Study of the Spectral Absorption Characteristics of Wild *Lancea tibetica* under Intense Solar Radiation on the Tibetan Plateau

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Abstract. *Lancea tibetica* is a valuable medicinal herb uniquely found in the Tibetan plateau. The photosynthetic pigments within its leaves are one of the indispensable substances for photosynthesis. However, The Tibetan plateau is one of the regions with the most intense solar radiation in the world. It has extreme solar radiation conditions. These extreme solar radiation conditions have multiple effects on local ecological conditions. In this study, the absorption spectrum of wild and laboratory *Lancea tibetica* leaves was observed using equipment like a spectrometer, followed by analyzing its characteristics. The results show that short-wavelength solar ultraviolet radiation has considerable small energy penetrating through plant leaves, and most of the energy is reflected by leaves or only a small proportion of energy is absorbed. Within the visible solar spectrum, most of the energy of the purple and indigo light is absorbed by leaves, with the absorbance of carotenoids being 0.731 at the maximum absorbent peak of 470nm. The transmitted intensity of the solar spectrum at this point is $0.38W\cdot m^{-2}\cdot nm^{-1}$, accounting for an absorption of nearly 81.42%. In the green light spectrum, the transmitted intensity is relatively high given the leaves' ability to retain the stability of their systems. The absorption of chlorophyll a and b is mainly concentrated in the red-light part, with transmitted intensity at 665nm and 649 nm being $0.80W\cdot m^{-2}\cdot nm^{-1}$ and $0.34W\cdot m^{-2}\cdot nm^{-1}$ only, playing a significant part in photosynthesis. The near infrared spectrum mainly consists of solar thermal energy, and the leaves of *Lancea tibetica* absorb less thermal radiation compared with ultraviolet and visible spectra.

1. Introduction

Plant growth is intimately associated with light; indeed, photosynthesis is the most crucial photochemical reaction in nature. Innumerable species of flora and fauna, through their vast capacity for energy conversion, continuously transform solar energy into organic bioenergy, providing the energy needed for their survival and growth on Earth[1-6]. The various photosynthetic pigments within plants act as mediators between plants and solar energy, and their capacity to absorb light energy directly influences the ability of plants to transform solar energy[7]. Of the characteristics of light affecting plant growth, three crucial factors are wavelength, intensity, and photoperiod. Globally, the Tibetan Plateau is one of the regions receiving the most intense solar radiation, with strong solar radiation impacting many areas, such as materials, forestry, animal husbandry, agriculture, and human health[8]. Observational studies have found that during the spring and summer (crop growing season) on the Tibetan Plateau, the ozone layer trough phenomenon has occurred[9]. An increase in ultraviolet radiation at ground level in Xizang could directly harm plateau agriculture, resulting in delayed seed germination, stunted plants, reduced leaf size (reducing the effective area for photosynthesis), extended growing periods, and decreased production[10].

Nonetheless, many plants still thrive in the unique environment of the Tibetan Plateau, including a variety of medicinal plants. Rapid progress has been made in the research and development of Tibetan medicine, with distinctive characteristics emerging. The materials for Tibetan medicine are derived from these plants. As shown in Fig. 1, *Lancea tibetica*, a medicinal plant unique to the Tibetan Plateau, grows in grasslands, sparse forests or alongside valleys at elevations ranging from 2,000 m to 4,500 m. A component of Tibetan medicine, known as 'Lan Shicao' or 'Waya Ba', *L. tibetica* has lung-cleansing and phlegm-dissolving properties[11-13] and possesses considerable ecological, medicinal and economic value. Furthermore, these findings not only enhance our understanding of how the plant, such as *L. tibetica*, adapts to its unique ecological environment but also provide valuable insights into its potential applications in medicinal plant research. The plant's adaptability to extreme environmental conditions may indicate the presence of unique bioactive compounds, which could hold significant value in drug development, potentially treating diseases associated with environmental stress or serving as a natural medicinal resource.

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Fig. 1. Lancea tibetica.

L. tibetica currently exists in the wild. Although it is one of the principal raw materials for Tibetan medicine, it is largely harvested in the wild, with no cultivation or effective exploitation. For cultivation, it is necessary to provide plants with an environment conducive to growth, including light, temperature, humidity, concentration, and appropriate nutrients. Traditional agronomy often focuses on environmental control and nutrient solution cultivation technologies. However, studies of the impact of light on plant growth used various artificially simulated light environments, most of which cannot be achieved under ordinary natural conditions, thus expanding the research scope for plant growth. By focusing on the light source, this study aims to determine the effects of illumination on the growth of *L. tibetica* on the Tibetan Plateau. By measuring the photosynthetic absorption spectrum of *L. tibetica*, the study also seeks to identify the light source that best matches plant growth, providing robust spectral data to maximise light utilisation and crop productivity.

Few studies, both domestic and international, have explored how illumination conditions affect plants on the Tibetan Plateau. Shi Shengbo, from the Northwest Institute of Plateau Biology, Chinese Academy of Sciences, conducted recent studies on the response and adaptation mechanisms of Tibetan Plateau plants to solar UV-B radiation[14]. Wang Gang, from Qinghai University, have studied the purification, modification and co-sensitisation of natural dye sensitisers from Tibetan Plateau plants, obtaining co-sensitisers with a broad spectrum of response[15]. Shen Haihua and scholars from Peking University, taking Tibetan Plateau plants as their research objects, explored the photosynthetic and respiratory characteristics of alpine plants under long-term warming environments and their response to temperature changes [16]. However, there is a wealth of research into the photosynthesis and illumination of plants in other special regions, both domestically and internationally. Zhou Kaibing from Hainan University studied the physiological and biochemical mechanisms of photosynthesis in mature mango trees in artificially enhanced intensity gradients of UV-B radiation and concluded that low and high-intensity UV-B radiation enhancements promote and inhibit leaf photosynthesis, respectively[17]. Hui Rong from the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, studied the impact of enhanced UV-B radiation on the diversity of cryptophytes and their ecological functions in the Earth's crust in desert areas[18]. Kenneth Dunton from the University of Texas, USA, mainly studied the ozone depletion and ultraviolet inhibition of Laminaria solidungula photosynthesis from a spectral and temporal perspective[19]. Thomas Vogelmann from Vermont State University used a dual-beam integrating sphere spectrophotometer to measure the UV–visible diffuse reflectance absorption of leaves and other biological samples. Watanabe Yasutada from Tokyo Metropolitan University studied the impact of solar ultraviolet radiation on the photosynthesis production and residue of freshwater algae.

Therefore, research into the photosynthetic absorption spectra of plants exposed to extreme conditions on the Tibetan Plateau is a long-term, significantly challenging task that can promote the monitoring, research and strategy development needed to combat the intense solar radiation that may occur under extreme natural conditions in China. This study, starting with medicinal plants unique to the Tibetan Plateau, should promote research into the physiological changes in various animals and plants surviving in such extreme environments. The intensity of solar radiation at different altitudes and the associated ecological impacts are the main research and development trends to adapt to the future radiation environment and ecology on the Tibetan Plateau. This study may attract more experts in related fields from both domestic and international communities to Xizang, which does not have expertise in scientific research hardware and software, thereby resulting in advances in scientific and technological methods. Moreover, it can also cultivate related high-level talent in Xizang, promoting the development of related disciplines such as ecology, botany, Tibetan medicine and as well as interdisciplinary subjects.

2. Observation of Photosynthetic Absorption Spectrum of Lancea tibetica Leaves

2.1 Experimental Equipment

The main experimental equipment utilised in this study was a solar spectrometer, solar irradiance metre and a 722 spectrophotometer. The solar spectrometer and solar irradiance metre have a spectral observation range from 280 nm to 1200 nm, covering ultraviolet, visible and near-infrared bands, which include the photosystems I and II of plant leaves; the 722 spectrophotometer performs the quantitative analysis of light and pigments of *L. tibetica* in the visible spectrum. As shown in Fig. 2, the solar spectrometer is used to observe the absorption of light on the front and back surfaces of *L. tibetica* leaves.

Fig. 2. Observation of Light Absorption of *Lancea tibetica* Leaves Using a Solar Spectrometert.

2.2 Experimental Methods

2.2.1 Measurement of Light Absorption by Lancea tibetica Leaves

The *L. tibetica* sampling site for this research was located on the slopes around the Pangduo Reservoir in Lhasa City, at an altitude of 4075.00 m, a latitude of 30.18 N and a longitude of 91.32ºE; the sampling time was 1200 on 1 July 2023. During the sampling period, the weather was clear with no cloud cover, and the solar radiation was intense. Using a solar irradiance metre, the transmittance and reflectance of *L. tibetica* leaves were measured directly under sunlight and compared with the local solar spectrum on the ground, thereby obtaining the outdoor absorption spectrum distribution of the leaves.

Owing to the outdoor ground reflection of solar radiation, which can affect the observation results of absorption, an equal number of *L. tibetica* samples was collected and taken to the laboratory to allow the transmission spectrum to be observed under darkroom conditions.

2.2.2 Determination of the Absorptance of Photosynthetic Pigments in Lancea tibetica Leaves

The photosynthetic pigments of *L. tibetica* leaves were extracted in the laboratory. The determination of absorptance consists of four main steps: sampling, extraction, measurement and calculation.

From the absorption of the chlorophyll pigment extract in the visible spectrum, the absorptance at a specific wavelength can be measured using the spectrophotometer; from this, the content of each pigment in the extract can be calculated. According to the Beer–Lambert law, the absorptance A of a coloured solution is directly proportional to the solute concentration c and the liquid layer thickness L:

$$A = KcL \quad (1)$$

As chlorophyll pigments have different absorption spectra in various solvents, the calculation formula is also different when extracting pigments with other solvents. Chlorophyll a and chlorophyll b have maximum absorption peaks at 665 and 649 nm, respectively, in 95% ethanol, with carotenoids at 470 nm. The following formulae were thus established:

$$Ca = 13.95A465 - 6.88A649 \quad (2)$$

$$Cb = 24.96A649 - 7.32A665 \quad (3)$$

$$CX{\cdot}C = (1000A470 - 2.05Ca - 114.8Cb)/245 \quad (4)$$

2.2.3 Calculation of the Absorption Spectrum Based on the Absorptance of Different Photosynthetic Pigments

The original solar spectrum intensity, I0 and the absorptance, A, of various photosynthetic pigments in *L. tibetica* obtained in the laboratory are already known from experiments. From the mathematical expression of Beer's law (where T is the transmittance, the ratio of the emergent light intensity I to the incident light intensity I0):

$$A = \lg(1/T) \quad (5)$$

Consequently, it is possible to calculate the transmitted light intensity after the absorption of different photosynthetic pigments, compare the degree of absorption of pigments to light at different wavelengths and summarise the types of pigments that significantly impact photosynthesis in the leaves.

3. Data Analysis of the Photosynthetic Absorption Spectra of *Lancea tibetica*

3.1 Analysis of Global Radiation Absorption

The solar radiation received by wild *L. tibetica* leaves consists of global solar radiation, which includes not only direct solar radiation but also ground-reflected and atmospheric-scattered solar energy. A comparison between the global solar spectrum and the absorption spectrum of the front and back sides of the leaf after light absorption is shown in Fig. 3.

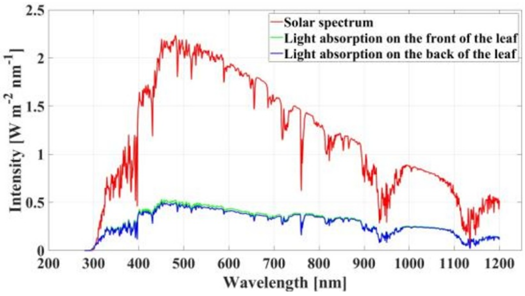

Fig. 3. Comparison of Global Radiation Absorption.

Owing to differences in colour, the arrangement of spongy mesophyll cells and stomatal openings on the front and back sides of *L. tibetica* leaves, the light transmitted after absorbing solar radiation differs. As shown in the figure, the absorption on both the front and back sides is essentially consistent. With the ground reflection present, the maximum transmitted light intensity occurs at 451 nm, with the front side peaking at 0.53 $W{\cdot}m^{-2}{\cdot}nm^{-1}$ and the back side at 0.50 $W{\cdot}m^{-2}{\cdot}nm^{-1}$, whereas the incident light intensity at this bandwidth is 2.20 $W{\cdot}m^{-2}{\cdot}nm^{-1}$. The incident light is reduced by approximately 75.76% after reflection and transmission through the front of the leaf and by approximately 77.07% after passing through the back of the leaf.

3.2 Laboratory Solar Spectrum Absorption Analysis

The solar spectrum absorption data collected in the laboratory for *L. tibetica* leaves mainly concern the absorption of direct solar radiation. Compared with the outdoor global solar radiation, ground reflection effects are eliminated, resulting in lower measured transmitted radiation, especially in the ultraviolet and visible light absorption spectra, whereas the thermal radiation in the near-infrared part is generally less absorbed, with approximately half the energy able to penetrate the leaf. This is shown in Fig. 4.

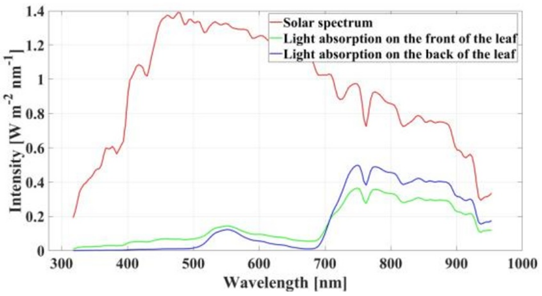

Fig. 4. Laboratory Solar Spectrum Absorption Comparison.

From the absorption of the solar ultraviolet spectrum, shown in Fig. 5, the minimum value of the original solar ultraviolet radiation is 0.19 W·m^{-2}·nm^{-1} at 317.6 nm, and the maximum value is 0.89 W·m^{-2}·nm^{-1} at 400.0 nm. After absorption on the front, the maximum value is only 0.04 W·m^{-2}·nm^{-1}, and it was almost zero on the back owing to the biophysical structure of *L. tibetica* leaves, which almost entirely blocks or absorbs solar ultraviolet radiation.

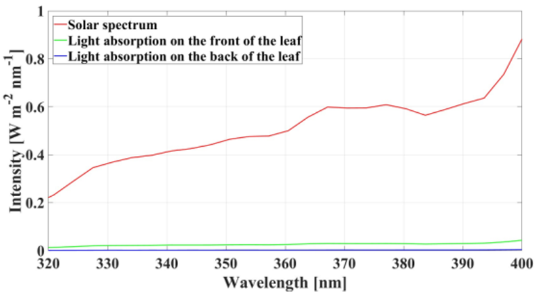

Fig. 5. Absorption of Solar Ultraviolet Spectrum by *Lancea tibetica* Leaves.

It is known that plant photosynthesis mainly utilises energy from the solar visible light spectrum. As shown in Fig. 6, from the absorption of the solar visible spectrum, most of the light in the violet light bandwidth (400–455 nm) and the indigo light bandwidth (455–492 nm) is absorbed by *L. tibetica* leaves, with the strongest transmission light after absorption from the front of the leaf occurring at 459.9 nm with an intensity of 0.069 W·m^{-2}·nm^{-1}. The green light bandwidth (492–577 nm) is less common, especially at 549.8 nm, where there is a small peak value of 0.143 W·m^{-2}·nm^{-1}, as plants selectively do not absorb green light to maintain the stability of their energy systems. The leaves appear green because they reflect a large amount of green light. In the yellow-orange light bandwidth (577–622 nm), as the wavelength increases, the absorptive capacity gradually increases, and the transmitted light spectrum intensity decreases towards the red light range. In the red light bandwidth (622–780 nm), the minimum transmitted light spectrum intensity is 0.01 W·m^{-2}·nm^{-1} at 672.9 nm, very close to the maximum absorption peak wavelength of chlorophyll a, indicating that at this bandwidth, the photosynthetic pigment chlorophyll a plays a significant role. At 707 nm, the transmitted spectra of the front and back sides of the leaf intersect, after which the ability of the front side to absorb red light surpasses that of the back, reaching a second peak at 749.3 nm on both sides. In the literature, it is reported that far-red light has an inhibitory effect on plant germination and flowering, and as the sampled *L. tibetica* was in its growth period in summer, the absorption of far-red light by the leaves was weaker.

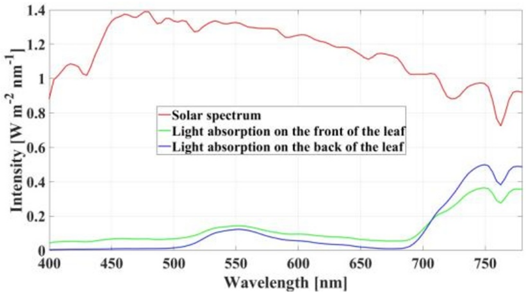

Fig. 6. Absorption of Solar Visible Spectrum by *Lancea tibetica* Leaves.

The absorption of the solar near-infrared spectrum is shown in Fig. 7. The solar near-infrared spectrum consists primarily of solar thermal radiation energy, and *L. tibetica* leaves absorb less of this wavelength compared with the ultraviolet and visible spectra, with approximately 53.51% of the incident light intensity transmitted through the back of the leaf. Owing to differences in cell structure, colour shades and mechanistic functions, the transmitted light intensity on the front of the leaf is 39.15% of the incident light, lower than the back, which contrasts the findings for the absorption of ultraviolet and visible light.

The absorption of the solar near-infrared spectrum is shown in Fig. 7. The solar near-infrared spectrum consists primarily of solar thermal radiation energy, and *L. tibetica* leaves absorb less of this wavelength compared with the ultraviolet and visible spectra, with approximately 53.51% of the incident light intensity transmitted through the back of the leaf. Owing to differences in cell structure, colour shades and mechanistic functions, the transmitted light intensity on the front of the leaf is 39.15% of the incident light, lower than the back, which contrasts the findings for the absorption of ultraviolet and visible light.

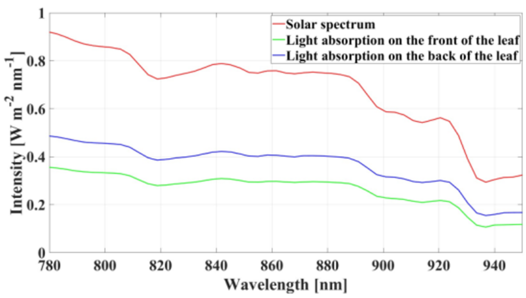

Fig. 7. Absorption of Solar Near-Infrared Spectrum by *Lancea tibetica* Leaves.

3.3 Analysis of Absorptances of Various Photosynthetic Pigments

For photosynthetic pigment extraction, *L. tibetica* leaves collected from the wild were divided into six groups in the laboratory and their absorptances were measured using a spectrophotometer. Based on the data calculated from the six experimental groups, the absorptances of carotenoids, chlorophyll b and chlorophyll a in *L. tibetica* leaves were obtained, as shown in Fig. 8.

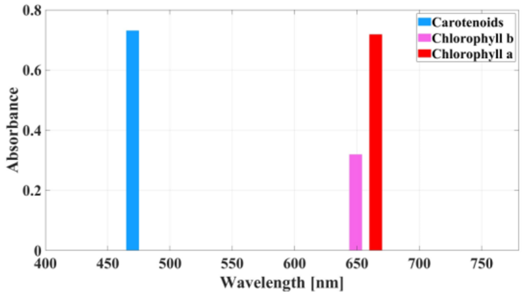

Fig. 8. Absorptances of Chlorophyll a, b and Carotenoids.

The maximum absorption peaks of all photosynthetic pigments occur within the visible light spectrum range (400–780 nm). The maximum absorption peak of carotenoids in 95% ethanol is at 470 nm and occurs in the blue light band, with a measured absorptance of 0.731; the maximum absorption peak of chlorophyll b is at 649 nm and occurs in the red light band, with a measured absorptance of 0.319; and the maximum absorption peak of chlorophyll a is at 665 nm and also occurs in the red light band, with a measured absorptance of 0.717.

3.4 Analysis of Photosynthetic Absorption Intensity for Lancea tibetica Leaves

Based on the observed global solar spectrum and the absorptance at the maximum absorption peaks of the photosynthetic pigments measured in the laboratory, the strongest absorption spectra for each photosynthetic pigment were derived and are shown in Fig. 9.

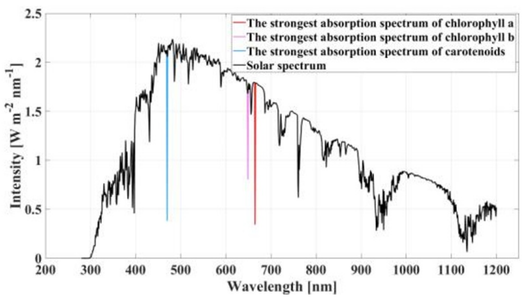

Fig. 9. Absorption Spectra of Chlorophyll a, b and Carotenoids.

The absorptance at the maximum absorption peak bandwidth of carotenoids is 0.731; the highest incident light intensity in the full solar spectrum at this point is 2.06 $W \cdot m^{-2} \cdot nm^{-1}$. After absorption by carotenoids, the transmitted light intensity is 0.38 $W \cdot m^{-2} \cdot nm^{-1}$, indicating approximately 81.42% absorbance. The absorptance at the maximum absorption peak bandwidth of chlorophyll b is 0.319; the highest incident light intensity in the full solar spectrum at this point is 1.68 $W \cdot m^{-2} \cdot nm^{-1}$. After absorption by chlorophyll b, the transmitted light intensity is 0.80 $W \cdot m^{-2} \cdot nm^{-1}$, indicating approximately 52.06% absorbance. The absorptance at the maximum absorption peak bandwidth of chlorophyll a is 0.717; the highest incident light intensity in the full solar spectrum at this point is 1.79 $W \cdot m^{-2} \cdot nm^{-1}$. After absorption by chlorophyll a, the transmitted light intensity was 0.34 $W \cdot m^{-2} \cdot nm^{-1}$, indicating approximately 80.84% absorbance.

The absorbance values and transmitted intensities measured in the study are crucial indicators of the plant's photosynthetic capacity and overall health. High absorbance values suggest that *Lancea tibetica* is efficiently capturing sunlight, which is essential for driving photosynthesis and producing the energy and nutrients necessary for growth and development. Conversely, low absorbance or high transmitted intensities may indicate stress conditions or limitations in the plant's ability to harness solar energy. By analyzing these spectral characteristics, researchers can gain insights into the plant's photosynthetic efficiency, which is directly linked to its ability to thrive in its environment and produce valuable compounds for medicinal or other purposes.

4. Conclusion

This study is among the few in recent years that investigate the solar spectral absorption characteristics of wild *L. tibetica* leaves. It has observed the transmission spectrum in the wavelength range of 280–1200 nm, covering ultraviolet, visible and near-infrared bands. The results of this study present a preliminary, sporadic characterisation of the spectral absorption characteristics of *L. tibetica* leaves. Although the observation period was short and the amount of data was limited, it still provides a valuable observational experience for future research into the photosynthesis of wild medicinal plants in Xizang. Distinctive features of this study:

(1) Regional significance is pronounced. The main focus of this research is the alpine region of the Tibetan Plateau. Known as the ‘Third Pole’ of the world, with minimal pollution, scant human activity and an abundance of pristine natural resources (apart from Antarctica and the Arctic), the solar radiation energy here is higher than in other regions. The Tibetan Plateau offers uniquely advantageous conditions for conducting spectral absorption measurements.

(2) Specific spectral measurements of plants unique to the Tibetan Plateau. *L. tibetica*, which this project plans to observe, mostly grows at elevations between 2,000 m and 4,500 m and is a precious wild medicinal plant unique to the Tibetan Plateau.

Innovation of the study:

Currently, *L. tibetica*, as one of the principal raw materials for Tibetan medicine, is still largely harvested in the wild and very little is cultivated artificially. This study measures the photosynthetic absorption spectrum of *L. tibetica* under different light conditions at various altitudes and growth environments on the Tibetan Plateau, providing robust photosynthetic spectral data to support simulating light environments when artificially cultivating *L. tibetica.*

It is necessary to conduct systematic observational research on the photosynthetic absorption characteristics of other wild medicinal plants unique to the Tibetan Plateau and provide robust data to identify the changes in the ecological environment of the plateau, plant growth, and solar energy resource utilisation, among other aspects.

Acknowledgements

We would like to express our sincere gratitude to the Natural Science Foundation Project of Xizang Autonomous Region (Grant NO. XZ202401ZR0023) for their financial support, which has enabled us to carry out this research. We are also deeply thankful to the Scientific Research and Cultivation Fund Project of Tibet University (Grant NO. ZDCZJH20-18) for their valuable contributions to the advancement of our work. Furthermore, we acknowledge the Research Project on Higher Education Teaching Reform of Tibet Autonomous Region (JG2023-18) for providing the necessary resources and guidance throughout the research process. Without the support from these funding bodies, the completion of this study would not have been possible.

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