

## Supplementary material

### **Title: Rhizosphere core microbes are associated with efficient potassium utilization in field-grown wheat**

Running title: Core microbes promote potassium utilization

Fengye Pan<sup>1,2,#</sup>, Wenchong Shi<sup>1,2,#</sup>, Yu Wang<sup>1,2</sup>, Yingdi Zhu<sup>1,2</sup>, Chenxi Kou<sup>1,2</sup>, Jiaqi Liang<sup>1,2</sup>, Xiaocun Zhang<sup>3</sup>, Xiaoliang Wu<sup>4</sup>, Mingcong Li<sup>1,2</sup>, Bo Zhou<sup>1,2,3</sup>, Fanmei Kong<sup>3,\*</sup>, Zheng Gao<sup>1,2,3,\*</sup>.

<sup>1</sup>National Key Laboratory of Wheat Improvement, Shandong Agricultural University, Tai'an, Shandong 271018, People's Republic of China.

<sup>2</sup>College of Life Sciences, Shandong Agricultural University, Tai'an, Shandong 271018, People's Republic of China.

<sup>3</sup>National Engineering Research Center for Efficient Utilization of Soil Fertilizer, College of Resources and Environment, Shandong Agricultural University, Tai'an, Shandong 271018, People's Republic of China.

<sup>4</sup>Taishan University, Tai'an, Shandong, 271000, People's Republic of China.

# These two authors contributed equally to this paper.

\* Corresponding author:

E-mail: gaozheng@sdau.edu.cn (Z. Gao); Tel: +086-538-15605386271

E-mail: fmkong@sdau.edu.cn (F. Kong); Tel: +086-538-13505385402

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**Table S1** Information on wheat varieties for 24 test materials

	Varieties
1	LH17010
2	LS4697
3	Changyue 5
4	Dexuan 1
5	Wennong 6
6	JM899
7	LS6045
8	Yumai 49
9	Shi 4185
10	Lan 58
11	Jimai 22
12	SN8355
13	Xinong 85
14	Yannong 22
15	Luohan 21
16	Shixin 616
17	SN483
18	Weimai 7
19	Taishan 21
20	Xiaoyan 92
21	Zhongnongda 127
22	Yumai 54
23	SN23
24	China Spring

**Table S2** The physical and chemical properties of the soils

Properties	
Soil type	Cinnamon soil
Soil color	Brown
pH	7.89
Total nitrogen	1.28 g/kg
Total Phosphorus	5.15 g/kg
Total potassium	11.06 g/kg
Hydrolyzable Nitrogen	102 mg/kg
Available Phosphorus	75.76 mg/kg
Available Potassium	93.08 mg/kg
Organic Matter	26.48 g/kg

**Table S3** Bacterial, Fungal, and Archaeal sequencing primer Information

Primer fragments	Primer names	Primer sequence	
Bacteria	799F	Front-end primer sequences	AACMGGATTAGATACCKG
V5V7-1	1193R	Back-end primer sequence	ACGTCATCCCCACCTTCC
Fungal	gITS7	Front-end primer sequences	GTGARTCATCGARTCTTTG
ITS2-2	ITS4-R	Back-end primer sequence	TCCTCCGCTTATTGATATGC
Archaea	Arch340F	Front-end primer sequences	CCCTAYGGGGYGCASCAG
V4-4	Arch1000F	Back-end primer sequence	GGCCATGCACYWCYTCTC
	Uni519F	Front-end primer sequences	CAGYMGCCRCGGKAAHACC
	Arch806R	Back-end primer sequence	GGACTACNSGGTMTCTAAT

**Table S4** The K-efficient group and K-inefficient group network properties

Network properties	The K-efficiency group	The K-inefficiency group
Modularity	0.691	0.674
Map density	0.034	0.022
Average degree	193.86	151.416
Network diameter	6	5
Weighted average	281.357	216.615
Average clustering coefficient	0.526	0.425

**Table S5** Statistics information on abundant and rare taxa of bacteria, fungi, and archaea

	Bacteria	Fungi	Archaea
Number of ASVs	6728	1755	590
Number of abundant ASVs	82	33	32
Proportion of the number of abundant ASVs	1.22%	1.88%	5.42%
Relative abundance of abundant taxa	16.06%	32.09%	38.28%
Number of rare ASVs	4620	1311	312
Proportion of the number of rare ASVs	68.67%	74.70%	52.88%
Relative abundance of rare taxa	4.56%	2.12%	0.90%

**Table S6** Mantel-test of bacterial, fungal, and archaeal abundant and rare taxa. Bac, Fun, and Arc indicated bacterial, fungal, archaea, respectively; Bac\_abundant, abundant taxa of bacteria; Fun\_abundant, abundant taxa of fungi; Arc\_abundant, abundant taxa of archaea; Bac\_rare, rare taxa of bacteria; Fun\_rare, rare taxa of fungi; Arc\_rare, rare taxa of archaea. AGKA, Aboveground K accumulation; SKA, Straw K accumulation; GKA, Grain K accumulation

Mental-teat result				
	spec	env	r	<i>P</i>
1	Bac	KUE	0.420306517	0.001
2	Bac	KHI	0.290709613	0.001
3	Bac	Yield	0.44514458	0.001
4	Bac	Biomass	0.151643211	0.006
5	Bac	AGKA	-0.015205736	0.584
6	Bac	SKA	-0.001926611	0.476
7	Bac	GKA	0.309546743	0.001
8	Bac_abundant	KUE	0.398145137	0.001
9	Bac_abundant	KHI	0.232913066	0.001
10	Bac_abundant	Yield	0.43848321	0.001
11	Bac_abundant	Biomass	0.128262129	0.008
12	Bac_abundant	AGKA	-0.008643697	0.54
13	Bac_abundant	SKA	0.00952487	0.413
14	Bac_abundant	GKA	0.301986188	0.001
15	Bac_rare	KUE	0.382086175	0.001
16	Bac_rare	KHI	0.290353042	0.001
17	Bac_rare	Yield	0.321965077	0.001
18	Bac_rare	Biomass	0.065967031	0.051
19	Bac_rare	AGKA	0.046035974	0.101
20	Bac_rare	SKA	0.068473976	0.045
21	Bac_rare	GKA	0.204709175	0.001
22	Fun	KUE	0.204180885	0.003
23	Fun	KHI	0.171677798	0.015
24	Fun	Yield	0.30314862	0.001
25	Fun	Biomass	0.095489803	0.083
26	Fun	AGKA	-0.150481756	0.993
27	Fun	SKA	-0.148069183	0.992
28	Fun	GKA	0.232702938	0.006

29	Fun_abundant	KUE	0.169550853	0.006
30	Fun_abundant	KHI	0.131824149	0.033
31	Fun_abundant	Yield	0.253897364	0.002
32	Fun_abundant	Biomass	0.06315345	0.181
33	Fun_abundant	AGKA	-0.14005612	0.986
34	Fun_abundant	SKA	-0.139849218	0.991
35	Fun_abundant	GKA	0.18207045	0.009
36	Fun_rare	KUE	0.078099297	0.055
37	Fun_rare	KHI	0.038048129	0.238
38	Fun_rare	Yield	-0.000341366	0.488
39	Fun_rare	Biomass	-0.008746612	0.567
40	Fun_rare	AGKA	0.004368733	0.487
41	Fun_rare	SKA	0.004357802	0.481
42	Fun_rare	GKA	-0.006903803	0.563
43	Arc	KUE	0.107855088	0.098
44	Arc	KHI	0.028257701	0.344
45	Arc	Yield	0.22407204	0.011
46	Arc	Biomass	0.036795536	0.317
47	Arc	AGKA	-0.036492958	0.652
48	Arc	SKA	-0.03318875	0.614
49	Arc	GKA	0.14012495	0.078
50	Arc_abundant	KUE	0.106062543	0.093
51	Arc_abundant	KHI	0.035786861	0.309
52	Arc_abundant	Yield	0.251132118	0.002
53	Arc_abundant	Biomass	0.068510559	0.194
54	Arc_abundant	AGKA	-0.050579462	0.727
55	Arc_abundant	SKA	-0.055472562	0.752
56	Arc_abundant	GKA	0.169039562	0.039
57	Arc_rare	KUE	0.059341348	0.091
58	Arc_rare	KHI	0.027425362	0.279
59	Arc_rare	Yield	0.119526561	0.009
60	Arc_rare	Biomass	0.023701695	0.312
61	Arc_rare	AGKA	-0.002109397	0.524
62	Arc_rare	SKA	0.016859966	0.329
63	Arc_rare	GKA	0.055521087	0.131

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**Table S7** Properties of bacterial-fungal-archaeal cross-domain networks

Network Attributes			
Nodes	7843		
Edges	296409		
Bacteria - Bacteria	200492		
Bacteria - Fungi	60477		
Bacteria - Archaea	16922		
Fungi - Fungi	13342		
Fungi - Archaea	4256		
Archaea-Archaea	920		

	Bacteria	Fungi	Archaea
Number of ASVs	6032	1416	395
ASV ratio	0.769093459	0.18054316	0.050363381
Overall connectedness	478383	91417	23018
Average connectivity (per ASV)	79.30752653	64.56002825	58.27341772

**Table S8** Mantel-test analysis of core microorganisms in relation to KUE, NUE, and PUE

Mantel-test result				
	spec	env	r	<i>P</i>
1	Core microorganism	KUE	0.448	0.001
2	Core microorganism	NUE	0.328	0.001
3	Core microorganism	PUE	0.328	0.001

**Table S9** Wheat plant height, fresh weight, dry weight, root weight, and AGKA raw data for the soil sterilization experiment

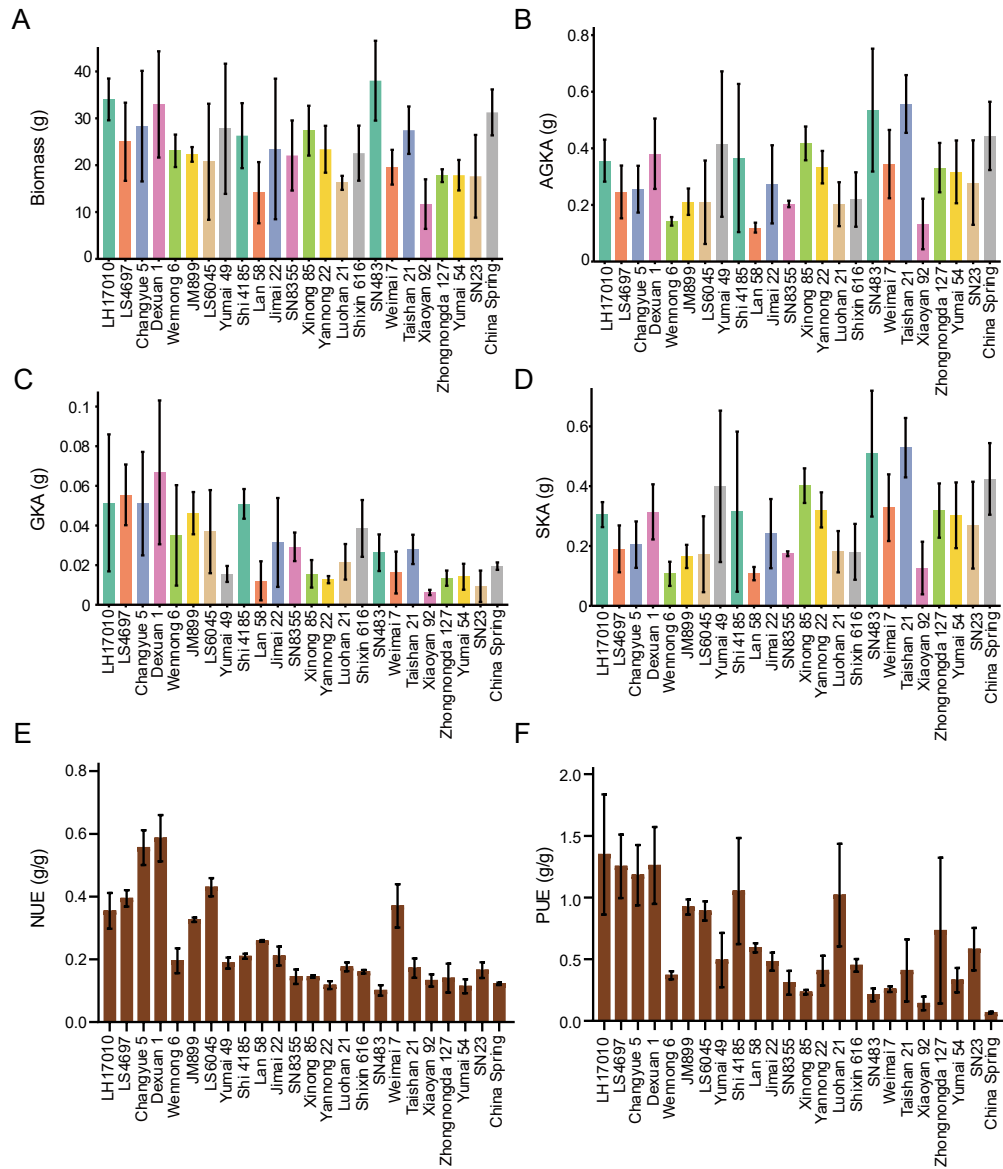
The soil sterilization experiment	Sterilized soil					Natural soil				
	Plant height (cm)	Fresh weight (g)	Dry weight (g)	Root weight (g)	AGKA (mg)	Plant height (cm)	Fresh weight (g)	Dry weight (g)	Root weight (g)	AGKA (mg)
1	18.1	0.194	0.0248	0.070	1.9242	24.8	0.279	0.0325	0.114	2.2295
2	21.8	0.256	0.0288	0.085	1.5343	23.5	0.318	0.0350	0.111	3.1076
3	21.0	0.238	0.0285	0.073	1.5183	23.5	0.277	0.0326	0.098	3.6500
4	22.6	0.295	0.0309	0.056	2.6590	21.4	0.251	0.0300	0.098	2.5124
5	20.8	0.232	0.0266	0.084	2.1832	22.8	0.292	0.0348	0.124	2.8961
6	21.5	0.261	0.0321	0.072	2.6564	24.6	0.264	0.0279	0.142	2.5411
7	19.6	0.179	0.0224	0.028	1.9639	22.5	0.246	0.0286	0.061	2.6049
8	21.7	0.191	0.0242	0.060	1.8776	22.9	0.206	0.0247	0.047	1.9439
9	17.9	0.195	0.0229	0.093	2.0077	23.7	0.287	0.0330	0.053	3.6948
10	20.4	0.202	0.0257	0.061	1.9940	24.6	0.290	0.0325	0.109	2.2295
11	20.9	0.186	0.0212	0.042	1.8587	23.9	0.346	0.0365	0.071	3.2408
12	20.4	0.306	0.0366	0.085	3.0288	21.3	0.218	0.0256	0.073	2.0147
13	21.0	0.201	0.0252	0.078	1.9552	22.2	0.260	0.0279	0.082	2.5411
14	20.2	0.279	0.0333	0.080	2.7557	23.5	0.249	0.0290	0.049	2.4286
15	20.9	0.187	0.0222	0.053	1.9463	21.7	0.196	0.0244	0.080	1.9203
16	17.5	0.148	0.0181	0.040	1.7360	22.7	0.225	0.0276	0.077	2.5138
17	19.7	0.142	0.0173	0.028	1.6593	26.2	0.336	0.0389	0.066	2.8825
18	22.0	0.249	0.0317	0.079	2.7279	23.7	0.226	0.0259	0.126	2.0383
19	21.0	0.226	0.0279	0.051	2.2899	25.8	0.304	0.0343	0.037	2.8545
20	20.5	0.249	0.0297	0.056	2.5557	25.5	0.369	0.0405	0.102	3.0010
21	19.8	0.216	0.0273	0.070	2.2407	23.0	0.287	0.0319	0.064	2.1883
22	20.5	0.208	0.0243	0.068	1.8854	23.0	0.205	0.0291	0.107	2.4370
23	21.0	0.218	0.0282	0.086	1.5024	18.1	0.189	0.0248	0.100	1.9517

**Table S10** Wheat plant height, fresh weight, dry weight, and AGKA raw data for the hydroponic experiment

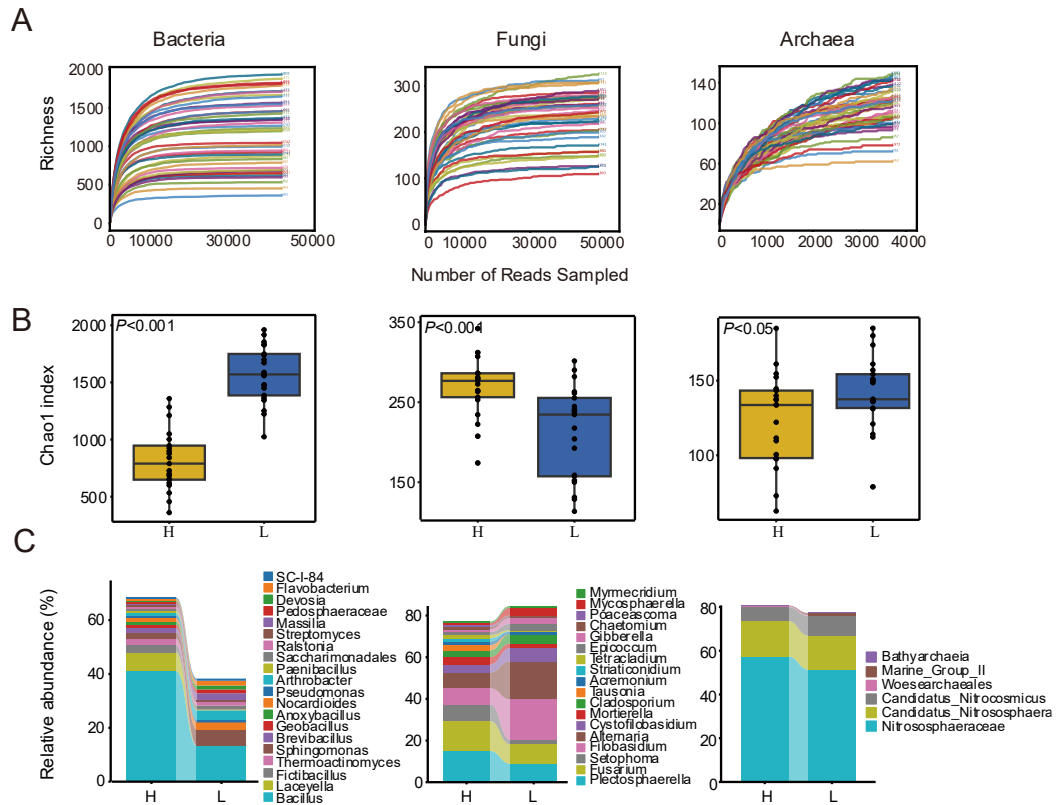
The Hydroponic experiment	CK				9H23-2				4-18			
	Plant height (cm)	Fresh weight (g)	Dry weight (g)	AGKA (mg)	Plant height (cm)	Fresh weight (g)	Dry weight (g)	AGKA (mg)	Plant height (cm)	Fresh weight (g)	Dry weight (g)	AGKA (mg)
1	17.8	0.336	0.0391	2.7280	18.75	0.393	0.0481	3.6822	16.2	0.252	0.0412	2.6696
2	15.0	0.237	0.0372	2.3023	18.9	0.421	0.0489	3.7435	15.7	0.227	0.0371	2.6317
3	17.4	0.280	0.0396	2.7629	18.8	0.309	0.0420	2.9417	16.7	0.254	0.0377	2.5564
4	18.5	0.295	0.0406	2.5504	17.6	0.342	0.0434	3.6226	17.7	0.272	0.0364	2.8825
5	16.5	0.300	0.0399	2.7838	17.6	0.345	0.0434	3.6226	16.7	0.275	0.0372	2.6388
6	18.1	0.308	0.0418	2.3273	17.0	0.365	0.0448	3.0717	17.2	0.252	0.0372	2.6388
7	16.6	0.292	0.0418	2.3273	17.3	0.388	0.0444	3.0443	16.1	0.274	0.0358	2.8350
8	18.0	0.275	0.0409	2.5692	17.8	0.364	0.0426	3.4444	16.4	0.281	0.0414	2.6825
9	16.4	0.243	0.0373	2.3085	16.8	0.324	0.0429	3.4687	16.9	0.283	0.0381	2.9790
10	17.0	0.280	0.0372	2.3023	16.5	0.313	0.0420	2.9417	15.1	0.277	0.0378	2.5632

**Table S11** Wheat plant height, fresh weight, dry weight, and AGKA raw data for the pot experiment

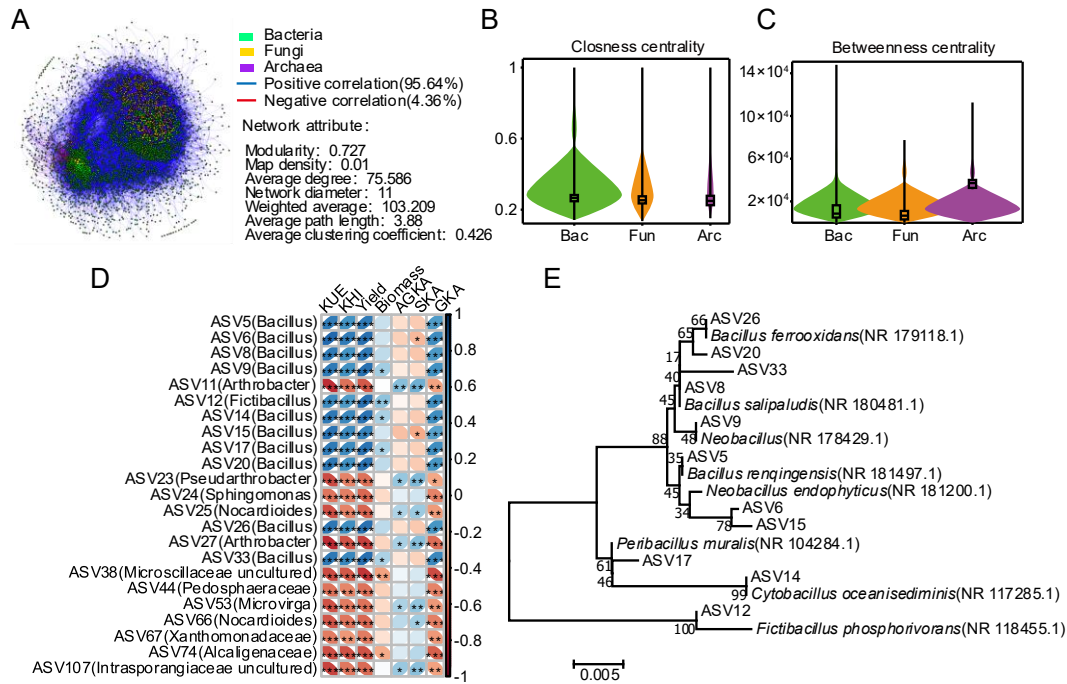
The pot experiment	CK				9H23-2			
	Plant height (cm)	Fresh weight (g)	Dry weight (g)	AGKA (mg)	Plant height (cm)	Fresh weight (g)	Dry weight (g)	AGKA (mg)
1	29.0	0.759	0.109	8.3956	36.6	0.797	0.104	9.5797
2	29.3	0.281	0.037	3.0910	41.1	1.010	0.122	11.9816
3	35.7	0.492	0.070	5.5381	39.4	1.030	0.114	11.1359
4	32.6	0.387	0.053	4.4625	26.0	0.476	0.053	5.2577
5	33.3	0.544	0.073	5.7754	25.0	0.299	0.031	2.7186
6	28.7	0.271	0.036	3.0075	37.2	0.803	0.095	9.2075
7	27.1	0.252	0.036	3.0075	39.6	1.000	0.120	11.2712
8	34.2	0.540	0.069	5.6187	30.8	0.815	0.084	7.5430
9	29.5	0.346	0.047	3.9040	38.3	0.666	0.077	6.7624
10	33.8	0.597	0.079	6.2501	33.0	0.383	0.048	4.7617
11	32.0	0.423	0.055	4.6309	37.2	0.621	0.081	7.1137
12	33.5	0.474	0.069	5.6187	36.5	0.725	0.085	7.6328
13	31.1	0.462	0.062	5.1281	40.0	0.901	0.112	10.0871
14	34.9	0.689	0.091	9.4443	37.4	0.766	0.088	7.9022
15	29.8	0.352	0.050	4.1532	38.2	0.879	0.094	8.7001
16	30.8	0.432	0.056	4.7151	39.2	0.606	0.108	10.1548
17	30.7	0.464	0.063	5.0097	36.8	0.819	0.072	6.2953
18	21.4	0.173	0.026	1.8418	20.0	0.180	0.025	2.1924
19	31.6	0.455	0.063	5.0097	38.9	0.871	0.108	9.9856
20	25.4	0.223	0.029	2.0543	39.1	0.923	0.115	10.3578
21	29.3	0.497	0.066	5.3444	35.2	1.003	0.125	12.0155
22	32.2	0.462	0.062	5.1281	35.5	0.632	0.072	6.2953
23	30.7	0.467	0.064	5.1825				



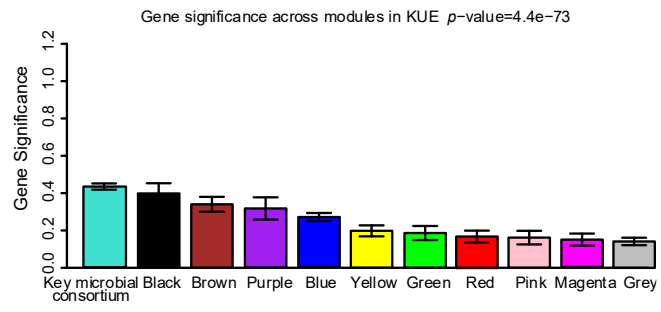
**Fig. S1** Indicators of potassium nutrients in 24 wheat varieties. Biomass(A); AGKA, Aboveground K accumulation(B); GKA, Grain K accumulation(C); SKA, Straw K accumulation(D); Nitrogen utilization efficiency (NUE, E); Phosphorus utilization efficiency (PUE, F). Error bars represent Mean  $\pm$  SD



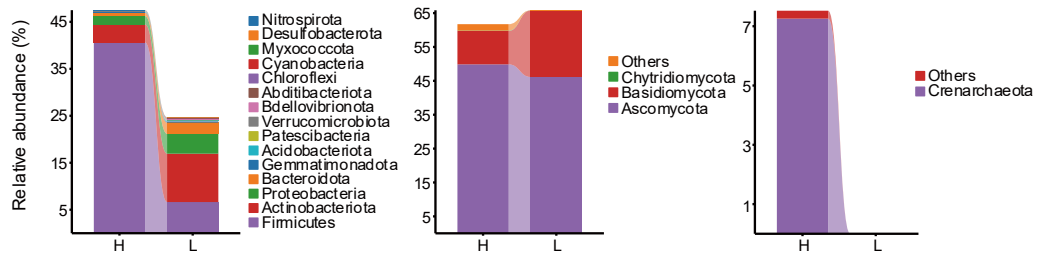
**Fig. S2** Community diversity and microbial composition of the K-efficient and K-inefficient group. Bacterial, fungal, and archaeal dilution curves (A),  $\alpha$ -diversity index (B), microbial composition (genus level, C). H, the K-efficiency group; L, the K-inefficiency group. The significance indicates statistically significant differences of different groups based on Student's t-test. \*, \*\*, and \*\*\* indicate significance at  $P < 0.05$ , 0.01, and 0.001, respectively



**Fig. S3** Core microorganisms in K-efficient wheat varieties. Bacterial-fungal-archaeal cross-domain network (A) and network attributes (B, C). Heatmap of correlation between core ASVs and potassium nutrient indicators(D). Evolutionary tree of the core microorganisms(E). Bac, Fun, and Arc indicated bacterial, fungal, archaea, respectively. AGKA, Aboveground K accumulation; SKA, Straw K accumulation; GKA, Grain K accumulation. \*, \*\*, and \*\*\* indicate significance at  $P < 0.05$ , 0.01, and 0.001, respectively

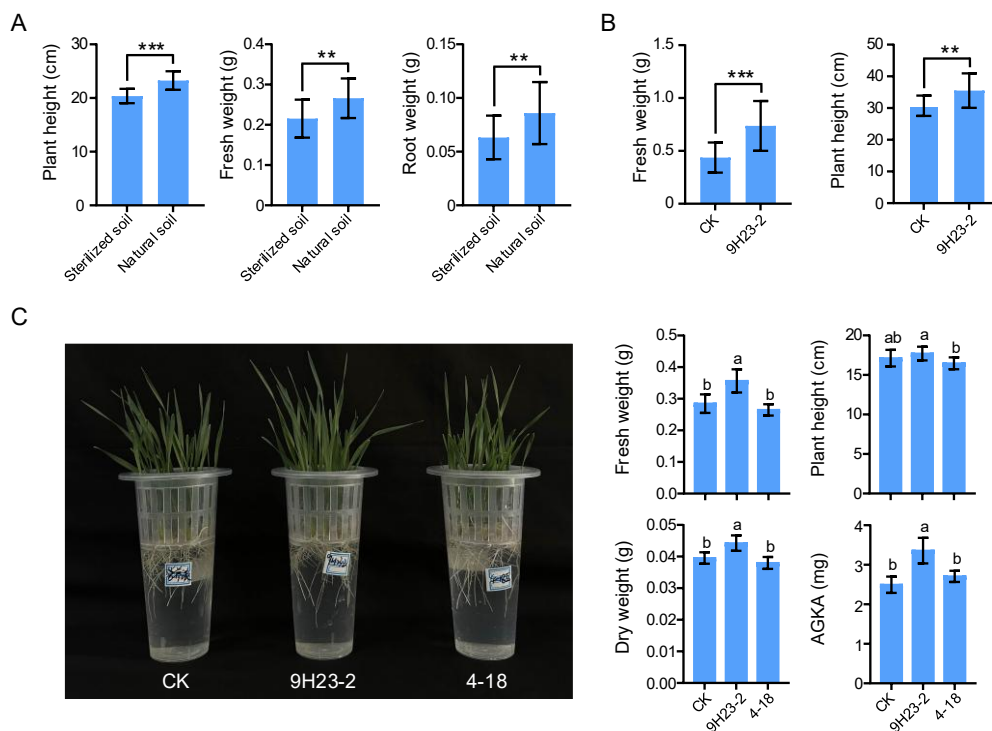


**Fig. S4** Ranking the importance of each module in WGCNA to KUE



**Fig. S5** Microbial composition of key microbial consortium (module turquoise) (phylum level). H, the K-efficiency group; L, the K-inefficiency group





**Fig. S7** Soil sterilization experiment, core microorganism potting and hydroponics experiment. Plant height, Fresh weight and Root weight of wheat under sterilized and natural soil (A). The potting experiments inoculated with core potassium solubilizing microorganism 9H23-2 (B) and hydroponic experiments to validate the effects of core potassium solubilizing bacteria (9H23-2) and non-core potassium solubilizing bacteria (4-18) on wheat growth and potassium nutrient accumulation (C). CK, control; 9H23-2, inoculated with 9H23-2; 4-18, inoculated with 4-18. Error bars represent Mean  $\pm$  SD. The significance above the columns indicates statistically significant differences of different groups based on Student's t-test (\*, \*\*, and \*\*\* indicate significance at  $P < 0.05$ ,  $0.01$ , and  $0.001$ , respectively). The letters above the columns indicates statistically significant differences of different groups based on Duncan's test ( $P < 0.05$ )