13th IPI-CAU-ISSAS International Symposium

6-8 November 2019, Kunming, China

Physiological mechanisms of optimal potassium fertilization to enhancing leaf photosynthetic capacity of oilseed rape

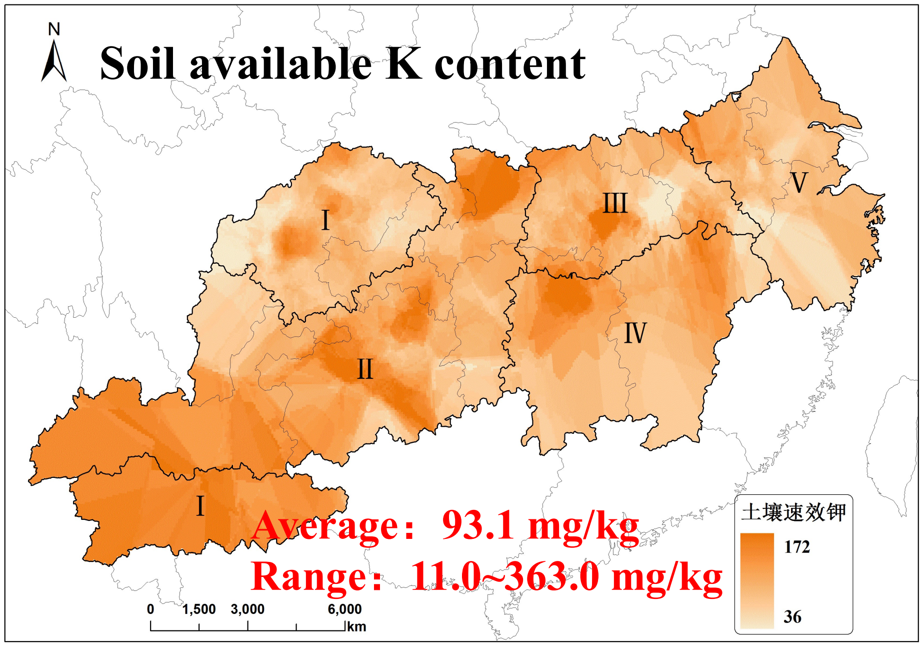
Tao Ren and Jianwei Lu

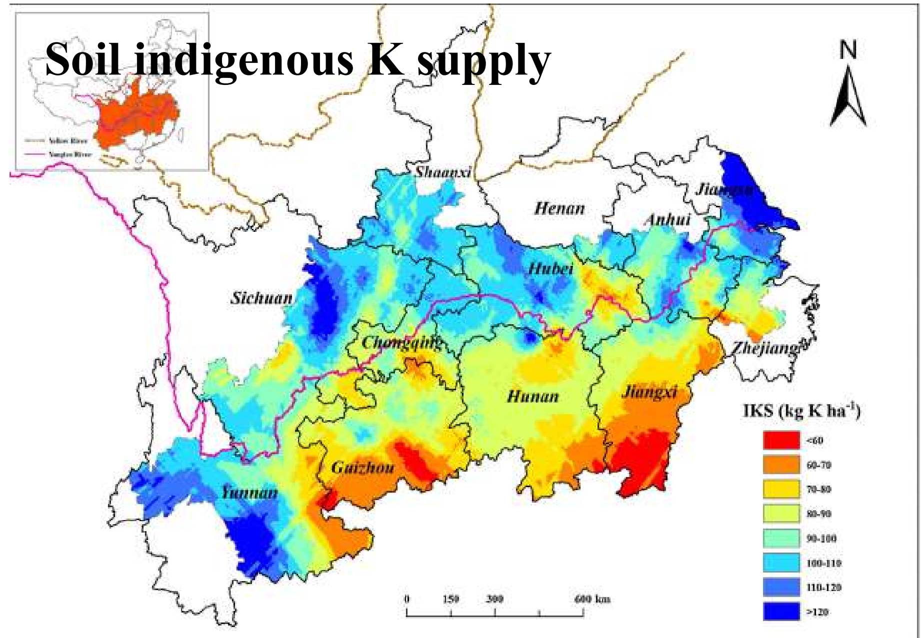
College of Resources and Environment, Huzhong Agricultural University

Outlines

1. Background
2. Potassium & Photosynthetic Area
3. Potassium & Photosynthetic Rate
4. Conclusions

Soil potassium status in China-typical winter oilseed rape production region





- The critical values of severe K deficiency and deficiency in winter oilseed rape cultivation soil were 60 and 135 mg/kg, respectively. At present, the percentage of soil available potassium in typical winter oilseed rape production region to below 60 mg/kg and 135 mg/kg soil was **24.6%** and **85.3%**, respectively.

(Ren *et al.*, 2013; Cong *et al.*, 2016)

Potassium deficiency limit crop growth

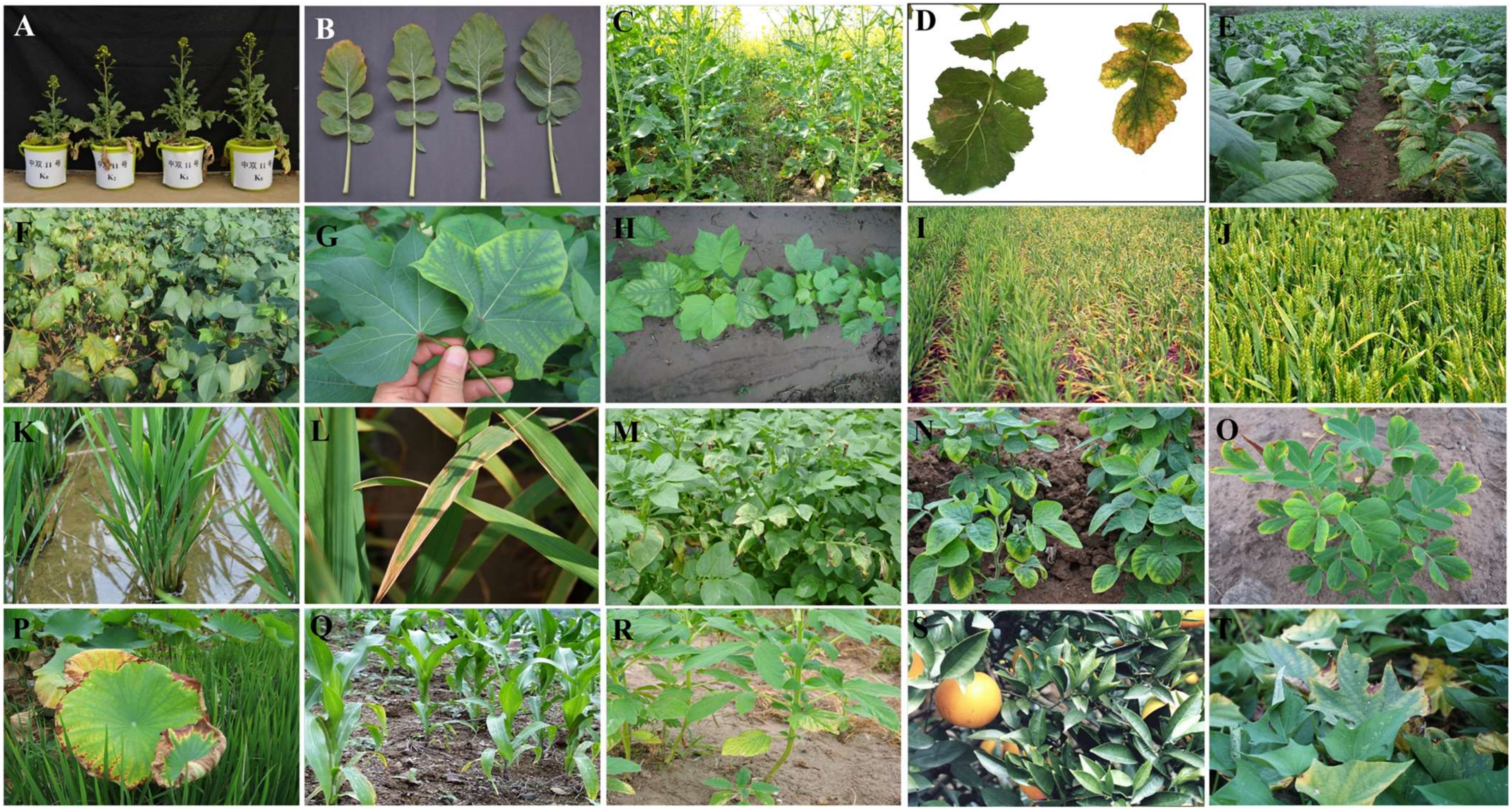
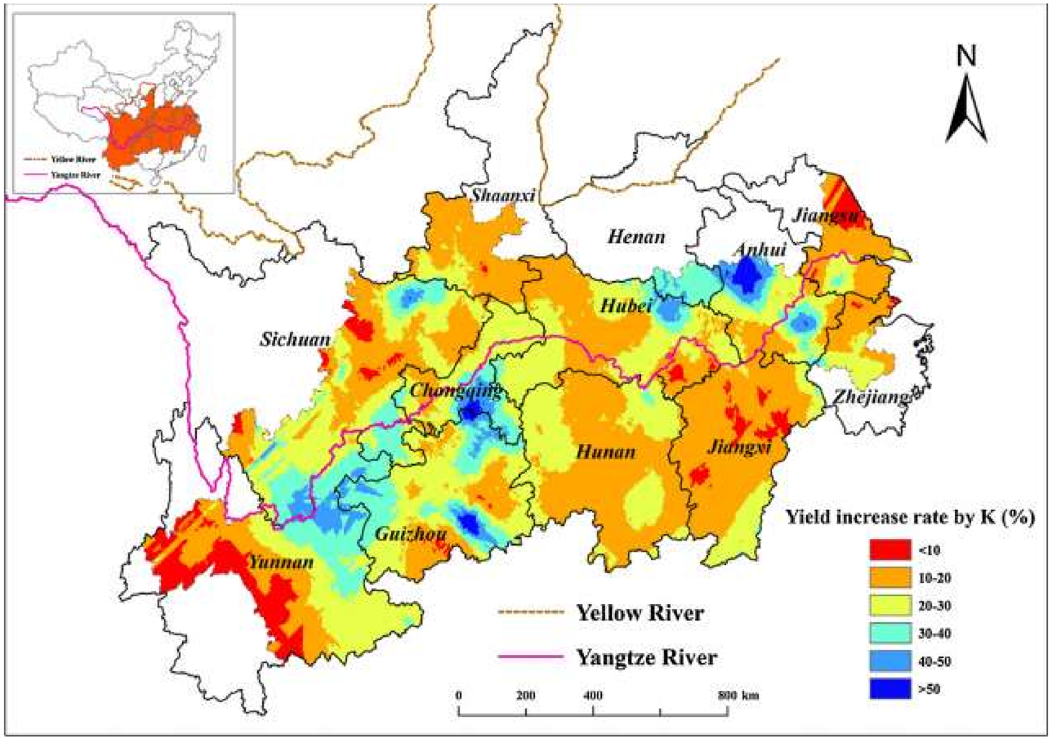
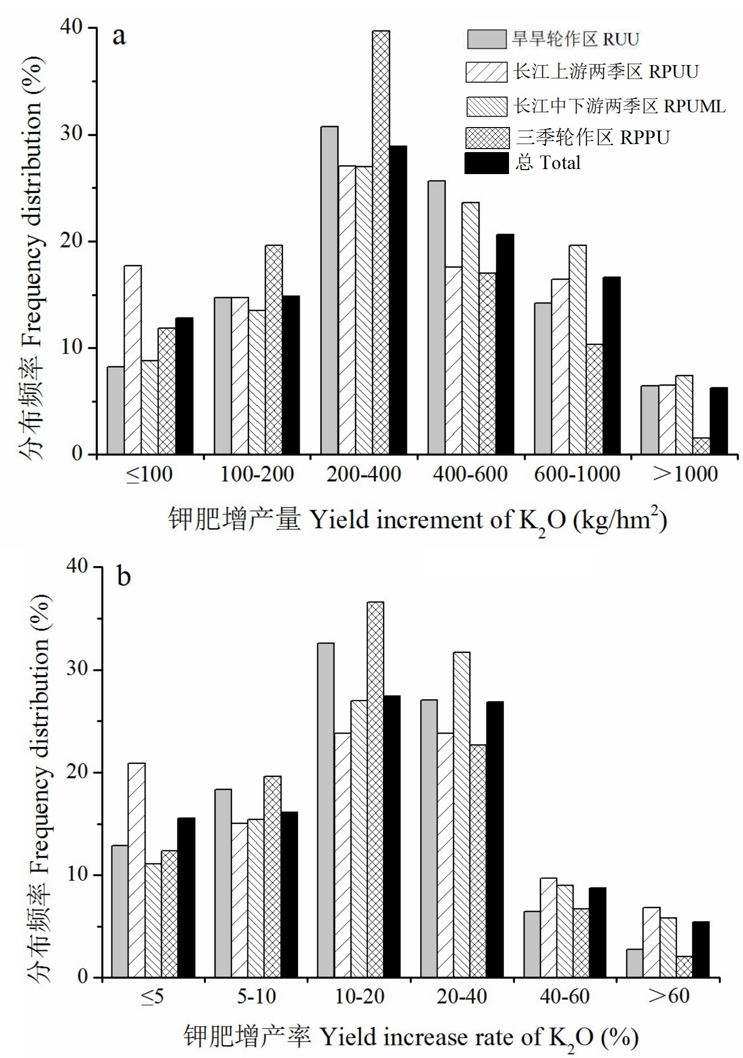


Photo by Jianwei Lu

Optimal potassium fertilization enhance crop yield

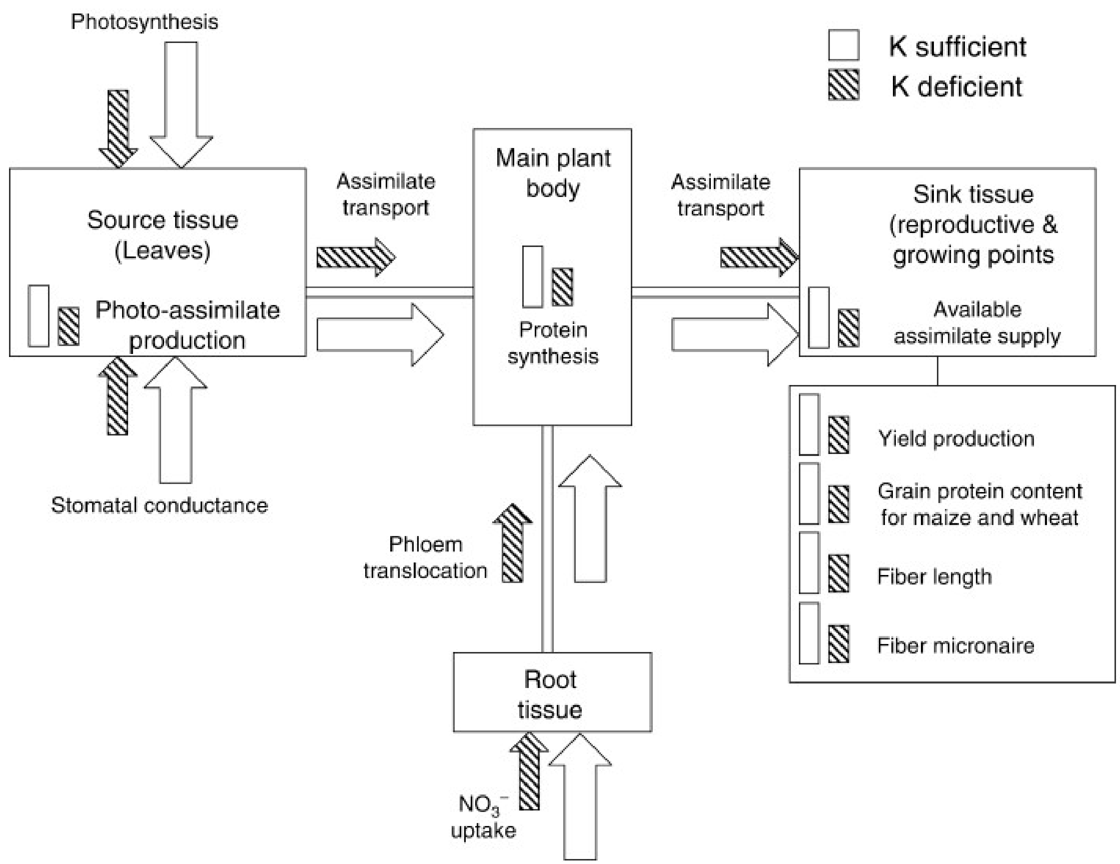




- **The average seed yield increase and yield increase rate of winter oilseed rape associated with optimal K fertilization were 408 kg/hm^2 and 21.6%, respectively, of which 54.2% of the experimental the seed yield increased rate distribution was in the range of 10-40%.**

(Li, 2015; Cong *et al.*, 2016)

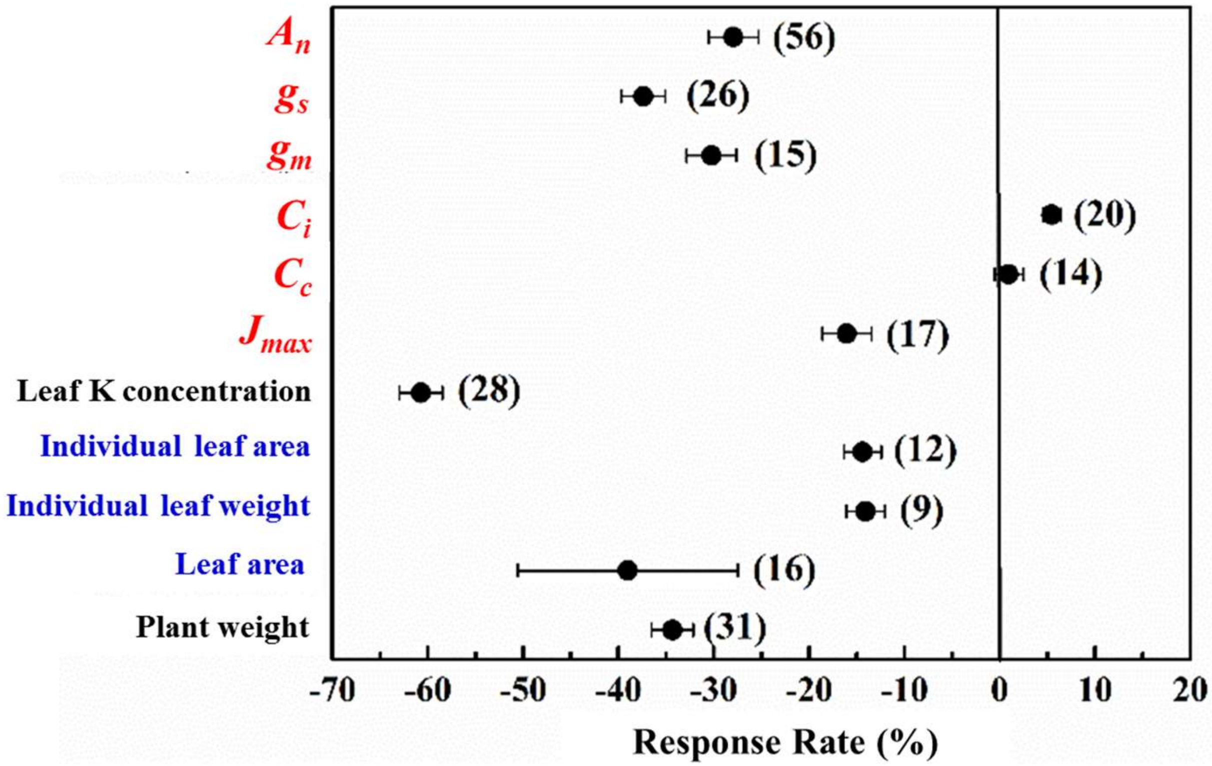
Mechanism of optimal potassium fertilization to enhance crop yield



➢ **Increasing photosynthetic rate** and **promoting assimilation product transfer** are important mechanisms for optimal K application to enhance crop yield.

(Pettigrew, 2008)

Potassium & plant photosynthesis based on meta-analysis



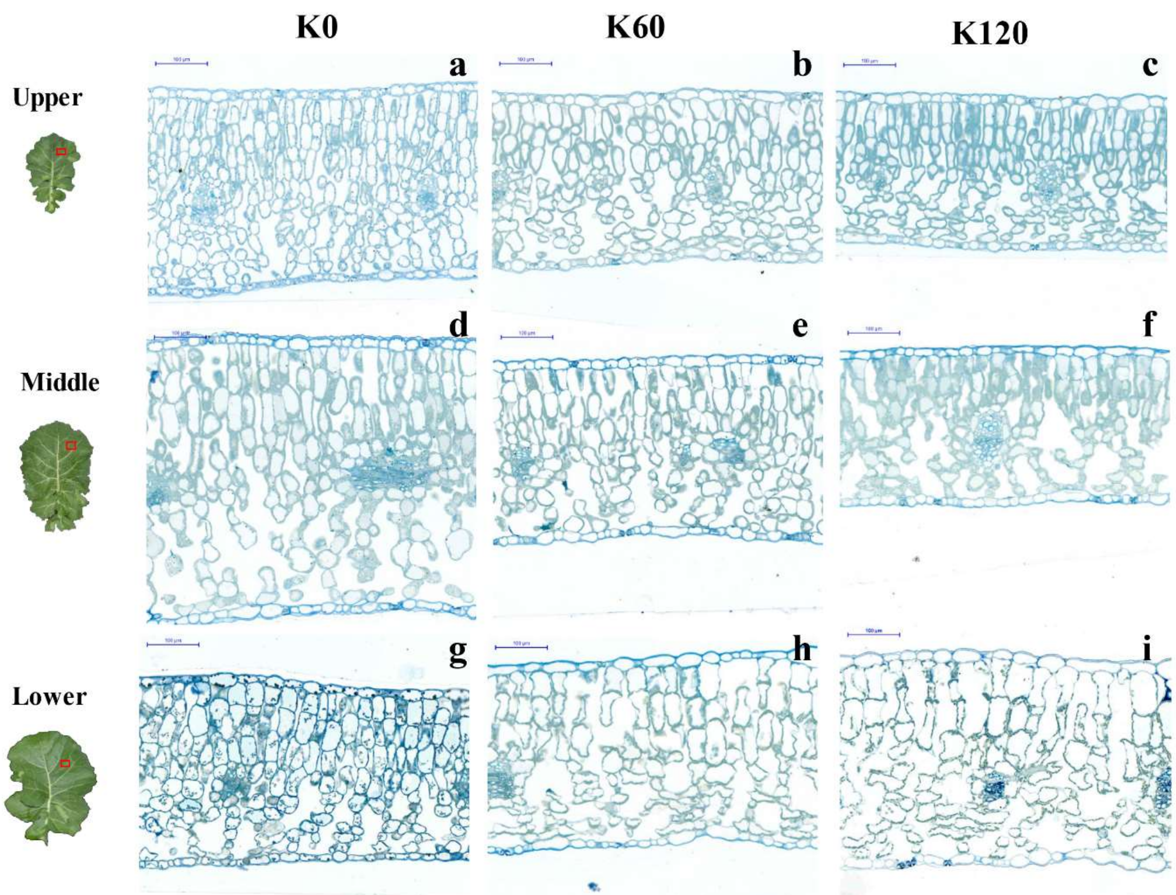
- The down-regulation of **photosynthetic area** and **photosynthetic C assimilation capacity** are two important reasons for low plant photosynthesis associated with potassium deficiency.

(Lu *et al.*, 2016)

The decrease in leaf area occurred earlier than that of A_n under K deficiency

LPI	Treatment	Individual leaf biomass(g)	Individual leaf area (cm^2)	A_n (μmol m^{-2} s^{-1})	*LMA* (g m^{-2})	K concentration (%)
7.1 (Upper leaf)	K0	0.28±0.00 b	**46.6±4.2 b**	**12.7±0.6 a**	61.4±4.5 a	**1.80±0.28 c**
	K60	0.32±0.04 b	**60.2±7.4 b**	**13.2±1.3 a**	53.6±2.3 ab	**2.87±0.23 b**
	K120	0.44±0.04 a	**92.9±12.7 a**	**13.2±1.1 a**	47.6±4.5 b	**3.47±0.29 a**
15.4 (Middle leaf)	K0	1.16±0.14 b	**199.8±16.8 b**	**10.4±0.8 b**	58.9±1.3 a	**0.67±0.04 c**
	K60	1.37±0.11 ab	**235.7±25.6 ab**	**16.2±1.6 a**	58.1±1.6 a	**1.30±0.20 b**
	K120	1.51±0.10 a	**280.1±22.2 a**	**16.5±1.0 a**	54.5±7.6 a	**1.99±0.16 a**
-2.4 (Lower leaf)	K0	0.52±0.02 c	**121.0±17.2 c**	**3.5±1.0 c**	43.8±4.7 a	**0.58±0.02 c**
	K60	0.87±0.03 b	**193.9±20.5 b**	**10.5±0.4 b**	45.1±4.4 a	**1.03±0.01 b**
	K120	1.40±0.09 a	**297.7±10.8 a**	**16.6±1.5 a**	47.0±3.7 a	**1.78±0.09a**

Leaf anatomical traits: mesophyll cells and chlorolplast



- **Mesophyll cells:** **The palisade and spongy tissue thickness/the spongy cell size was reduced**
- **Chloroplast:**

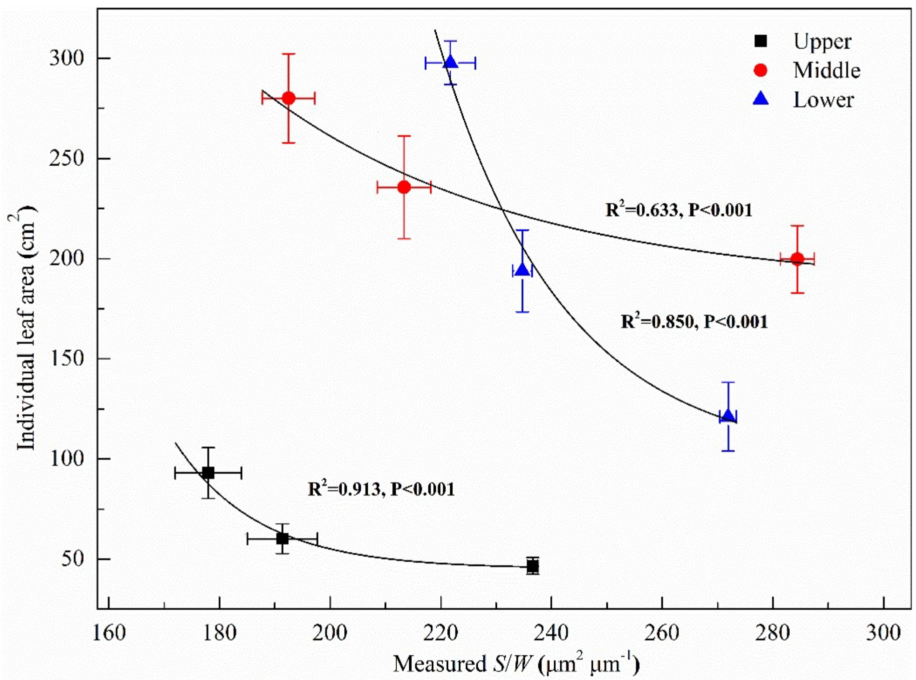
- **Mesophyll cells:** **The palisade and spongy cell size was reduced, however, mesophyll cell density was increased.**
- **Chloroplast: chloroplast density was lower under the K0 treatment**

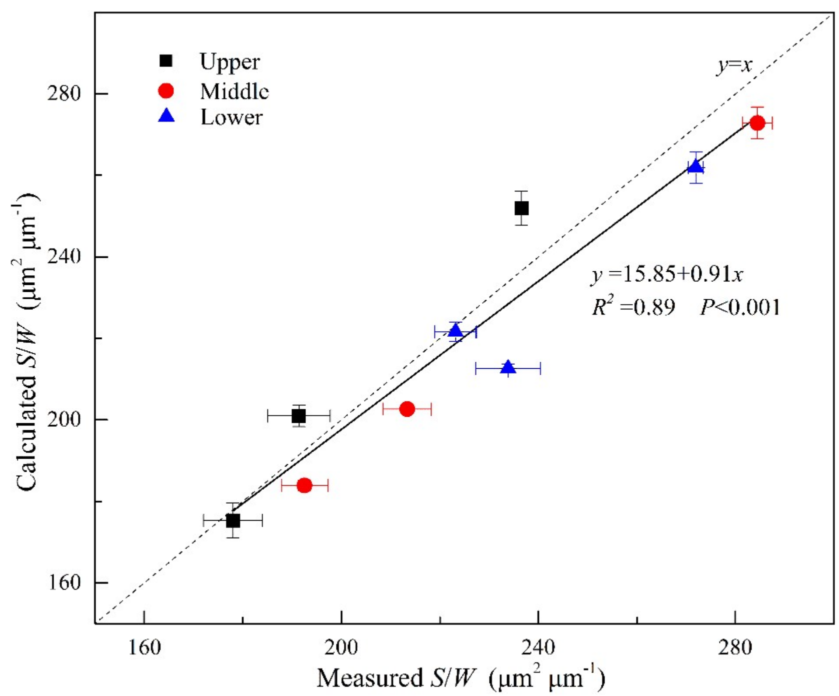
- **Mesophyll cells:** **the mesophyll cells were larger than those under the K0 treatment.**
- **Chloroplast: the chloroplast density and the S_c/S value was increased, while the $D_{chl\text{-}chl}$ was decreased.**

where S_c/S, chloroplast surface area exposed to intercellular airspace; $D_{chl\text{-}chl}$, the distance between the neighbour chloroplast.

The mesophyll cell area per transverse section width (S/W) could be used to explain the changes of leaf area

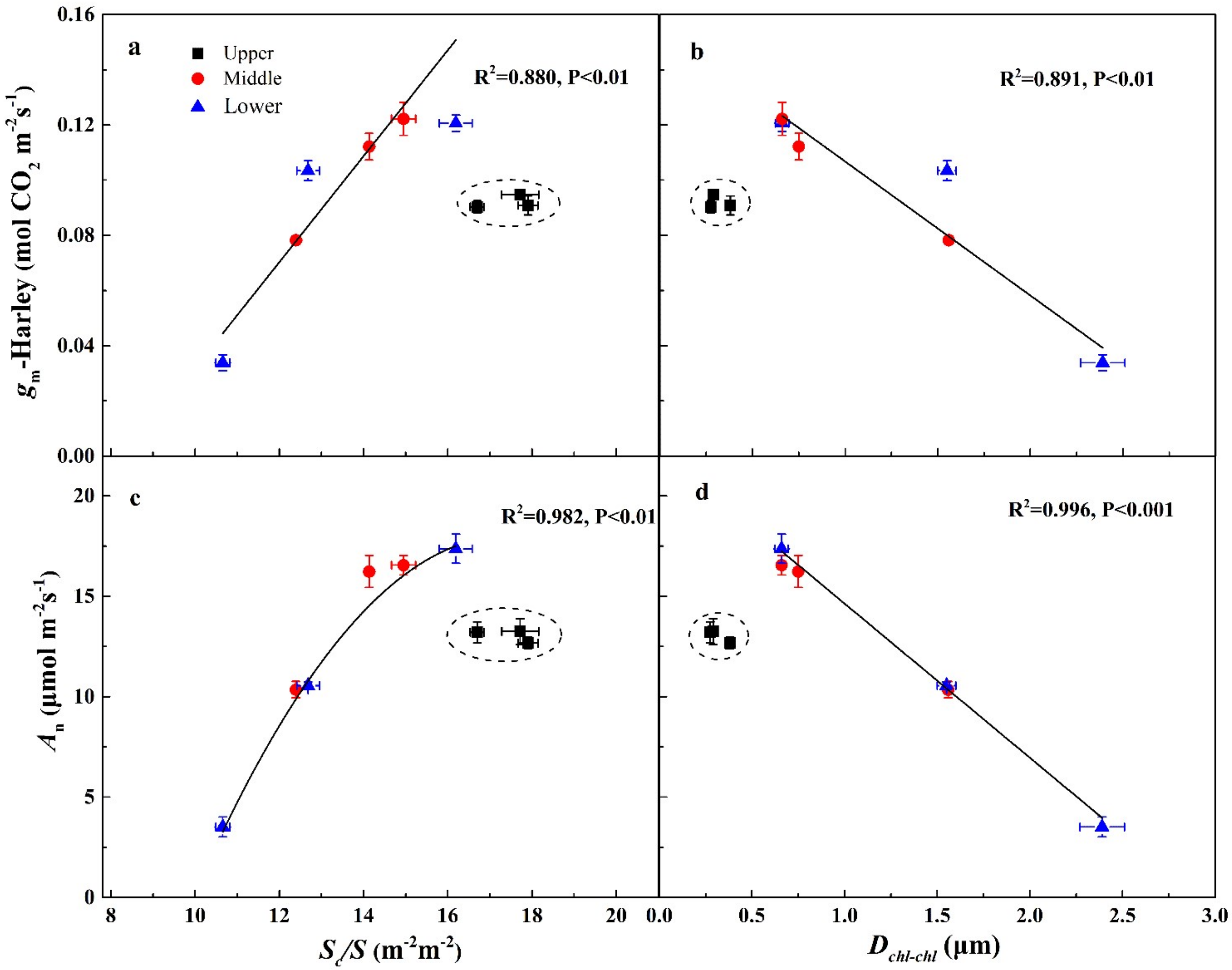
$$S/W = S_p \times D_p \times T_p + S_s \times D_s \times T_s$$



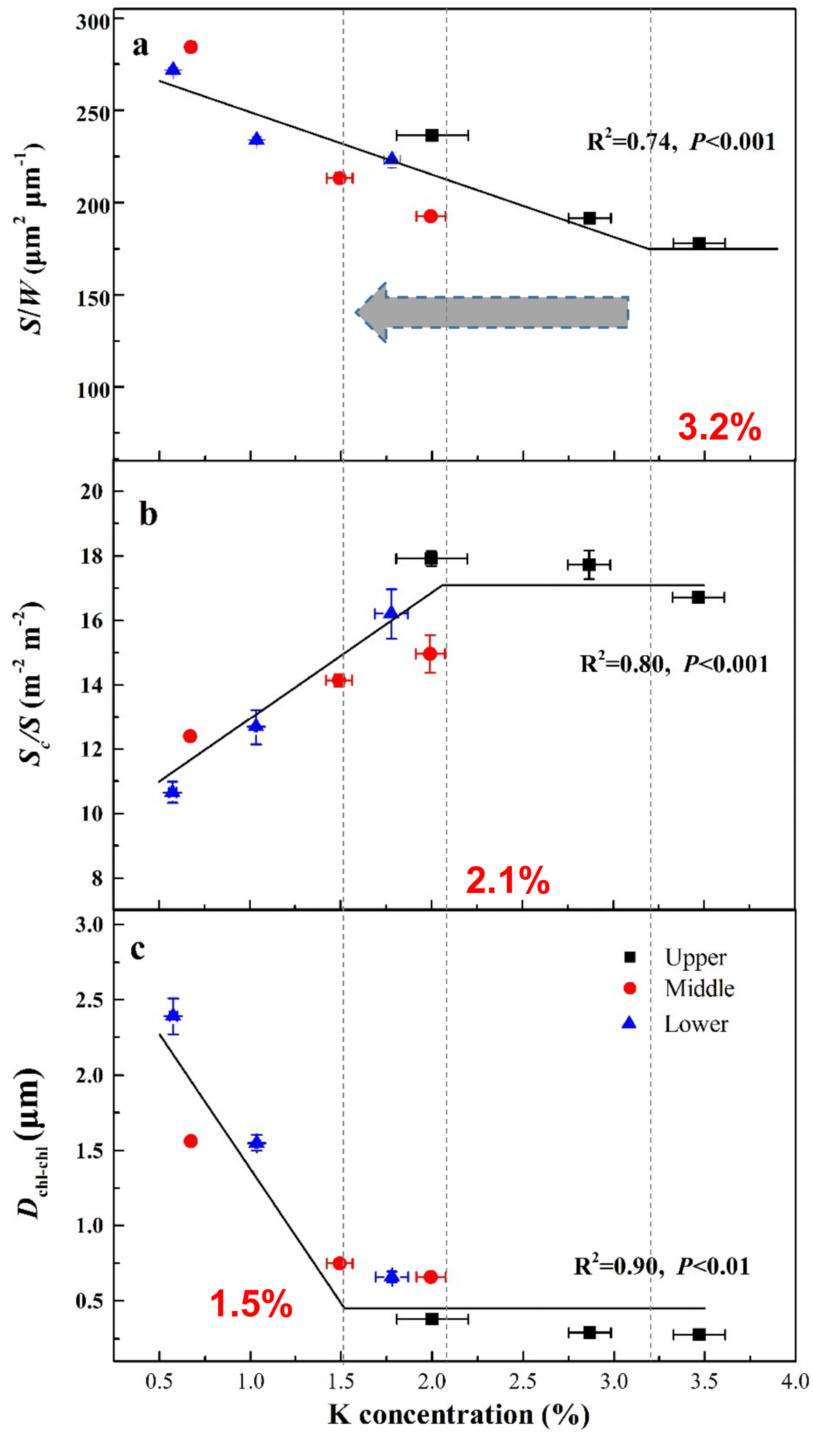


where S_p and S_s are the spongy and palisade tissue cell sizes, respectively; D_p and D_s are the cell density per unit area in transverse spongy and palisade tissues, respectively; and T_p and T_s are the thickness of spongy and palisade tissues, respectively.

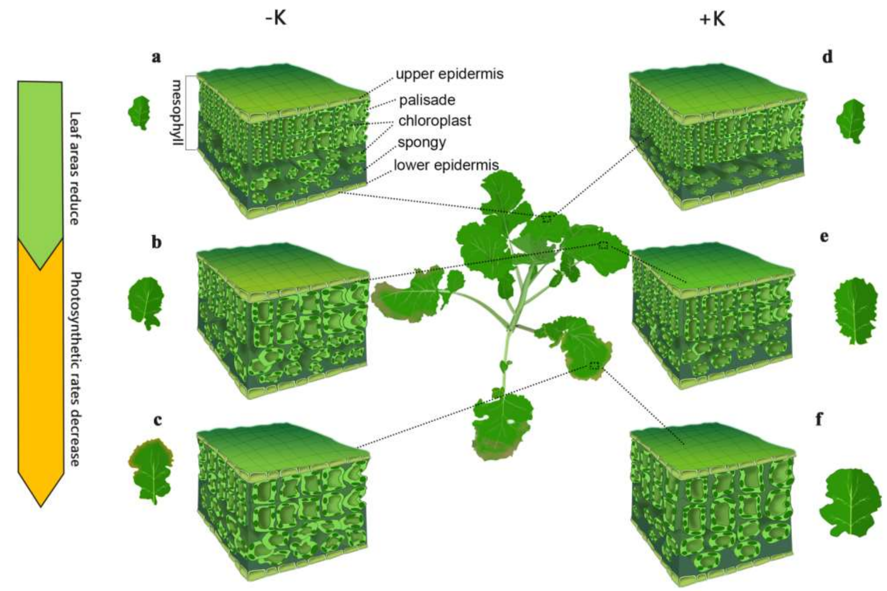
Key structural factors (S_c/S, $D_{chl\text{-}chl}$) influencing photosynthesis rate through regulating g_m



where S_c/S, chloroplast surface area exposed to intercellular airspace; $D_{chl\text{-}chl}$, the distance between the neighbour chloroplast.



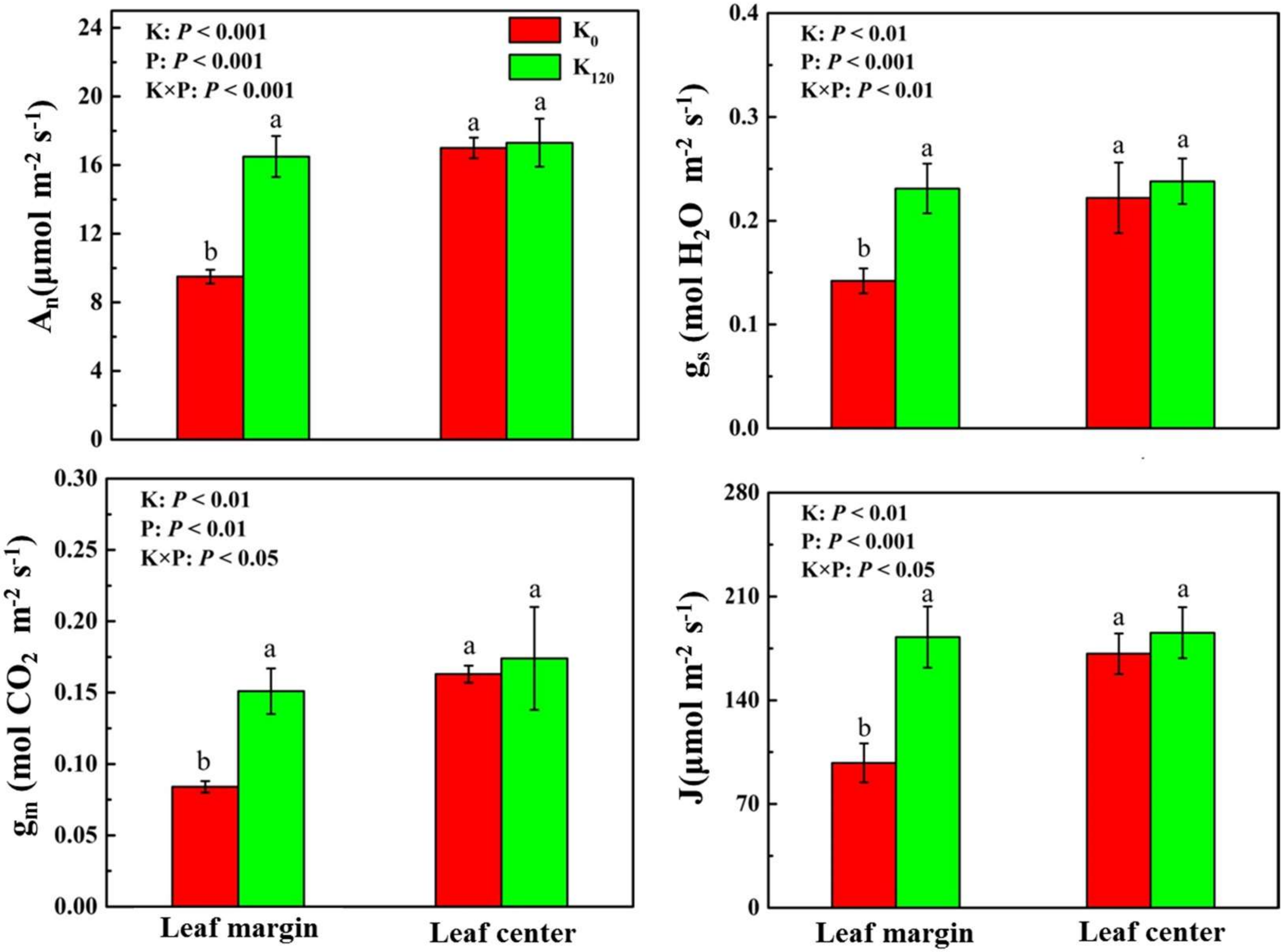
Regulation of key structural factors by leaf K concentration

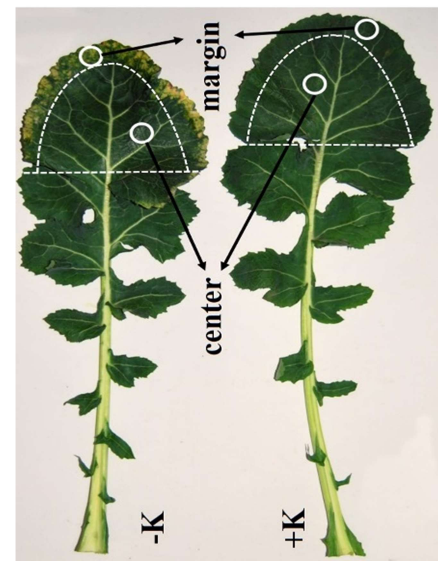


- These sequential changes in ***S/W***, ***S_c/S*** and ***$D_{chl-chl}$*** under K deficiency stress were responsible for the uncoordinated changes observed in leaf area and photosynthetic rate. **The reduction in leaf area precedes that in photosynthesis under K deficiency**

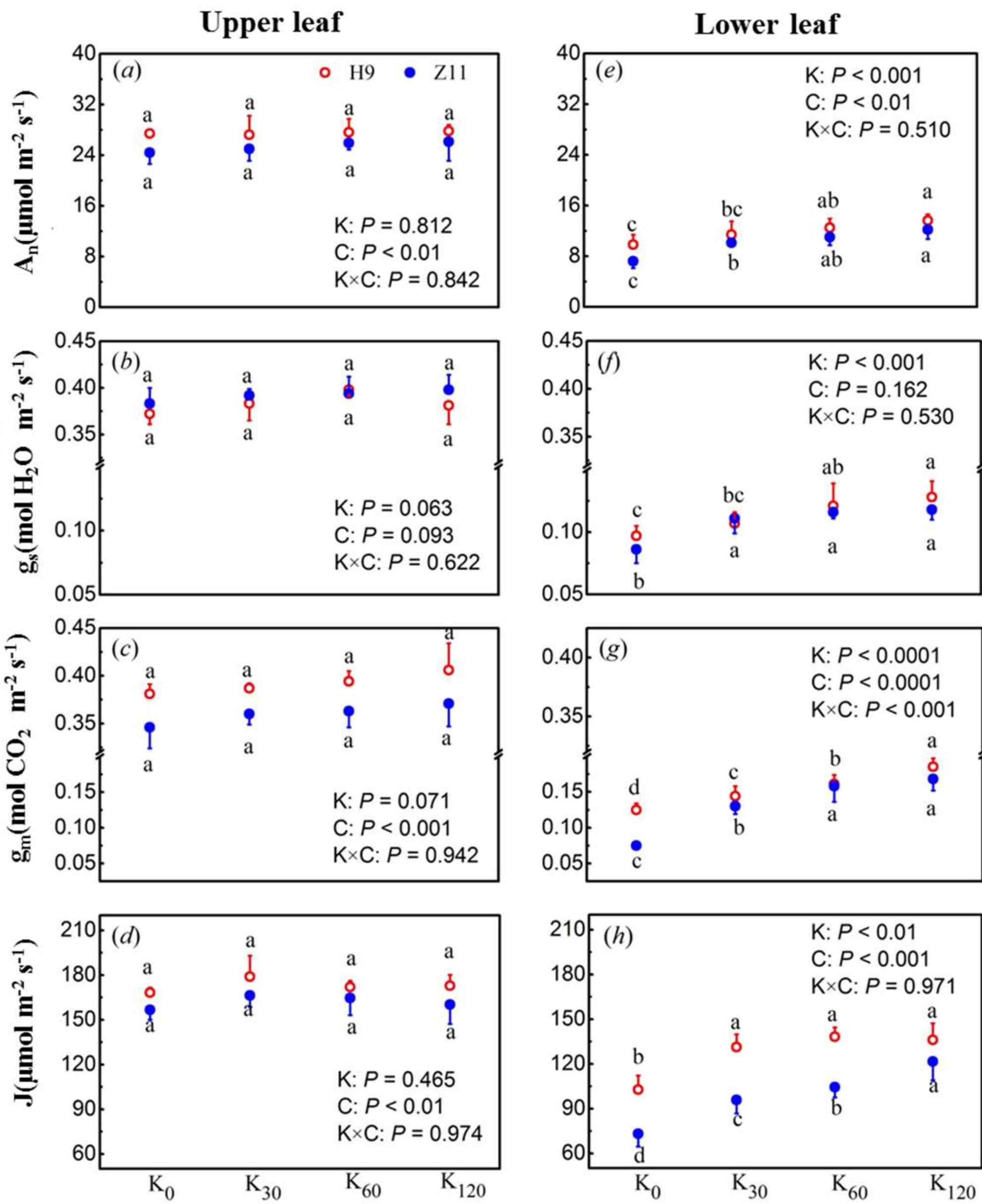
Leaf photosynetic rate

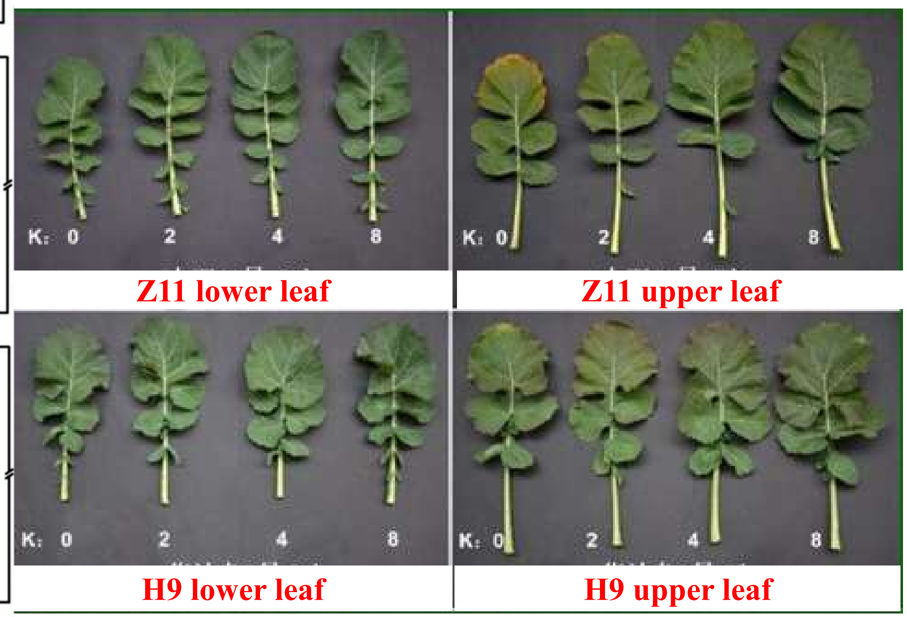
Individual leaf



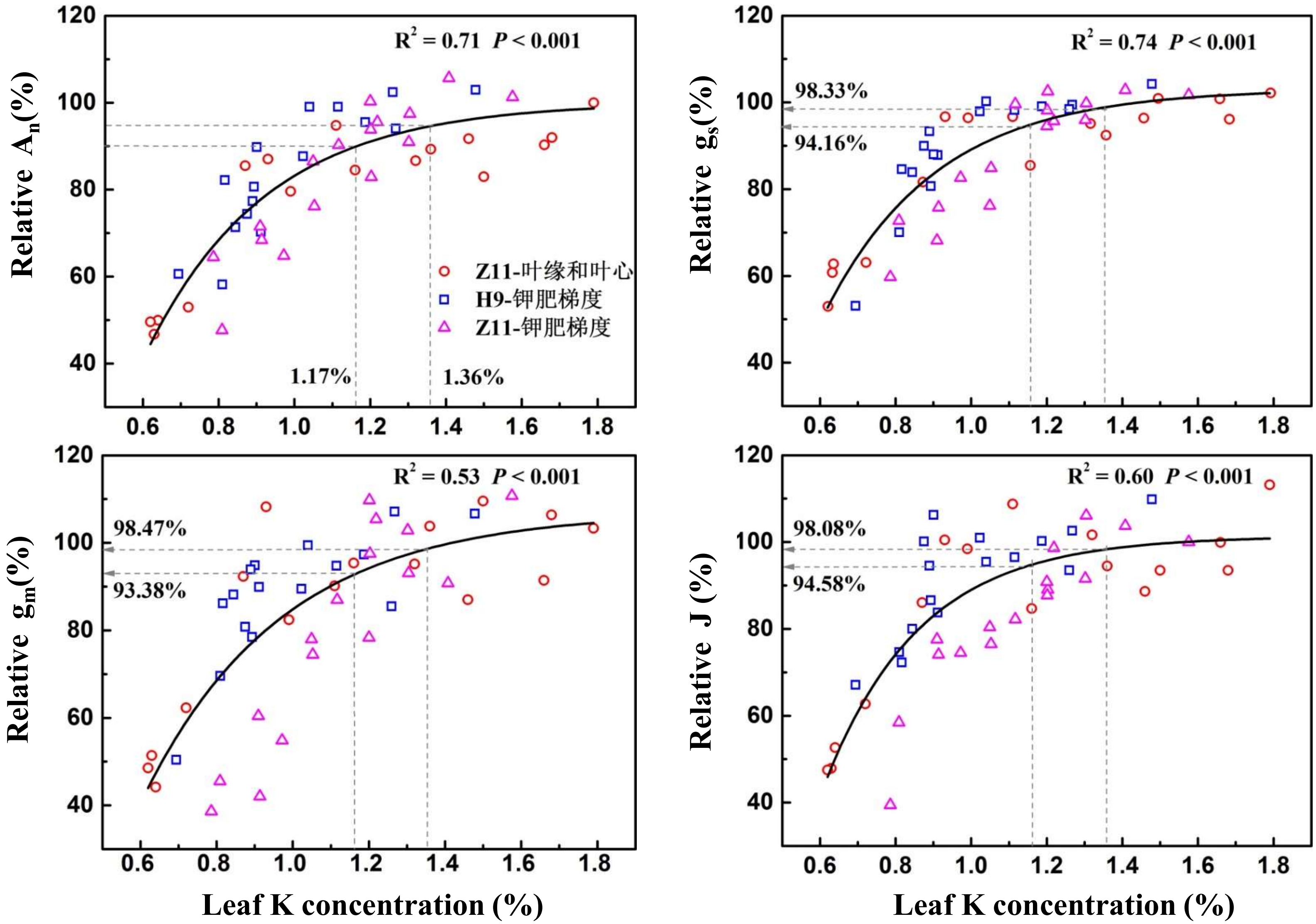


Variety & Leaf position

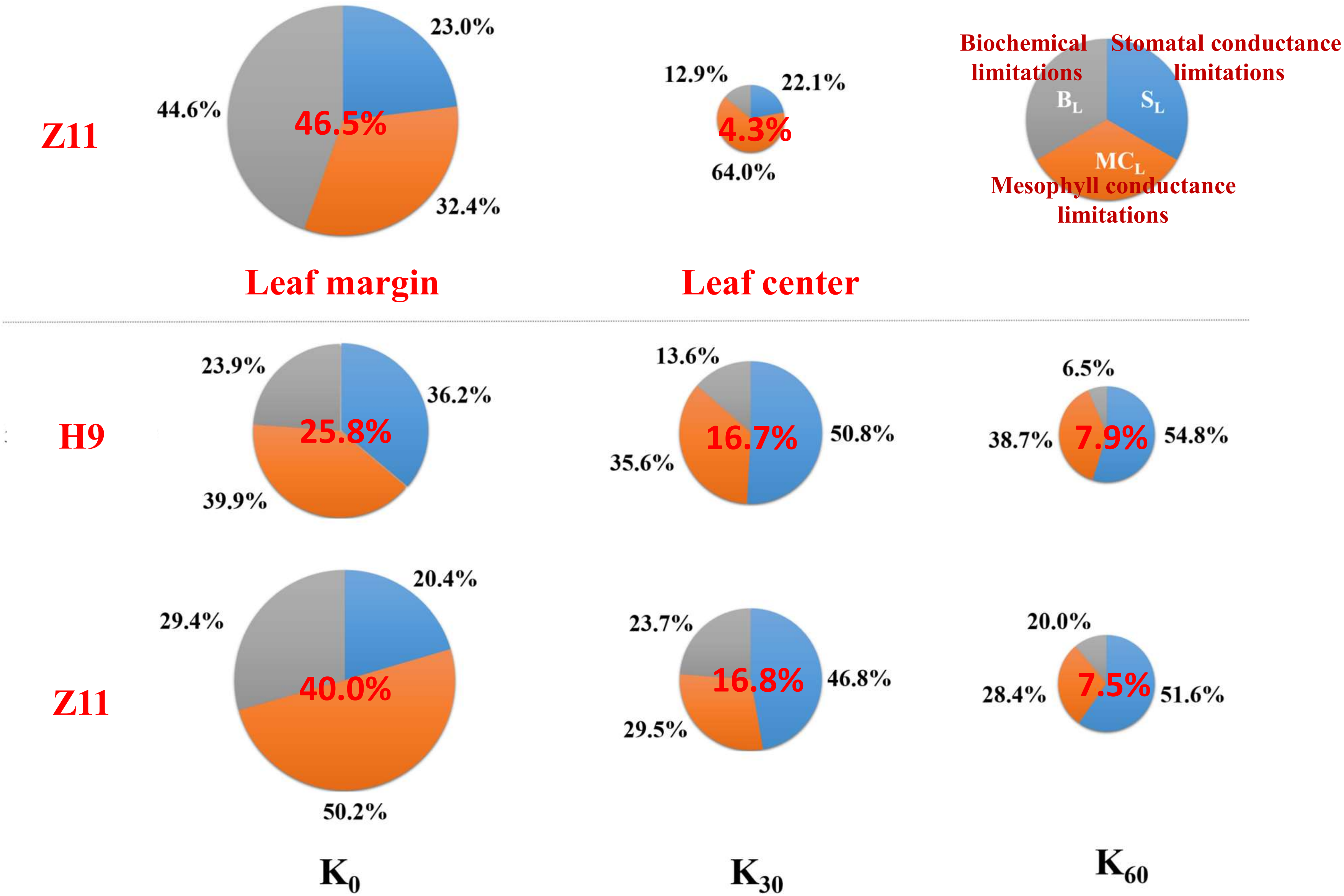




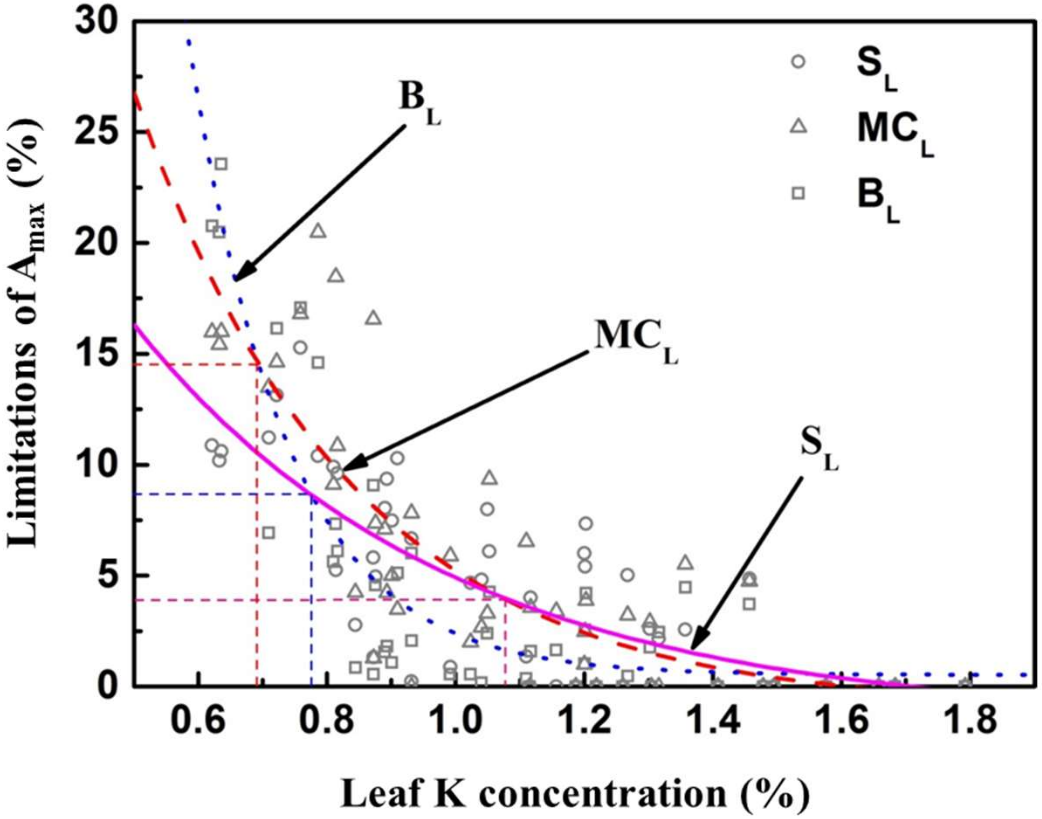
The relationship between leaf K concentration and critical leaf photosynthetic parameters



Leaf photosynthesis limiations under different K deficiency stress



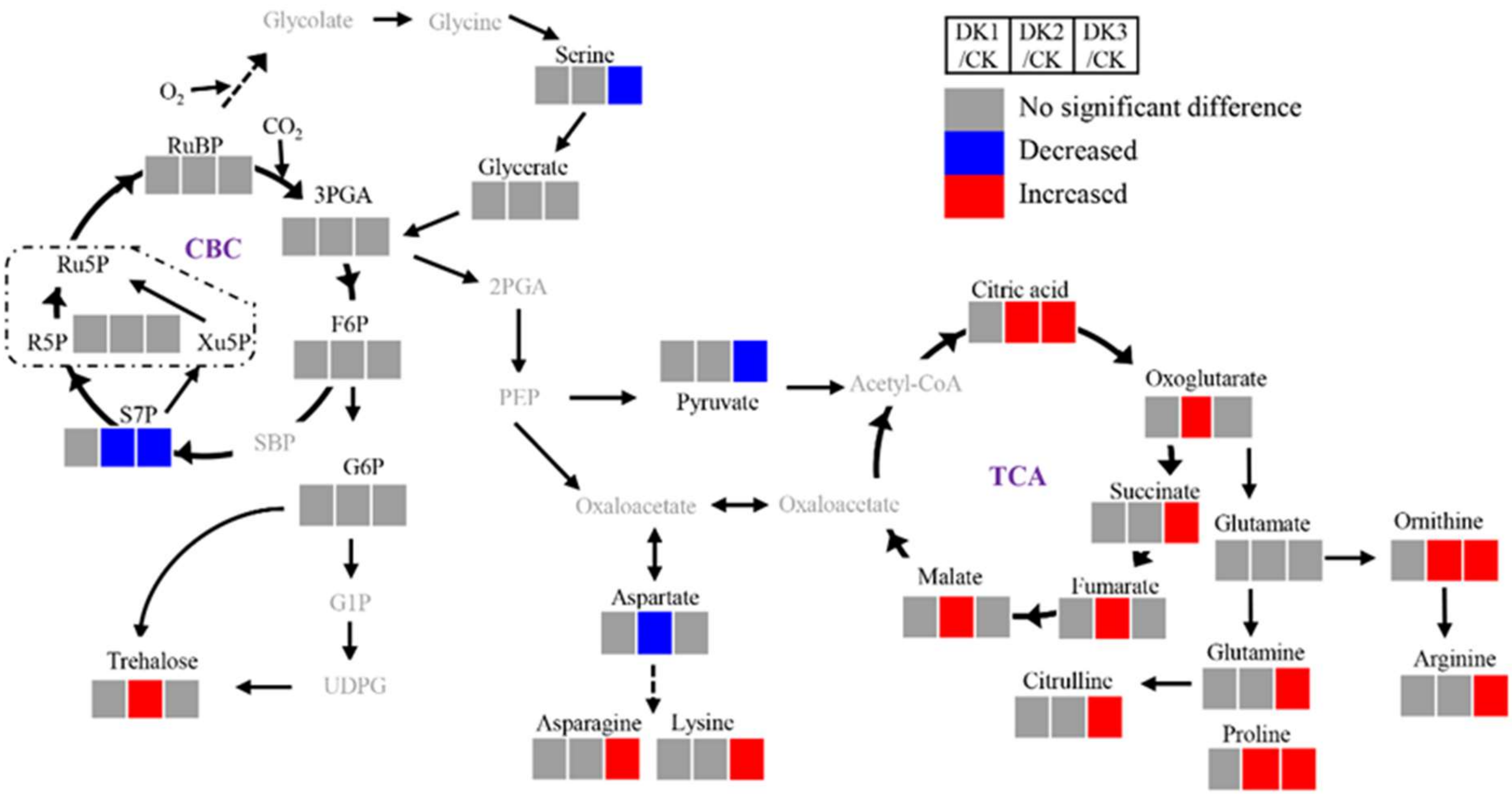
The relationship between leaf K concentration and leaf photosynthesis limitations



Leaf K concentration (%)	Limitations of A_n
1.07<K<1.17-1.36	B_L<MC_L<S_L
0.78<K<1.07	B_L<S_L<MC_L
0.69<K<0.78	S_L<B_L<MC_L
K<0.69	S_L<MC_L<B_L

- **Photosynthetic limitation declined precipitously with increasing leaf K concentration. Among these limitations, B_L dropped the most, followed by M_{CL}, and S_L dropped the least. According to the intersection points of the fitted curves, it is easy to identify the predominant constraint shifting among the three components.**

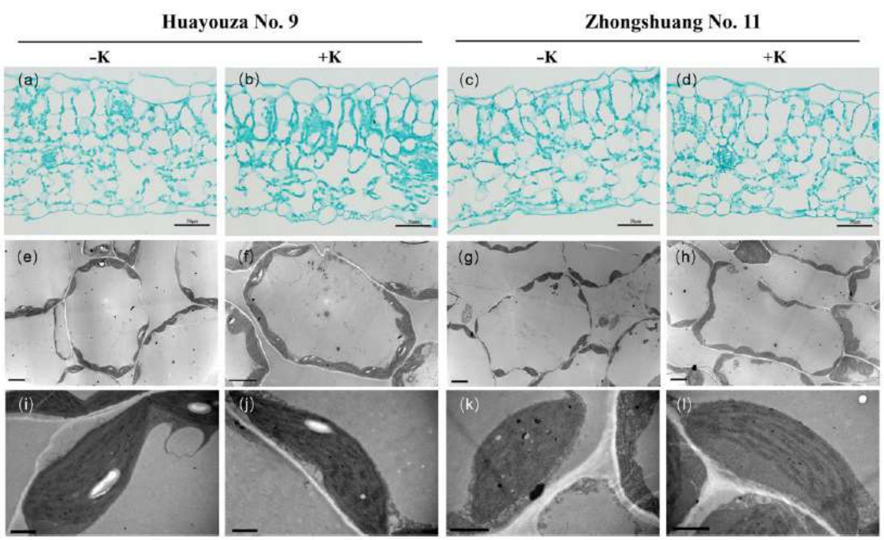
Shift of central carbon metabolism under different photosynthetic limitations affected by potassium deficiency stress



- There were no major changes in metabolites under stomatal limitation; the organic acid was strongly up-regulated under mesophyll conductance limitation; under biochemical limitation, the increased citric acid mainly flows to the metabolic pathway of synthetic amino acids.

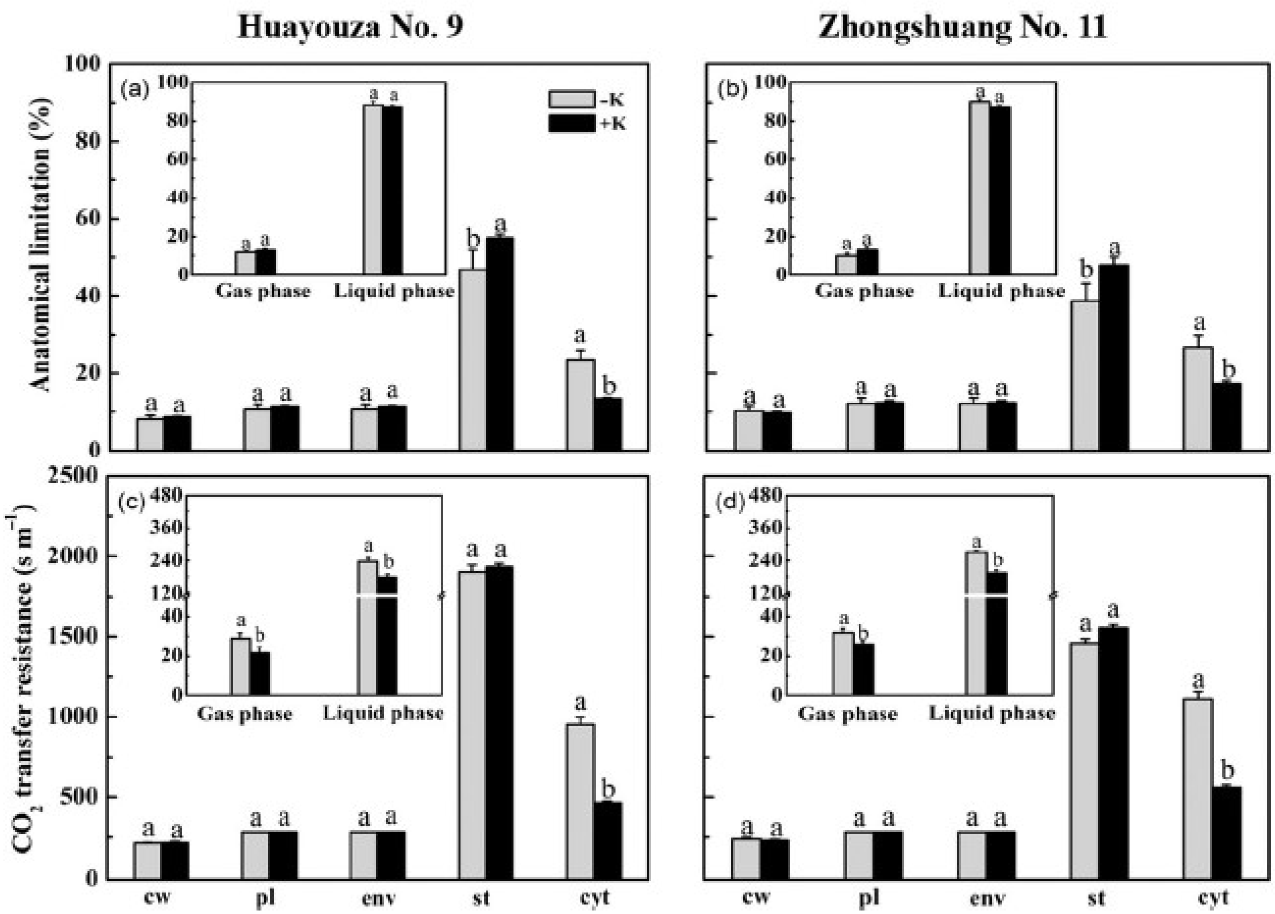
Leaf anatomical variation could be used to explain the changes of mesophyll conductance under moderate potassium deficiency stress

Cultivar	Treatment	f_{ias} (%)	T_{mes} (μm)	S_{mes}/S (m^{-2} m^{-2})	S_c/S (m^{-2} m^{-2})	T_{cw} (μm)	$L_{cyt,1}$ (μm)	$L_{cyt,2}$ (μm)	$D_{chl\text{-}chl}$ (μm)	L_{chl} (μm)	T_{chl} (μm)
H9	-K	25.9b	144a	15.9b	10.0b	0.116a	0.383a	1.43a	1.37a	5.97b	1.75a
	+K	35.4a	147a	17.9a	13.0a	0.117a	0.193b	1.21b	1.03b	6.70a	1.78a
Z11	-K	24.9b	152a	12.7b*	7.3b*	0.129a*	0.391a	1.49a	1.94a*	4.03b*	1.38a*
	+K	29.6a*	148a	14.9a*	10.6a*	0.121a	0.233b*	1.37b*	1.15b	5.48a*	1.44a*



f_{ias}, the volume fraction of intercellular air space; **T_{mes}**, mesophyll thickness; **S_{mes}/S**, mesophyll surface area exposed to intercellular airspace per unit leaf area; **S_c/S**, chloroplast surface area exposed to intercellular air space per leaf area; **T_{cw}**, cell wall thickness; **$L_{cyt,1}$**, the distance of chloroplast from cell wall; **$L_{cyt,2}$**, the diffusion pathway length in interchloroplastial areas; **$D_{chl–chl}$**, the distance between adjacent chloroplasts; **L_{chl}**, chloroplast length; **T_{chl}**, chloroplast thickness;

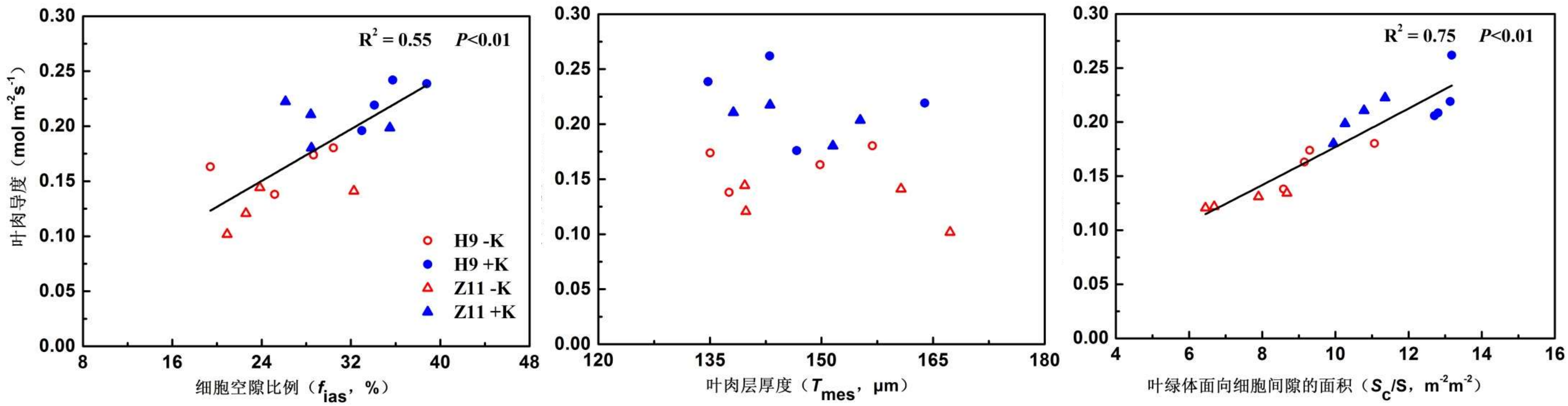
Partial limitation of g_m based on one-dimensional gas diffusion model

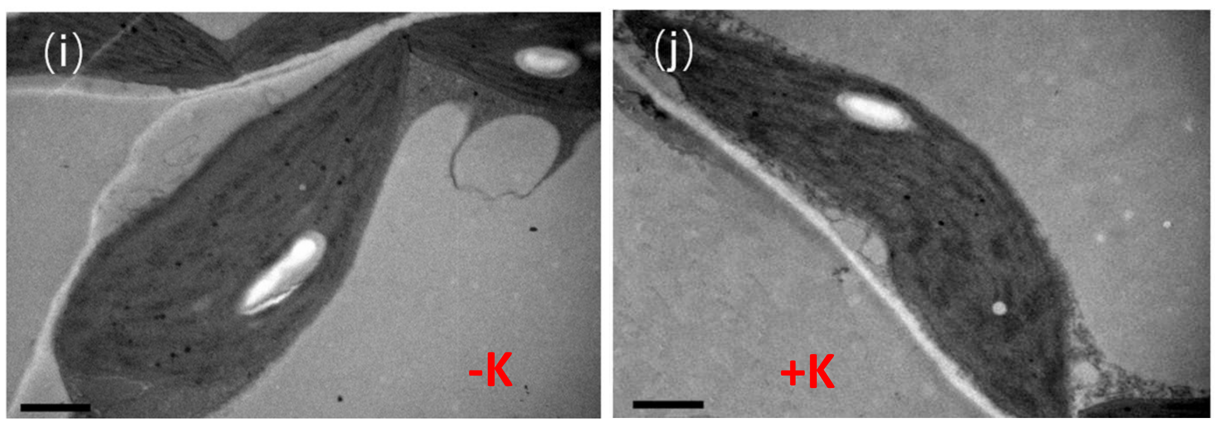


- CO_2 transfer resistance during liquid phase contributed more than 90% of mesophyll resistance. While for the liquid resistance, sufficient K treatment could reduce the CO_2 transfer resistance through cytoplasm.

cw, cell wall; **pl**, plasmamembrane; **env**, chloroplast envelope; **st**, stroma; cyt, cytoplasm.

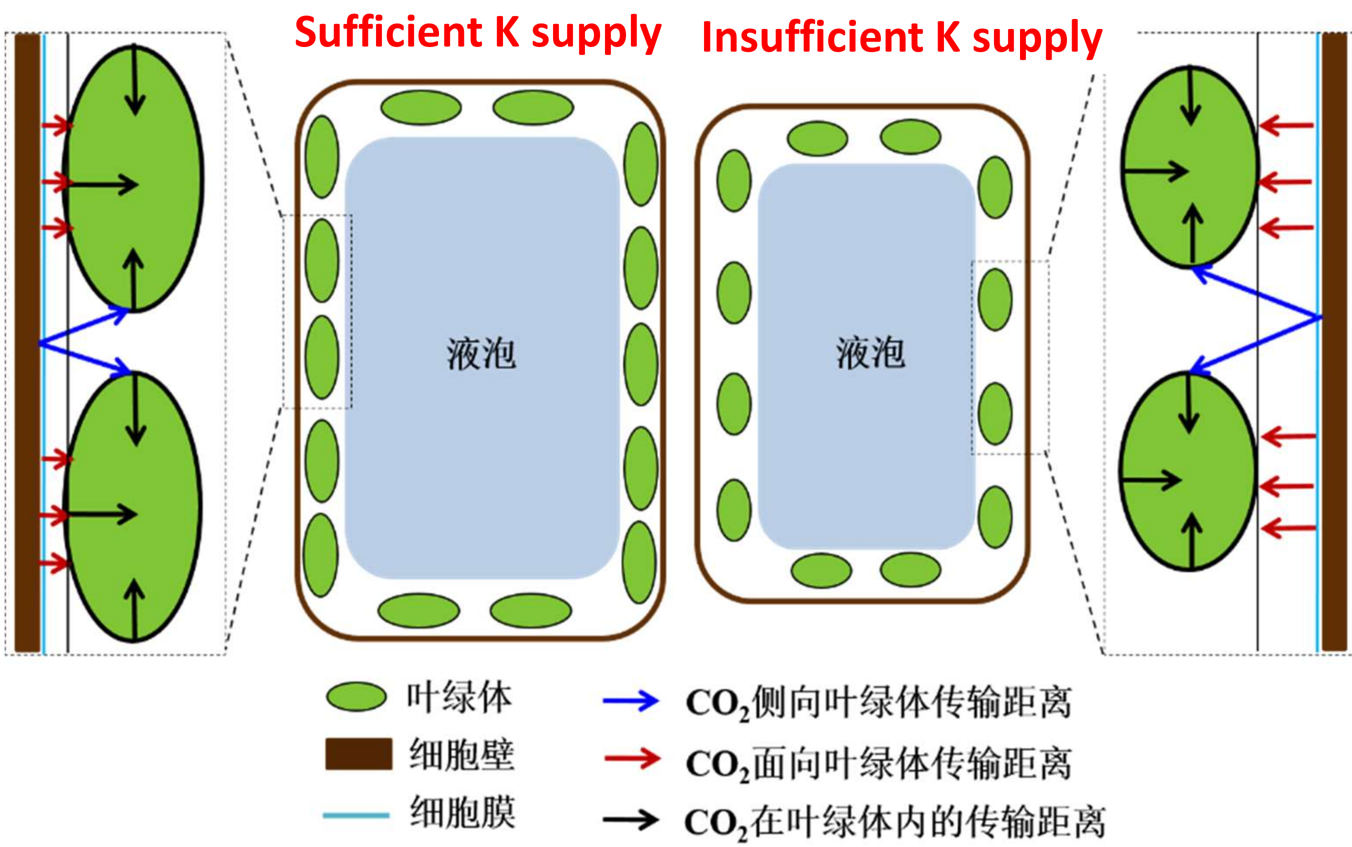
Correlation between leaf anatomical parameters and g_m





- Potassium-induced variation of mesophyll conductance (g_m) is associated with leaf anatomical traits, notably internal air space (f_{ias}), exposed surface area of chloroplasts per unit leaf area (S_c/S) and the pathway length in cytoplasm.

Pattern diagram of potassium affecting leaf mesophyll conductance



- The improvement of g_m under K supplementation is primarily due to enhanced S_c/S and CO_2 diffusion conductance through the cytoplasm.

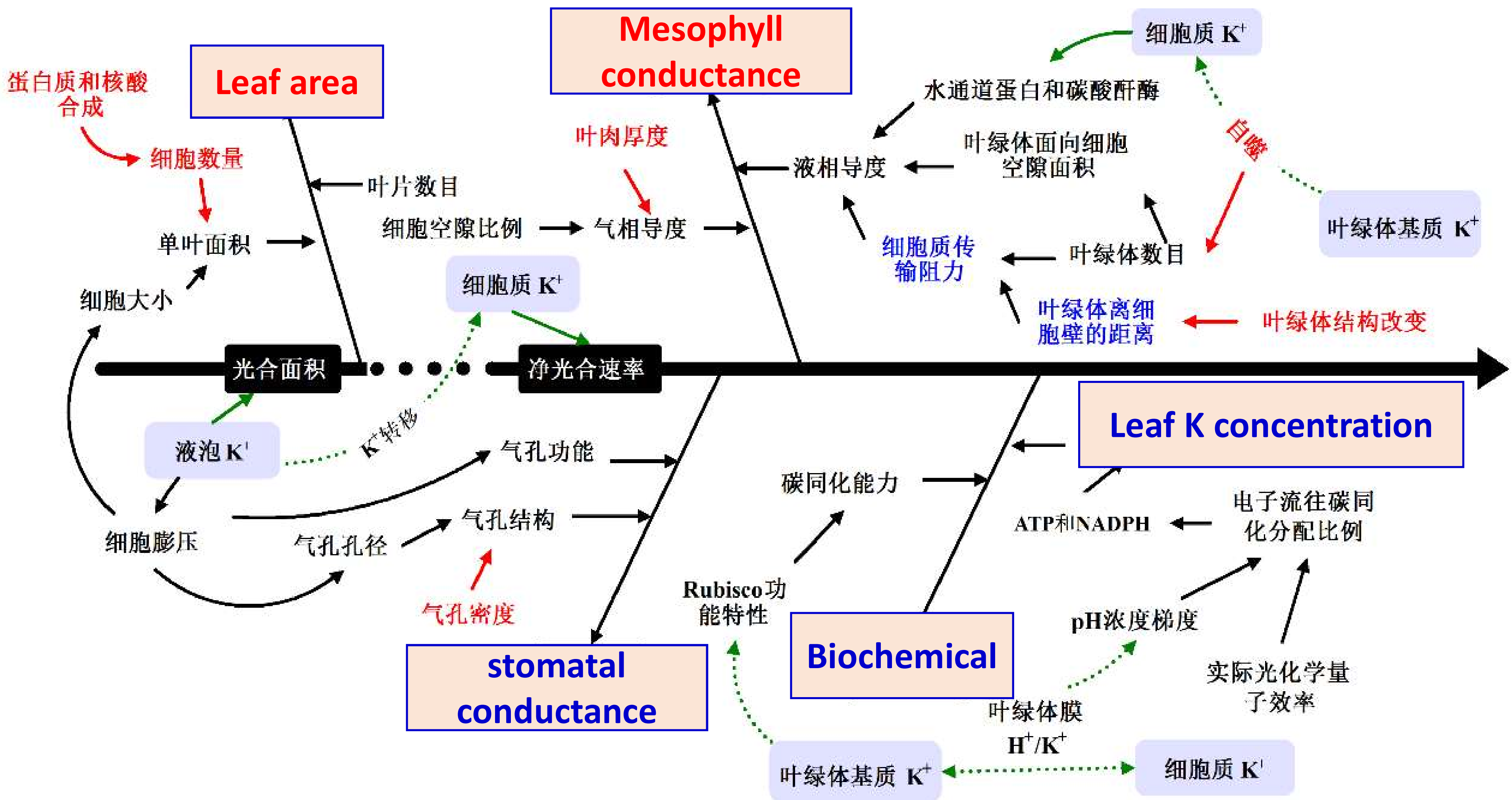
Conclusions

- Leaf potassium concentration is an important factor influencing photosynthetic capacity. In the early stage of potassium deficiency stress, the decrease of leaf photosynthetic area precedes the decrease of photosynthetic capacity, which is mainly due to the changes of mesophyll cell morphology (S/W) determining the leaf area earlier than those affecting photosynthetic capacity.

- The combination of stomatal conductance, mesophyll conductance and biochemical limitation led to a decrease in photosynthesis rate under potassium deficiency stress. The limitations would be increased with the decrease of leaf potassium concentration.

- Under moderate potassium deficiency stress ($0.7\%<K<1.1\%$), mesophyll conductance limitation is the major limiting factor of photosynthesis rate, owing to decline the chloroplast surface area exposed to intercellular airspace, increase the CO_2 diffusion pathway in the cytoplasm and improve the CO_2 transport resistance in the mesophyll layer.

Prospective



Thank you!