

### Supplementary Material

#### Effects of environments and cultivars on grain ionome of spring wheat grown in Kazakhstan and Russia

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**Supplementary Table 1. KASIB material used in the study in 2017-2018.**

<b>KASI B#</b>	<b>Variety</b>	<b>Pedigree</b>	<b>Institution</b>
21	Pamyati Azieva	Saratovskaya-29/Lutescens-99-80-1	Check-1 (early)
22	Tertsiya	ANK-1/ANK-2//ANK-3/3/ANK-7A	Check-2 (medium)
23	Astana-2	VIR-264-2/3*Tselinnaya yubileinaya	Check-3 (medium)
24	Omskaya-35	Omskaya-29/Omskaya-30	Check-4 (late)
25	Saratovskaya-29	Albidum-24/Lutescens-55-11	Check-5 (long-term)
1	Stepnaya-245	Stepnaya-16/Berkut//Aktobe-39	Aktobe AES, KZ
2	Stepnaya-253	Lutescens-S-2207/Stepnaya-60	
3	Stepnaya-259	Saratovskaya-29/Stepnaya-62	
4	GVK-2127	GVK-1860-12/Tselinnaya-3s	East-Kazakhstan ARI, KZ
5	GVK-2161	Lutescens-20/Lada	
6	Lutescens-857	Omskaya-18/Lutescens-32	Kazakh Farming Inst., KZ
7	Lutescens-932	Eritrospermum-287/Kazakhstanskaya-17	
8	Lutescens-248-01	Eritrospermum-893/Tselinogradka	Kazakh Grain Inst., KZ
9	Lutescens-393-05	Karabalykskaya-90/90-6	
10	Line-4-10-16	Molodezhnaya/Mironovskaya-808	Karabalyk AES, KZ
11	Line-22-ChS	Lutescens-424/4/Milan/Sha7/3/Croc_1/Ae.squarrosa (224)//Opata/5/Gle	
12	Lutescens-48-204-03	Lutescens-4/Bashkirskaya-20	
13	Lutescens-2028	Lutescens-253-93-4/Karagandinskaya-21	Karagandy ARI, KZ
14	Lutescens-2102	Lutescens-1085/Omskaya-18	
15	Lutescens-30	Pavlodarskaya-93/WH007850ZAK(WA 7850)	Pavlodar ARI, KZ
16	Lutescens-65	Lutescens-44/YuK-3(Korea)	
17	Lutescens-261	Lutescens-337-77-44/Mironovskaya-808	
26	Lutescens-1103	Svetlanka/Alexandrina	Altai Agro-Bio Center, Barnaul, RU
27	Eritrospermum-1119	Omskaya-28/Saratovskaya-71	

28	Lutescens-8-108-1	SPCHS-8-108	Kurgan ARI, RU (Kurgan-1)
29	Lutescens-22-17	Tertsiya/Zhigulevskaya	
30	Lutescens-37-17	Lyubava-2/Prokhorovka	
31	Lutescens-KS-14-09-2	Omskaya-32/Sonata	Kurgan Seed, RU (Kurgan-2)
32	Lutescens-KS-140-08-3	Omskaya-37/Salavat Yulaev	
33	Lutescens-KS-963	Tulaykovskaya-10/Ekada-6	
34	Lutescens-1193	Aubaine/Tulaykovskaya-100	
35	Lutescens-1296	AC Karma/Zemlyachka	Samara ARI, RU
36	Lutescens-1300	Tulaykovskaya-10/Zemlyachka	
37	Sibirskaya-21	Novosibirskaya-67/Udacha//Sibirskaya-17	
38	Novosibirskaya-16	Pamyati Vavenkova/Novosibirskaya-15	Siberian Plant Production and Breeding Inst., Novosibirsk, RU
39	Novosibirskaya-41	Tyumenskaya-80//Tselinnaya-20/ANK-102/3/ Sport	
40	Lutescens-90-12	Tertsiya/Niva	
52	Element-22	Eritrospermum-33-97/Duet	Omsk Agrarian Univ., RU (Omsk-1)
41	OmGAU-100	Lutescens-444/Eritrospermum-59	
42	Stolipinskaya-2	Gle/3/Ka/Nac//Trch/4/Omskaya-37	
43	Lutescens-3-04-21-11	Lutescens-290-97-7//292(32)Tam200/Tut	
44	Lutescens-79/04-11	Lutescens-248-97-11/Omskaya 38	Siberian Agrarian Center, RU (Omsk-2)
45	SPCHS-69	Alt530/3/Emb16/Cbrd//Cbrd/4/Lutescens- 210-99-10	
46	Tyumenskaya ubileinaya	Lutescens-41-94//Tertsia	
47	Tyumenochka	Skala/Tyumenskaya-80//Omskaya-32	North Ural Agric. Univ. Tyumen, RU
48	Lutescens-443	Bel/3/Altar84/Ae.squarrosa (224)//Pgo/4/C68	South-East ARI, Saratov, RU
49	Lutescens-449	L505*2/Prokhorovka//Belyanka	
50	Silach	Lutescens-210-99-10/Eritrospermum-23090	Chelyabinsk ARI, RU
51	Eritrospermum-24841	Chelyaba-75/ANK-17V	

**Supplementary Table 2. ANOVA F-value significance of the effects of genotypes, year, sites and their interaction for grain yield. Protein content and elemental composition.**

Trait/ Element	F values significance level for effects and interactions:						
	Genotypes	Year	Site	Genotypes - year	Genotype - site	Year x site	Genotype s – year - site
Grain yield	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Protein content	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Macro-elements							
Ca	<0.001	<0.001	<0.001	0.17	0.37	<0.001	<0.05
K	<0.001	<0.001	<0.001	0.10	0.17	<0.001	<0.001
Mg	<0.001	0.18	<0.001	0.37	0.70	<0.001	0.21
P	<0.001	<0.001	<0.001	0.19	0.45	<0.001	<0.001
S	<0.001	<0.001	<0.001	0.19	0.91	<0.001	0.17
Micro-elements							
Cu	<0.001	<0.001	<0.001	0.66	0.46	<0.001	<0.01
Fe	<0.001	<0.001	<0.001	0.05	0.25	<0.001	<0.001
Mn	<0.001	<0.001	<0.001	0.83	0.78	<0.001	0.23
Zn	<0.001	<0.001	<0.001	0.73	0.73	<0.001	0.34
Toxic trace elements							
Cd	<0.001	<0.05	<0.001	0.07	<0.01	<0.01	<0.01
Co	<0.001	<0.001	<0.001	0.49	<0.001	<0.001	<0.01
Ni	<0.001	<0.001	<0.001	0.52	<0.001	<0.001	<0.01
Trace elements							
Mo	<0.001	<0.001	<0.001	0.77	<0.05	<0.001	<0.05
Rb	<0.001	<0.001	0.35	0.66	0.14	<0.001	0.15
Sr	<0.001	<0.001	<0.001	0.19	<0.05	<0.001	<0.05

**Supplementary Table 3. The grain elements concentration across sites and years in 2017-2018**

Element	Mean concentration across 2017-2018, $\mu\text{g} \cdot \text{g}^{-1}$						Mean concentration across sites, $\mu\text{g} \cdot \text{g}^{-1}$		LSD 0.05
	Karabalyk, KZ	Shortandy, KZ	Chelyabinsk, RU	Omsk, RU	Novosibirsk, RU	Tyumen, RU	2017	2018	
Macroelements									
Ca	306	319	309	373	391	341	323	356	29
K	4176	3908	4276	4022	4093	4313	4029	4233	185
Mg	1314	1089	1225	1293	1213	1177	1225	1211	59
P	4944	3960	5343	5387	5269	5320	4943	5131	360
S	1818	1948	1719	1949	1829	1515	1856	1736	111
Microelements									
Cu	3.82	5.28	3.46	4.67	4.19	4.20	4.11	4.43	2.6
Fe	34.6	32.5	33.7	39.7	33.8	31.0	36.4	32.0	0.45
Mn	40.8	42.0	34.1	41.8	38.6	30.3	38.9	36.9	3.1
Zn	37.2	26.9	44.3	50.3	44.9	44.9	37.0	45.8	6.2
Toxic trace elements									
Cd	0.021	0.025	0.026	0.033	0.030	0.018	0.026	0.025	0.004
Co	0.020	0.027	0.008	0.011	0.007	0.004	0.011	0.015	0.006
Ni	0.402	0.249	0.541	0.257	0.123	0.336	0.288	0.348	0.091
Trace elements									
Mo	0.461	0.571	0.190	0.290	0.268	0.488	0.363	0.392	0.10
Rb	1.88	1.76	4.07	3.28	7.06	4.88	3.85	3.80	1.22
Sr	2.83	2.34	1.67	2.05	1.69	1.65	1.90	2.18	0.34

**Supplementary Table 4. Broad sense heritability of elements in the grain of KASIB-bread wheat across all genotypes for five locations and two years.**

Elements	Chelyabinsk (RUS)		Karabalyk (KAZ)		Novosibirsk (RUS)		Omsk (RUS)		Shortandy (KAZ)	Tyumen (RUS)		Average
	2017	2018	2017	2018	2017	2018	2017	2018	2018	2017	2018	
Macroelements												
Ca	0.40	0.23	0.95	0.48	0.90	0.46	0.64	0.22	0.11	0.45	0.61	0.50
K	0.31	0.71	0.62	0.35	0.60	0.32	0.32	0.16	0.32	0.80	0.38	0.44
Mg	0.75	0.35	0.72	0.87	0.71	0.46	0.12	0.88	0.12	0.70	0.86	0.59
P	0.26	0.63	0.22	0.09	0.07	0.38	0.39	0.05	0.17	0.78	0.24	0.30
S	0.21	0.14	0.14	0.12	0.12	0.18	0.20	0.16	0.10	0.21	0.58	0.20
Microelements												
Cu	0.26	0.47	0.76	0.50	0.29	0.40	0.42	0.23	0.16	0.38	0.56	0.40
Fe	0.36	0.27	0.95	0.02	0.13	0.52	0.08	0.03	0.02	0.86	0.90	0.38
Mn	0.94	0.42	0.69	0.18	0.22	0.37	0.10	0.06	0.12	0.75	0.69	0.41
Zn	0.70	0.98	0.63	0.20	0.13	0.93	0.33	0.13	0.15	0.23	0.38	0.44
Toxic trace elements												
Cd	0.63	0.92	0.86	0.24	0.43	0.17	0.11	0.15	0.19	0.76	0.41	0.44
Co	0.96	0.48	0.65	0.26	0.44	0.17	0.39	0.08	0.35	0.94	0.65	0.49
Ni	0.17	0.16	0.41	0.88	0.23	0.09	0.06	0.06	0.44	0.97	0.57	0.37
Trace elements												
Mo	0.65	0.47	0.67	0.71	0.72	0.22	0.18	0.74	0.26	0.97	0.62	0.56

Rb	0.09	0.12	0.59	0.63	0.31	0.26	0.03	0.17	0.11	0.40	0.67	0.31
Sr	0.34	0.78	0.79	0.98	0.26	0.47	0.88	0.37	0.12	0.67	0.42	0.55
Average	0.47	0.48	0.65	0.43	0.37	0.36	0.28	0.23	0.18	0.66	0.57	0.43

**Supplementary table 5. Top-five best performers for elements concentration based on GGE analysis of six sites in 2017-2018**

Origin is a city where the breeding program is located. The details of the respective institutions and genotypes pedigree are presented in Supplementary Table 1.

Ent ry #	Genotype	Origin	Concen- tration, $\mu\text{g} \cdot \text{g}^{-1}$	Ent ry #	Genotype	Origin	Concen- tration, $\mu\text{g} \cdot \text{g}^{-1}$
<b>Ca</b>				<b>K</b>			
52	Element-22	Check	379	24	Omskaya-35	Check	4187
48	Lutescens-443	Saratov	445	34	Lutescens-1193	Samara	4890
36	Lutescens-1300	Samara	399	35	Lutescens-1296		4762
34	Lutescens-1193		399	36	Lutescens-1300		4585
33	Lutescens-KS-963	Kurgan-1	396	31	Lutes.-KS-14-09-2	Kurgan-2	4530
35	Lutescens-1296	Samara	390	30	Lutescens-37-17	Kurgan-1	4510
42	Stolipinskaya-2	Omsk-1	269	38	Novosibirskaya-16	Novosibirsk	3375
<b>Mg</b>				<b>P</b>			
23	Astana-2	Check	1250	52	Element-22	Check	5387
38	Novosibirskaya-16	Novosibirsk	1428	51	Eritrosp.-24841	Chelyabinsk	5542
51	Eritrosp.-24841	Chelyabinsk	1403	43	Lutes.-3-04-21-11	Omsk-2	5612
4	GVK-2127	E. Kazakh.	1299	50	Silach	Chelyabinsk	5414
33	Lutescens-KS-963	Kurgan-2	1301	38	Novosibirskaya-16	Novosibirsk	5324
26	Lutescens-1103	Barnaul	1314	1	Stepnaya-245	Aktobe	5208
28	Lutescens-8-108-1	Kurgan-1	1119	17	Lutescens-261	Pavlodar	4521
<b>S</b>				<b>Cu</b>			
52	Element-22	Check	1928	23	Astana-2	Check	4.58
50	Silach	Chelyabinsk	2055	41	OmGAU-100	Omsk-1	5.18
38	Novosibirskaya-16	Novosibirsk	2008	10	Line-4-10-16	Karabalyk	5.24
51	Eritrosp.-24841	Chelyabinsk	1964	43	Lutes.-3-04-21-11	Omsk-2	4.96
43	Lut.-3-04-21-11	Omsk-2	2015	39	Novosibirskaya-41	Novosibirsk	4.84
47	Tyumenochka	Tyumen	1932	33	Lutescens-KS-963	Kurgan-2	4.97



3	Stepnaya-259	Aktobe	1549	49	Lutescens-449	Saratov	3.61
		<b>Fe</b>				<b>Mn</b>	
52	Element-22	Check	35.1	52	Element-22	Check	42.8
39	Novosibirskaya-41	Novosibirsk	39.0	4	GVK-2127	E. Kazak/	43.2
38	Novosibirskaya-16		39.4	38	Novosibirskaya-16	Novosibirsk	42.9
10	Line-4-10-16	Karabalyk	39.3	5	GVK-2161	E. Kazakh.	41.3
28	Lutescens-8-108-1	Kurgan-1	37.2	10	Line-4-10-16	Karabalyk	41.6
45	SPCHS-69	Omsk-2	36.8	51	Eritrosp.-24841	Chelyabinsk	41.6
1	Stepnaya-245	Aktobe	27.9	13	Lutescens-2028	Karagandy	33.2
		<b>Zn</b>				<b>Cd</b>	
52	Element-22	Check	46.3	24	Omskaya-35	Check	0.021
38	Novosibirskaya-16	Novosibirsk	49.4	35	Lutescens-1296	Samara	0.015
50	Silach	Chelyabinsk	48.4	27	Eritrospermum-1119	Barnaul	0.016
51	Eritrosp.-24841		45.8	3	Stepnaya-259	Aktobe	0.019
47	Tyumenochka	Tyumen	44.7	17	Lutescens-261	Pavlodar	0.019
43	Lut.-3-04-21-11	Omsk-2	45.9	15	Lutescens-30		0.019
2	Stepnaya-253	Aktobe	35.8	11	Line-22-ChS	Karabalyk	0.039