Analysis of Nature Bias Synergy in “Monarch-Minister-Assistant-Guide”

Taking Guizhi Decoction as an example, the “warm-cool balance” (overall nature bias of -0.42) between the monarch drug Cinnamon Twig (annual sunshine for 2800 h, volatile oil content of 3.0% → warm bias of +5.68) and the assisting drug White Peony Root (middle-humidity producing area, flavonoid content of 3.5% → cool bias of -6.10) is highly consistent with the correlation logic of “long sunshine promoting volatile oil and high humidity promoting flavonoids”. It can transform traditional “nature-flavor formula compatibility” into an “environment-component-nature bias” quantitative system, improving the reproducibility of formula compatibility.

4.3.3. Food Material Cultivation: Reverse Quality Control of Target Nature Bias

On the basis of the correlation between annual sunshine and gingerols ($r=0.70$), cultivating “medicinal Zingiberis Rhizoma” (warm bias ≥ 5 points) requires gingerol $\geq 2.18\%$, corresponding to cultivation conditions of annual sunshine ≥ 2600 h and soil moisture $\leq 22\%$, providing quantitative standards for the nature bias quality of “genuine medicinal materials” and making up for the limitation of traditional cultivation “emphasizing yield over nature bias”.

5. Limitations and Future Work

5.1. Research Limitations

Owing to the constraints of public data, this study has three main limitations:

- ① Bias in extreme habitat samples
- The number of public samples from extreme habitats such as high altitudes (>5000 m) and deep seas (>1000 m) is only 12, accounting for 18.2% of the total extreme habitat samples (66 species), which may affect the verification accuracy of adaptability in extreme scenarios.
- ② Lack of genotype data
- There is a scarcity of metabolic difference data among different genotypes of the same species (e.g., Lycium barbarum from Ningxia vs. Qinghai) in public databases, preventing in-depth analysis of the regulatory effect of genotype on natural bias.
- ③ Insufficient clinical correlation
- The existing data focus mainly on “plant component-nature bias”, lacking evidence of a correlation between “plant nature bias and human physiological indicators (e.g., inflammatory factors, thermogenic efficiency)”, making it difficult to directly support clinical recommendations for precise dietary therapy.

5.2. Future Work Directions

To address the above limitations and leverage the application potential of three-dimensional rules, future research will advance in four aspects:

- ① Expanded public data coverage
- Collaborating with research institutions to supplement samples from extreme habitats (high altitudes >5000 m, deep seas >1000 m) and genotype-level data, a “full-habitat and full-genotype” plant nature bias database (target sample size ≥ 1200 species) was constructed to improve the adaptability accuracy of the rules in extreme scenarios and genotype differences.
- ② Deepen interdisciplinary correlation research

On the basis of public human metabolome data, we explored the correlations between “plant warm-tending components (e.g., gingerols) and human thermogenic pathways (TRPV1 receptors)” and “plant cool-tending components (e.g., flavonoids) and human inflammatory factors”, initially establishing an evidence chain linking “plant nature bias to human physiological indicators” to support precise clinical dietary therapy.

③ Development of practical application tools

A plant nature bias query system (including a mini-program) is built on the basis of three-dimensional rules, integrating component and habitat data from public databases to enable grassroots users to quickly obtain nature bias scores and compatibility recommendations and cooperate with the agricultural sector to develop a “targeted nature bias-planting conditions” regulatory tool, providing quantitative guidance for the cultivation of medicinal and edible homologous food materials.

④ Extending special scenario applications

Explore the application of the rules in nature bias regulation of prepared dishes (e.g., controlling the warm bias score of lamb and radish soup to +2 points) and customized dietary therapy for special populations (e.g., hypertensive patients prioritizing cool-tending food materials with flavonoids $\geq 2.5\%$), promoting the transformation of theoretical results into people's livelihood applications.

6. Conclusions

On the basis of the verification and analysis of 934 valid plant-derived samples, the core conclusions of this study are as follows:

6.1. Strong Universality and Reliable Data of the Three-Dimensional Rules

The three-dimensional evaluation results show excellent adaptability, with a consistency rate of 97.2% for 781 common plant samples and 92.5% for 153 special group samples after correction. It can cover habitats such as northern arid regions, southern high-humidity regions, high-altitude areas (≥ 3500 m, consistency rate 92.9%), and deep-sea regions (≥ 200 m, consistency rate 91.4%), as well as seasonal scenarios (consistency rate 92.8%~94.0%). The coefficient of variation of the core correlation parameters (soil moisture–flavonoid content, $r=-0.82$; annual sunshine–gingerol content, $r=0.70$) is less than 5%, ensuring traceable and reproducible data.

6.2. Clear Regulatory Mechanism and Definite Quantitative Logic

The three-level synergistic mechanism of “environment-driven, metabolism-determined, and growth fine-tuned” is as follows: soil moisture drives cool bias by inhibiting volatile oil/gingerol synthesis and promoting flavonoid synthesis ($r=-0.82$), whereas annual sunshine drives warm bias by promoting the synthesis of volatile oils ($r=0.75$), gingerols ($r=0.70$), and terpenoids ($r=0.72$); flavonoids ($R^2=0.91$) and alkaloids ($R^2=0.87$) determine cool bias intensity, whereas volatile oils (segmented model $R^2=0.92$), gingerols ($R^2=0.88$), and terpenoids ($R^2=0.85$) determine warm bias intensity; growth characteristics (growth cycle $r=0.68$, monthly average rate $r=0.72$) achieve fine-tuning.

6.3. Excellent Adaptability to Classic TCM Theories

The conformity rates of the rules with three classic TCM theories—“wetness generates cold, drought generates heat” (92.9%), “Yang transforms into qi, Yin forms substance” (94.7%), and “correspondence between heaven and humans” (92.1%)—range from 92.1% to 94.7%. It can scientifically explain the theoretical essence (e.g., high humidity promoting flavonoid synthesis corresponds to “wetness generates cold”), providing dual “data-mechanism” support for the modernization of TCM theories.

6.4. Establishment of a Standardized Nature Bias Evaluation System

A three-dimensional rule with “quantifiable parameters, evidence-based correction, and reproducible processes” is formed. After the quantitative dimension of warm-tending components (volatile oil-gingerol-terpenoid) is improved, nature bias can be transformed from “empirical qualitative description” to “public data-driven scientific quantification”, providing a unified standardized basis for TCM dietary therapy and quality evaluation of medicinal plants.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: The sole author of this study independently completed all work: responsible for the research concept and overall design; undertaking the collection, screening, and integration of plant-derived sample data; verifying the adaptability of the three-dimensional evaluation rules via methods such as Pearson correlation analysis and linear regression; analyzing the nature bias regulatory mechanism in combination with plant physiology theory; drafting the initial manuscript; optimizing the subsequent content; organizing the logical structure; and being fully responsible for the final review and finalization of the paper.

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