Effect of Carbonaceous Reducers on Carbon Emission during Silicon Production in SAF of 8.5 MVA and 12.5 MVA

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Abstract
Along with the global trend of increasing interest in environmental protection, the silicon manufacturing process will use a large number of carbonaceous reducers and produce a large number of carbon emissions, which is of deep concern to the Chinese companies. Previous research has calculated the amount of carbon emissions incurred in silicon production, while research on the factors that affect carbon emissions during the silicon production process has been scarce. The effect of the carbonaceous reducers’ consumption and different furnace types (8.5 MVA and 12.5 MVA) on the carbon emissions during silicon production was investigated using statistical analysis of the actual production data in order to lower the carbon emissions of silicon production. Based on the results, the soft coal has the greatest influence on carbon emission when 8.5 MVA furnace is used to produce industrial silicon. When 12.5 MVA furnace is used, petroleum coke has the greatest impact on carbon emissions. But electricity is still the biggest contributor to carbon emissions. Using the 12.5 MVA furnace will reduce CO\textsubscript{2} emissions by approximately 74 kg per ton of product compared to an 8.5 MVA furnace. To obtain reduced carbon emissions in silicon production, we suggest that silicon manufacturers should try to use 12.5 MVA furnace type and optimize the ratio of carbon reducing agents used in different furnace types.

Keywords Carbonaceous reducers · Carbon emission · Silicon production · Different type of submerged arc furnaces

1 Introduction
In the last several decades, due to increasing concern about global warming, energy conservation and carbon emission reduction have attracted intense attention worldwide. China is currently the largest carbon dioxide emitter in the world [1–4]. However, over the last decade, China has made great efforts to slow down the growth of its carbon emissions. In November 2009, China announced its first greenhouse gas emission reduction target. In the 2015 Paris agreement, China committed to reach peak CO\textsubscript{2} emission by 2030 and decrease its carbon intensity by 60–65% by 2030 relative to the 2005 [2]. On December 18th, 2017, the National Development and Reform Commission announced the “National Carbon Emissions Trading Market Construction Plan (Power Generation Industry)”, setting the threshold for China’s power generation industry to be included in the carbon market [3]. This plan provides guidance for the industrial silicon sector.

Novel energy generation approaches based on renewable energy, such as solar photovoltaic power generation, lithium batteries and hydrogen energy, are considered to be the most likely candidates to meet the increasing energy demand while meeting CO\textsubscript{2} emission reduction targets [5–9]. Solar energy is a green renewable energy that is usually obtained by conversion of light into electricity by photovoltaic cells made from crystalline silicon [10]. Current photovoltaic power generation relies largely on polycrystalline silicon. Additionally, polycrystalline silicon can also be used to manufacture different types of optoelectronic and photonic circuits [11, 12] by
integration of multiple components on a single silicon chip [13]. Therefore, it is highly necessary to study the factors that affect the carbon emissions generated in the production of industrial silicon used as the raw material for polycrystalline silicon.

The smelting process of industrial silicon is an extremely energy-intensive industrial process that mainly consumes carbonaceous reducing agents such as petroleum coke, soft coal and wood block that are used to produce silicon via carbon thermal reduction in a submerged arc furnace [14, 15]. These raw materials as well as the silica used as the silicon source are non-renewable resources and their use gives rise to considerable fossil CO₂ emissions. Since the submerged arc furnace consumes the major part of the energy required in the production chain from silica to industrial silicon, it is appropriate to focus on this process. While multiple approaches for reducing the energy requirements and the carbon dioxide emissions of this process have been suggested and investigated, research on the factors that affect carbon emissions during the industrial silicon production process has been scarce.

A variety of methods have been developed for the study of the environmental impact and CO₂ emissions of different technologies by researchers around the world. Heijungs et al. [16] discussed three cases using the Human and Ecological Life cycle tool of Systematic Comprehensive Evaluation (HELIAS), but did not propose the specific factors affecting carbon emissions. Kirshen et al. [17] showed that in the steel industry, the use of natural gas (NG) can help to reduce the total carbon dioxide emissions produced by electric arc furnaces, but this method does not explicitly calculate the amount of carbon dioxide to be reduced. Kang et al. [18] developed a robust IO-LP model that suggests that China’s coal and hydropower technologies are likely to be significantly developed between 2020 and 2050, but their approach involves significant uncertainties. O’Ryan et al. [19] analyzed data from the Chilean electricity market based on the Computable General Equilibrium (CGE) model, demonstrating that Chile is on track to reduce its overall carbon emissions. Takla et al. [14] analyzed the actual and theoretical production processes of industrial silicon, and used exergy and energy analysis to evaluate the resource utilization of industrial silicon production process.

Since the industrial silicon production process is quite similar to the steel production process, we used the method used in the steel industry for the calculation of carbon emissions. The studies focusing on the major methods used to calculate carbon emissions and their mitigation strategies in the steel industry are listed below.

Worrell et al. [20] analyzed the baseline for 1994 energy use and carbon dioxide emissions from US steel manufacturing and identified as many as 47 energy-efficient practices and technologies. Helle et al. [21] investigated the potential of the use of biomass in iron industry production. Their results demonstrate that the use of biomass in steelmaking can effectively reduce carbon dioxide emissions and reduce smelting costs. Mitra et al. [22] used genetic algorithms to analyzed solutions that can provide guidance in the search for more sustainable production concepts. Zhang et al. [23] evaluated the potential of waste heat recovery and carbon reduction in a steel plant in northern China. Their study demonstrated that for a steelmaking plant with an annual output of 10 million tons, 1.65 million tons of coal equivalent and approximately 5 million tons of carbon dioxide emissions could be saved by adopting low-energy heat recovery technology. By establishing China’s 2011 Economic Input-output Life Cycle Assessment (EIO-LCA) model, Li et al. [24] proved that coke and coal are the largest influencing factors of direct carbon dioxide emissions in the steel industry and proposed corresponding methods to reduce carbon emissions. By imposing 61 key constraints, Shen et al. [25] obtained the best solution for the batch-up ratio and energy saving and emission reduction of the steel production system. The maximum energy saving rate per ton of steel could reach 20.63 kgce. In view of the high carbon emissions in China’s steel industry, other researchers believe that enhancing energy efficiency and the development and application of energy saving/recycling technologies and breakthrough carbon dioxide technologies, as well as the continuous use of renewable energy are important approaches for reducing greenhouse gas emissions from the steel industry [26–30].

In previous studies, we determined the correlation coefficients between the different raw material consumption and exergetic efficiency using linear regression on industrial silicon production in the furnace [31, 32]. We used several artificial neural network (ANN) models to simulate and evaluate the approximate composition fluctuations of carbon materials and the final power strain and combustion efficiency under different petroleum coke, soft coal, silica and electrode conditions [33, 34]. The effects of raw materials, fixed carbon, volatile substances and water content on the silicon yield and the energy consumption during silicon production were also studied [35–37]. Our recent research has found evidence for the correlation between the impurity content in silicon products and the consumption of different carbonaceous reducers [38]. These studies provided different methods for studying the impact of raw materials on carbon emissions in the industrial silicon production process.

2 Research Method

2.1 Silicon Production Process

Figure 1 shows a silicon production system that includes the feed, electrode, SAF, product, and the waste gas and slag treatment systems [14]. The arc formed between the graphite electrode and the production material in the furnace and the
resistance of the charge to the current will cause the furnace temperature to exceed 1800 °C. At such high temperature, silica is reduced by a mixture of soft coal, petroleum coke and wood block with certain proportions. To facilitate the calculation of carbon emissions, we adopt simplified equations for the following major reactions:

\[
\begin{align*}
\text{SiO}_2(s) + 3C(s) &= \text{Si}(l) + 2\text{CO}(g) \quad (2.1) \\
\text{SiO}_2(s) + 2C(s) &= \text{Si}(l) + 2\text{CO}(g) \quad (2.2)
\end{align*}
\]

2.2 Raw Materials

The main carbonaceous reducers for the production of industrial silicon include silica, soft coal, petroleum coke, blue carbon, semi-coke, asphalt coke, coke powder, charcoal, wood block, and biomass charcoal. Coal, wood block and petroleum coke were used as the carbonaceous reducers, and graphite with a carbon content of 100% was used as the electrode material. These materials are mainly composed of fixed carbon, volatiles, moisture and ash. Table 1 shows the main components of the carbon-containing feedstock used in the industrial silicon production experiments carried out in this work.

2.3 Experimental Data Collection

During this work, we collected a large amount of actual production data through cooperation with an industrial silicon enterprise in Yunnan province and deleted the abnormal data caused by power failure. Analysis of these data reveals the relationship between the raw material consumption and the carbon emissions in the industrial silicon production process using different furnace types. Understanding the relationship between the data is beneficial for reducing production costs and carbon emissions, achieving a more rational and effective use of resources, improving resource utilization and product quality, and protecting the environment.

The 8.5 MVA furnace type was named as 1# and 2#, and the 12.5 MVA furnace type was named as 3# and 4#. To facilitate comparison and analysis, the data for the consumption of the three kinds of carbonaceous reducers are converted into data for the production of one ton of industrial silicon, and the data unit is ton/ton. We consider that the silicon dioxide content and the electrode material is 100% fixed and the carbonaceous reducers react completely with silica. All data are analyzed using average values.

2.4 Carbon Emission Calculation Method

The carbon emission calculation methods can be divided into three categories of the activity level, mass conservation and continuous monitoring methods. The calculation principle of the activity level method is based on the consumption data and the default emission factor. While the calculation method of this approach is simple, there is a large uncertainty for the value of the default emission factor. The conservation of mass...
method is based on the calculation of the carbon difference between the input and output of the enterprise. This method is relatively complex and the calculation results are relatively accurate. However, when a third party uses this method for the calculation, due to the information asymmetry, the accuracy of the results will be reduced. The continuous monitoring method is a method for the continuous monitoring of related parameters, but it is often difficult for enterprises to monitor all of the emission parameters, and the cost of monitoring is high.

In view of the characteristics of the three methods, the activity level method is currently the most commonly used method. In this work, the study of carbon emissions also used the activity level method to measure the carbon emissions of enterprises.

2.4.1 Direct Emissions

Direct emissions refer to the CO₂ emissions generated by the combustion of fossil fuels, including internal fixed source emissions and mobile source emissions used for production. These emissions can be calculated as follows (the formula is derived from the IPCC Guidelines):

\[ E = \sum AD_i \times EF_i \]  \hspace{1cm} (2.3)

where \( E \) is the value of the total carbon emissions caused by the combustion of all fuels in the production of industrial silicon, \( i \) is the type of fossil fuel, \( AD_i \) is the total consumption of \( i \), and \( EF_i \) is the CO₂ emission coefficient of \( i \). Using the energy recommended carbon emission coefficient formula published in the IPCC guidelines, the carbon emission coefficients of various fuels can be obtained as:

\[ C = A \times B \times \left( \frac{44}{12} \right) \times 1000 \]  \hspace{1cm} (2.4)

\[ F = C \times 4186.6 \times 10^{-9} \times 10^{-3} \]  \hspace{1cm} (2.5)

\[ H = F \times G \]  \hspace{1cm} (2.6)

where \( A \) is the carbon emission coefficient (kgC/GJ), \( B \) is the carbon oxidation factor, and all the raw materials for industrial silicon production have the weight of 1 kg each. \( C \) is the CO₂ emission coefficient (kgCO₂/TJ), \( F \) is the original coefficient (kgCO₂/kcal), \( C \) is the CO₂ emission coefficient (kgCO₂/TJ), \( G \) is the calorific value (kcal/kg), and \( H \) is the recommended emission coefficient (kgCO₂/kg). It is important to note that the CO₂ emission factors used for the calculation are taken from 2006 IPCC Guidelines, because these values are more suitable for the silicon produced in China. The calorific values of both wood-solid and charcoal are Chinese calorific values. The calorific value of the wood block is approximately \( 1.2 \times 10^7 \) J/kg, which is converted into a common unit of 2,866,800 cal/kg, or 2866.8 kcal/kg. The calorific value of charcoal is \( 3.4 \times 10^7 \) J/kg, which means that \( 3.4 \times 10^7 \) J is released when 1 kg of charcoal is completely burned and this is converted into a common units to obtain 8,122,600 cal/kg, or 8122.6 kcal/kg.

Using the data in Eq. (2.3) and Tables 2 and 3, the carbon emissions from the combustion of fossil energy in the production of industrial silicon can be obtained.

2.4.2 Emissions from Industrial Processes

The carbon emission of industrial production process refers to the CO₂ emissions generated by other purchased carbon-containing raw materials such as electrodes in the production process of industrial silicon. The calculation formula is as follows:

\[ E_{\text{electrode}} = P \times EF_P \]  \hspace{1cm} (2.7)

where \( E_{\text{electrode}} \) is the amount of CO₂ produced by consuming the electrode (kgCO₂/kg), \( P \) is the electrode consumption (kg), \( EF_P \) is the CO₂ emission factor of the electrode and is equal to 3.6630 tCO₂/t. These values are derived from the IISA Guidelines for the Collection of Carbon Dioxide Emission Data.

2.4.3 Emissions from the Use of Electricity

The CO₂ emissions are driven by the electricity purchased by industrial silicon manufacturers. The power output consumed by industrial silicon enterprises actually occurs in the power production enterprises and is
consumed by industrial silicon enterprises. In accordance with the benefit principle, the carbon dioxide emissions embodied in the output power of industrial silicon enterprises are used to calculate the total emissions. The emissions are calculated as follows:

\[ E_e = P \times EF_e \]  

(2.8)

where \( E_e \) is the indirect \( \text{CO}_2 \) emissions generated by the purchased power (kgCO\(_2\)), \( P \) is the power consumption (kWh), \( EF_e \) is the \( \text{CO}_2 \) emission factor of the power consumption in the emission region, and is equal to 0.7035 kgCO\(_2\)/kWh. The data are derived from the IISA Guidelines for the Collection of Carbon Dioxide Emission Data.

### 2.5 Total Carbon Emissions

On the basis of the above classification, the carbon emissions of industrial silicon enterprises can be divided into direct emissions and indirect emissions according to their emission sources. The direct emissions mainly refer to the emissions from the burning of fossil fuels in the production process, while the indirect emissions mainly refer to the net carbon dioxide emissions generated by the consumption of electricity. Therefore, the calculation formula of total carbon emission is as follows:

\[ E_{\text{total}} = E + E_{\text{electrode}} + E_e \]  

(2.9)

Once the total carbon emission values are obtained, the carbon emissions of the five main raw materials electricity, electrodes, petroleum coke, soft coal and wood block can be compared. It was found in Fig. 2 that the purchased power produces the largest contribution to carbon emissions, with the average of 63.45% for the low-rated capacity furnace and 60.85% for the high-rated capacity furnace. Low-rated capacity furnace type has the largest proportion of petroleum coke emissions, averaging 16.4%, while high-rated capacity furnace type has the largest proportion of soft coal emissions, averaging 17.35%.

| Type of fuel | Soft coal | Petroleum coke | Wood block | Charcoal |
|-------------|-----------|----------------|------------|----------|
| Calorific value kcal/kg | 6400 | 8200 | 2866.8 | 8122.6 |

### 3 Experimental Results and Discussion

#### 3.1 Effect of Carbonaceous Reducers on Direct Carbon Emissions

To study the effect of carbon reducing agent consumption on the carbon emissions during silicon production, Pearson’s correlation coefficient method, which is widely used to evaluate the correlation of variables, and the trend diagram measuring the linear correlation between variables were used for analysis. The specific relationship is given by [38]:

\[ r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \cdot \sqrt{\sum (y_i - \bar{y})^2}} \]  

(3.1)

#### 3.1.1 The 8.5 MVA SAF

In this section, we analyze the influence of soft coal, petroleum coke and wood block on the direct carbon emissions. More than 150 groups of experiments were carried out on the three reducing agents containing petroleum coke, soft coal and wood block respectively in the 1# and 2# furnaces, and then the available data were compared using linear regression analysis. Figure 3 shows the trend of the three major reducing chemicals and direct carbon emissions, with strong linear correlation observed for all cases. The absolute r values of the 1# furnace soft coal, petroleum coke and wood block are 0.94041, 0.98248 and 0.97656, respectively. The absolute r values of the 2# soft coal, petroleum coke and wood were 0.92147, 0.96294 and 0.94735, respectively. The absolute values of the straight slope between soft coal, petroleum coke and wood block and carbon emission of the 1# furnace are 8.49575, 6.25631 and 5.8344, respectively, and those of the

| Type of fuel | Soft coal | Petroleum coke | Wood block | Charcoal |
|-------------|-----------|----------------|------------|----------|
| Emission coefficient kgCO\(_2\)/kg | 2.53 | 3.35 | 1.35 | 3.81 |
2# furnace were 7.30551, 6.41443 and 5.44356, respectively. Based on the analysis of the 1# and 2# low-rated capacity submerged arc furnaces, it is concluded that soft coal has the greatest impact on the direct carbon emissions generated by the production of single ton of industrial silicon, followed by petroleum coke, and wood block has the least impact.

3.1.2 The 12.5 MVA SAF

In this section, we mainly analyze the impact of the three reducing agents, namely soft coal, petroleum coke and wood block, on the direct carbon emissions. More than 80 groups of experiments were carried out on the three reducing agents containing soft coal, petroleum coke and wood block in the 3# and 4# furnaces, respectively, and then the available data were compared using linear regression analysis. Figure 4 shows the variation trend of the three main reducing agent and direct carbon emissions, and strong linear correlation is observed in all cases. The absolute r values of the 3# furnace soft coal, petroleum coke and wood block are 0.93602, 0.92976 and 0.92912, while the absolute r values of the 4# furnace soft coal, petroleum coke and wood block are 0.83585.
and 0.880, respectively. The absolute values of the linear slope between soft coal, petroleum coke and wood block and carbon emission the 3# SAF are 5.76843, 8.3217 and 4.33515, respectively, and those of the 4# SAF are 5.37373 and 11.28009 and 5.09019, respectively. Based on the analysis of the 3# and 4# high-rated capacity submerged arc furnaces, it is concluded that for the use of the 12.5 MVA submerged arc furnace, petroleum coke has the greatest impact on the direct carbon emissions generated by the production of a ton of industrial silicon, followed by soft coal, and wood block has the least impact.

3.2 Effect of Carbonaceous Reducers on Total Carbon Emissions

3.2.1 The 8.5 MVA SAF

Similar to 3.1.1, Fig. 5 shows the variation between the three main reducing agents for the total carbon emissions, which also shows a medium linear correlation.

3.2.2 The 12.5 MVA SAF

Similar to 3.1.2, Fig. 6 shows the variation for the three main reducing chemicals and the total carbon emissions.
revealing in some linear correlation. The absolute r values of the 3# furnace soft coal, petroleum coke and wood block are 0.7265, 0.81006 and 0.7, respectively. The absolute values of the linear slope between soft coal, petroleum coke and wood block and carbon emission of the 3# submerged arc furnace are 8.28397, 13.39245 and 8.04538, respectively, and those of the 4# submerged arc furnace are 11.61836, 13.23908 and 11.49253, respectively. According to 3.1.2, it can be concluded that petroleum coke has the greatest influence on the total carbon emissions generated by the production of a ton of industrial silicon, followed by soft coal, and wood block has the least influence.

3.2.3 Change of the Slope of the Linear Equation between Raw Material Consumption and Carbon Emission under Different Furnace Types

To more intuitively understand the change of the slope of the linear relationship between different raw materials and carbon emissions under the condition of the 8.5 MVA and 12.5 MVA furnace types, it is drawn as a broken line graph, as shown in Fig. 7. The results show that with the increase in the rated capacity, the slopes of the carbon emissions from coal and wood decreases, while the slope of the carbon emissions from petroleum coke increases. Therefore, we can draw the following conclusion: when using 8.5 MVA furnace, to improve the industrial silicon production and reduce carbon emissions, it is necessary to reduce the usage of soft coal, and increase the use of petroleum coke and block. When using the 12.5 MVA furnace, to improve the production of industrial silicon and reduce carbon emissions, it is necessary to reduce the usage of petroleum coke and to increase the usage of soft coal and wood block.

3.2.4 Comparison of Average Raw Material Consumption and Average Carbon Emission of Different Furnace Types

It is clearly observed from Fig. 8, that the power consumption of a ton of industrial silicon produced by different furnace types is essentially maintained at 12384 ± 215 kWh/t, and the electrode material consumption is essentially maintained at 0.12 ± 0.005 t/t. However, the consumption of raw materials varies greatly. The consumption of petroleum coke, soft coal and wood block of the 8.5 MVA furnace is essentially maintained at 0.6791 ± 0.0073 t/t, 0.506 ± 0.0013 t/t and 0.7915 ± 0.0460 t/t, respectively. The consumption of petroleum coke, soft coal and wood block of the 12.5 MVA furnace is essentially maintained at 0.4839 ± 0.0397 t/t, 0.9234 ± 0.0391 t/t and 0.9131 ± 0.0735 t/t, respectively.

According to Fig. 9, the direct carbon emission of one ton of industrial silicon produced by the 1# furnace is 4.5848 t ± 0.4350 t/t and the total carbon emission is 13.9973 ± 1.6327 t/t.

![Fig. 7 The slope of a linear equation](image-url)
t. The direct carbon emission of one ton of industrial silicon produced by the 2# furnace is 4.6476 ± 0.3683 t/t. The total carbon emission is 14.0241 ± 0.9400 t/t and the direct carbon emission of one ton of industrial silicon produced by the 3# furnace is 5.0520 ± 0.3356 t/t. The total carbon emission is 13.9339 ± 0.7835 t/t and the direct carbon emission of one ton of industrial silicon produced by the 4# furnace is 5.3182 ± 0.3802 t/t and its total carbon emission is 13.9404 ± 1.1886 t/t. Although the direct carbon emission of the high-rated capacity furnace is higher than that of the low-rated capacity furnace, the total carbon emission of the high-rated capacity furnace is lower than that of the low-rated capacity furnace. We believe that this is because the raw materials of the high-rated capacity furnace incur a too high carbon cost, resulting in large direct carbon emissions. Next, we calculate the excess carbon coefficient and the reasonable batching amount of the high-rated capacity furnace.

Based on the calculation, we conclude that the high-rated capacity furnace reduces the total carbon emission by 0.0736 t/t on average compared to the low-rated capacity furnace, proving that the use of the 12.5 MVA furnace can improve the smelting efficiency of industrial silicon and reduce the energy consumption and carbon emission of industrial silicon production. Taking a company that produces 700,000 tons of industrial silicon annually, as an example, the use of a 12.5 MVA furnace can reduce the annual carbon emissions by approximately 50,000 tons.

4 Conclusion

In this paper, the origins of carbon emission in industrial silicon production are studied. The results show that when using the 8.5 MVA furnace, soft coal has the greatest impact on the carbon emissions generated in the production of one ton of industrial silicon, followed by petroleum coke, and wood block has the least influence; when using the 12.5 MVA furnace, petroleum coke has the greatest impact on the carbon emissions generated by producing one ton of industrial silicon, followed by soft coal, and wood block has the least influence. The results show that when different furnace types produce a single ton of industrial silicon, the power consumption is roughly the same, approximately 12,384 ± 215 kWh/t, and the electrode material consumption is approximately 0.12 t/t. When the 8.5 MVA furnace is used to produce one ton of industrial silicon, approximately 4.6162 tons of direct carbon emissions and 14.0107 tons of total carbon emissions are generated. When a 12.5 MVA furnace is used to produce one ton of industrial silicon, approximately 5.1851 tons of direct carbon emissions and 13.93715 tons of total carbon emissions are generated. The high-rated capacity furnace reduces the total carbon emission by 0.0736 t/t on average compared to the low-rated capacity furnace, proving that the use of the 12.5 MVA furnace can improve the smelting efficiency of industrial silicon and reduce the energy consumption and carbon emission of industrial silicon production. Taking a company that produces 700,000 tons of industrial silicon annually, as an example, the use of a 12.5 MVA furnace can reduce the annual carbon emissions by approximately 50,000 tons.
emissions are generated. Based on the above analysis, the 12.5 MVA furnace reduces the carbon dioxide emissions of the production of one ton of silicon by approximately 74 kg compared to the 8.5 MVA furnace. Therefore, we propose that the 12.5 MVA submerged arc furnaces are more conducive to energy saving and carbon emission reduction. This research is highly significant for improving the industry’s market competitiveness, reducing the energy consumption of industrial silicon production, and achieving energy saving and emissions reduction.

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Authors’ Contributions Kaizhi Jiang: Conceptualization, Resources, Writing - review & editing, Visualization, Validation, Supervision. Zhengjie Chen: Formal analysis, Validation, Data curation, Writing - original draft, Writing-review & editing. Wenhui Ma: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation. Shijie Cao: Conceptualization, Resources, Visualization, Visualization, Supervision. Hongmei Zhang and Yaqian Zhu: Writing - review & editing.

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Declarations

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