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PERFORMANCE INDEX DERIVED FROM CHLOROPHYLL A FLUORESCENCE INDUCTION CURVE INDICATES THE SALT INDUCED GRAIN YIELD LOSS IN WHEAT

Z. Sun[1], S. Liu[2], J. Fan[1], Q. Li[1], K. Wang[1], M. Guo[1], G. Zhang[1], L. Ren[1], G. Zheng[1], T. Ma[1], H. Pu[1], J. Cai[3], D. Jiang[3], F. Chen[1*] and Xiangnan Li[2*]

[1]Agricultural Research Institute of Xu-huai Region, Lianyungang Academy of Agricultural Science, Yingzhou RD 8, Lianyungang 222000, China; [2]Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China; [3]National Engineering and Technology Center for Information Agriculture/Key Laboratory of Crop Physiology and Ecology in Southern China, Ministry of Agriculture, Nanjing Agricultural University, Nanjing, China
[*]Correspondence Author Email: lixiangnan@iga.ac.cn

ABSTRACT

Soil salinity severely limits plant growth and reduces grain yield in wheat (*Triticum aestivum*). Forty-three local wheat cultivars and breeding lines were exposed to a salt treatment (by adding 200 mM NaCl solution) for two weeks, and chlorophyll content and chlorophyll a fluorescence parameters, performance index (PI) and maximum quantum yield of PS II (Fv/Fm) were determined just after salt treatment. It was found that salt stress resulted in different reductions in chlorophyll content and chlorophyll a fluorescence parameters among the 43 wheat cultivars and breeding lines. The salt induced decrease in PI and Fv/Fm varied in a large range among 43 wheat cultivars. The grain yield loss induced by salt stress was mainly due to the decrease in grain weight in wheat. It was concluded that PI was a good parameter for screening genotypes with higher grain weight and grain yield under salt stress.

Key words: Chl a fluorescence; *Triticum aestivum*; salinity; grain yield.

INTRODUCTION

Over 7 % of the total land are within the ambit of the salt effects around the world (Munns 2002). Wheat (*Triticum aestivum*L.) possesses moderate tolerance to salt stress; soil salinity causes the loss in its grain yield by 60% (El-Hendawy *et al.*2017). Salt stress reduces the root water uptake, and the over accumulation of Na^+ and Cl^- impair the photosynthesis systems, thus depressing the photosynthetic electron transport and photosynthetic efficiency (Chaichi*et al.* 2016; Sun *et al.* 2016). Reduced photosynthetic efficiency significantly limits the plant growth and grain yield (Silveira and Carvalho 2016). Genetic variations of salt tolerance in wheat has been well documented (Oyiga *et al.* 2016). It has been documented that mild salt (6.0 dS m^{-1}) significantly reduced the PS II quantum yield in salt sensitive cultivar, while had no effect on that in salt resistant cultivars in wheat. Thus, the selection of resistant genotypes is a good way to overcome the salt induced limitations in wheat production.

The imminent task is the efficient characterization of wheat cultivars for salt stress tolerance (Oyiga *et al.* 2016). Yet, the identification, quantification and monitoring of salt tolerance are extremely complicated and difficult. Fast chlorophyll a fluorescence rise kinetics based in the "Theory of Energy Fluxes in Biomembranes", has been used widely for quick and large-scale evolution of stress tolerance in plants, due to its quick, nondestructive and precise characteristic (Strasser *et al.* 2004; Li *et al.* 2014a, 2016b). It has been shown that the chlorophyll a fluorescence parameters are very sensitive to salt stress (Mehta *et al.* 2010; Shu *et al.* 2013). For instance, the PS II maximum quantum yield (Fv/Fm) was used to improve the identification of quantitative trait loci related to salt tolerance in *Medicago truncatula* (Exbrayat *et al.* 2014).

In this study, 43 local wheat cultivars and breeding lines were exposed to salt stress, and the chlorophyll content and two parameters of chlorophyll a fluorescence were measured. The relationships between these parameters and grain yield components of 43 wheat cultivars were investigated. The hypotheses in this study were that: (1) there is a variation in sensitivity of chlorophyll a fluorescence parameters in wheat cultivars exposed to salt stress; and (2) performance index can indicate the salt induced grain yield loss in wheat.

MATERIALS AND METHODS

A pot experiment was carried out in a climate chamber in the agricultural station in Lianyungang. Forty-three local wheat cultivars and breeding lines were used in this experiment. Wheat were grown in plastic pots (25 cm in diameterand22 cm in high) filled with 7.5 kg clay soil. Before sowing, 1.18 g N, 0.174 g P and 0.748 g K were added in each pot. Four wheat plants were grown in each pot. At five-leaf stage, the200 mM NaCl solution was added to half of the pots for two weeks as the salt treatment. The rest of the pots were irrigated just with water as the control. The experiment had a randomized block design, with three replicates for each treatment. Each replicate included four pots.

After salt treatment, the relative chlorophyll content was measured with SPAD 502 chlorophyll meter (Soil Plant Analysis Development, Minolta, Japan). Three leaves from each treatment were selected, and 5 replications were included for SPAD measurement on each leaf. Using the same leaves as for chlorophyll content, the chlorophyll a fluorescence curves were determined with Pocket-PEA (Hansatech, Norfolk, UK). All plants were dark adapted for half hour just before measurements (Li *et al*. 2014b). The chlorophyll a fluorescence parameters, including Fv/Fm and performance index (PI), were calculated with the programme PEA Plus 1.04 (Strasser *et al*. 2004). At maturity, the grain yield components were determined. The relative values were determined by calculating the ratio of the salt induced reduction to the control for a given parameter: Relative value = (Control — Salt)/Control. Regression analyses were applied for the relationships between the measured parameters.

RESULTS AND DISCUSSION

Chlorophyll content and chlorophyll a fluorescence: Photosynthesis is sensitive to the environmental changes; it is necessary to maintain the balance between light absorbed and energy consumed by ATP (Brestic *et al*. 2015). During photosynthetic induction, transport processes of electron and proton undergo rapid changes, which directly affect the efficiency of electron transport through PS II (Kaiser *et al*. 2017). Salt stress limits these processes in photosynthesis, such as the limitation in thylakoid electron transport by enhancing membrane viscosity and restricting the plastoquinone diffusion(Li *et al*. 2014a; Rachoski *et al*. 2015). Here, a large variation was found in the salt induced reduction in Fv/Fm among 43 cultivars (Table 1). Under salt treatment, the highest and lowest reduction in Fv/Fm was observed in cultivar Jimai 22 (reduced by 44%) and line 0118-2 (by 8%), respectively. It has been reported that Fv/Fm is sensitive to various abiotic stresses, such as chilling, heat, heavy metal toxicity and salt (Kalaji *et al.* 2017; Sun *et al.* 2016; Li *et al.* 2016a; Herde *et al.* 1999). However, Rachoski *et al.* (2015) documented that the Fv/Fm is not as good marker of PS II vitality as PI_{ABS} (performance index based on light absorption) for salinized rice somaclones, unless they are highly susceptible to salinity. Also, PI showed a strong negative correlation with the leaf malondialdehyde (MDA) content, which indicates the salt induced oxidative damage in rice (Rachoski *et al.* 2015). In this study, PI also showed a large variation among these 43 wheat cultivars. The highest reduction in PI induced by salt stress were found in lines 0354 and B4, the PI in salt treatment was 51% lower than the control in both lines. Also, PI was decreased by more than 30% in salt treatment compared with the control, in 28 wheat cultivars. The lowest salt induced reduction in PI was found in Shannong19, where the ratio of the salt-induced reduction to the control was 10%.

The relative chlorophyll content is widely applied for monitoring plant nitrogen status and estimating the damage of freeze stress (Xiong *et al*. 2015; Wang *et al*. 2016). It is common to use SPAD meter to test leaf chlorophyll concentration. SPAD readings are calculated with the transmission of red light at 650 nm and the transmission of infrared light at 940 nm (Xiong *et al*. 2015). Here, the salt induced variation in SPAD values is lower than those for Fv/Fm and PI among the wheat cultivars. The highest reduction of SPAD induced by salt stress was found in lines 0192, which was reduced by 28% in salt treatment compared with the non-salt control. In lines F2-116, 09-192, B5, B3 and F4-1, salt stress had no significant effects on SPAD values. It suggested that the SPAD was not as sensitive as the two chlorophyll a fluorescence parameters: Fv/Fm and PI. Plant salt stress can be divided into early-occurring osmotic stress and accumulating Na^+ and Cl^- stress (Deinlein *et al*. 2014). The chlorophyll degradation is mostly induced by the accumulating ionic Na^+ stress. In many plant species, no significant changes in chlorophyll content can be observed during the early salt stress events (Zhang and Shi 2013;Yang *et al*. 2014). In the present study, the salt treatment maintained for 14 days, which did not affect significantly the chlorophyll content in the salt resistant wheat cultivars.

Grain yield: As compared to control, salt treatment did not affect the spike number per plant and grain number per spike, but reduced the grain weight, thus decreasing the grain yield (Table 2). This was consistent with the previous study (Zhang *et al*. 2016). The salt induced yield reduction is related to decreased carbon assimilation efficiency, less nutrition uptake and translocation to the grains, and depressed carbohydrate metabolism (Deinlein *et al*. 2014). The highest yield loss was found in Jimai22, whose spike number and grain number per spike was reduced by 19% and 27%, respectively. The grain yield was not significantly affected by salt stress in the line 0118-2 and cultivars Aifeng99, Shannong19 and Shannong 20. The ratio of salt-induced reduction to the control for spike number per plant varied from 0 to 26% among 43 wheat cultivars. The largest decrease in spike number was found in lines 0104-2 and 0109-1, both had a reduction by more than 25%. However, no changes in spike number was found in line 09-192 under salt stress. The highest and lowest reduction in grain number per spike induced by salt stress was in Jimai22 (reduced by 27%) and Shannong3 (only reduced by 2%), respectively. The salt induced reduction in grain weight varied from 2% to 25%, with the highest value in line 0354 and the

Table 1. Effect of salt stress on the maximum quantum yield of PSII (Fv/Fm) and performance index (PI) of wheat cultivars (Mean ±SE, n=3).

NO.	Cultivar	Fv/Fm			PI			SPAD		
		Control	Salt	(Control-Slat)/Control	Control	Salt	(Control-Slat)/Control	Control	Salt	(Control-Slat)/Control
1	0108	0.781±0.06	0.566±0.01	0.38	10.92±0.67	7.35±0.66	0.51	58.3±4.9	48.5±3.0	0.17
2	0192	0.788±0.05	0.629±0.03	0.32	11.22±0.68	7.54±0.67	0.42	63.4±5.2	45.6±2.8	0.13
3	0307	0.776±0.04	0.661±0.04	0.24	10.74±0.66	7.23±0.65	0.34	58.3±4.9	44.5±2.7	0.05
4	0317	0.681±0.04	0.503±0.03	0.28	6.41±0.44	3.34±0.48	0.51	52.4±4.7	44.8±3.0	0.20
5	0354	0.721±0.04	0.445±0.03	0.13	11.00±0.67	5.38±0.66	0.35	59.2±5.0	49.2±3.0	0.02
6	0356	0.747±0.03	0.523±0.03	0.37	11.80±0.71	6.23±0.71	0.42	58.3±4.9	53.6±2.7	0.18
7	0375	0.811±0.05	0.642±0.02	0.27	10.75±0.66	7.42±0.67	0.43	61.5±5.1	49.5±3.0	0.20
8	0104-2	0.773±0.05	0.553±0.03	0.40	9.16±0.58	6.44±0.61	0.28	54.3±4.7	44.5±2.7	0.15
9	0105-1	0.849±0.05	0.538±0.03	0.37	9.32±0.59	6.32±0.60	0.32	52.4±4.7	44.5±3.0	0.15
10	0106-3	0.838±0.03	0.525±0.01	0.26	5.98±0.42	3.45±0.43	0.48	59.2±5.0	48.5±3.0	0.15
11	0118-2	0.723±0.04	0.663±0.03	0.33	12.33±0.74	8.42±0.73	0.35	60.0±5.0	50.0±3.0	0.16
12	0109-1	0.785±0.05	0.632±0.03	0.27	7.19±0.48	5.42±0.55	0.36	62.5±5.1	53.2±6.6	0.25
13	09-192	0.725±0.03	0.634±0.04	0.27	11.51±0.70	7.43±0.67	0.19	60.5±5.0	59.2±5.9	0.20
14	09-351	0.773±0.05	0.566±0.03	0.28	8.94±0.57	6.32±0.60	0.30	71.2±5.6	54.3±6.6	0.18
15	B1	0.770±0.05	0.523±0.03	0.27	7.85±0.51	4.52±0.49	0.29	59.4±5.0	51.4±4.7	0.24
16	B2	0.734±0.03	0.534±0.02	0.40	8.01±0.52	4.54±0.49	0.33	60.4±5.0	48.5±4.3	0.14
17	B3	0.772±0.05	0.588±0.03	0.20	10.27±0.63	6.74±0.62	0.33	62.3±5.1	59.3±4.9	0.28
18	B4	0.744±0.06	0.532±0.03	0.34	10.88±0.66	5.34±0.66	0.35	64.3±4.4	51.3±3.5	0.13
19	B5	0.851±0.05	0.634±0.03	0.32	13.41±0.79	11.01±0.76	0.17	65.5±4.5	64.3±3.6	0.23
20	C0108-1	0.767±0.05	0.604±0.03	0.32	8.41±0.54	5.67±0.56	0.32	72.0±4.8	65.9±3.7	0.21
21	C39	0.818±0.05	0.53±0.03	0.20	9.06±0.57	6.12±0.59	0.35	58.9±4.2	54.5±3.1	0.19
22	F2-116	0.681±0.04	0.611±0.04	0.15	6.59±0.45	5.43±0.76	0.33	63.2±4.4	60.5±3.0	0.24
23	F4-06	0.813±0.06	0.549±0.02	0.21	10.99±0.67	7.43±0.63	0.31	58.9±4.2	46.8±3.2	0.20
24	F4-1	0.850±0.05	0.588±0.04	0.16	13.40±0.79	11.24±0.67	0.28	62.5±4.3	59.3±3.4	0.17
25	F4-116	0.788±0.05	0.632±0.02	0.30	12.34±0.74	7.99±0.76	0.47	62.1±4.3	50.6±3.4	0.08
26	F4-21	0.795±0.05	0.583±0.03	0.26	10.69±0.65	6.88±0.63	0.39	70.4±4.7	52.5±3.8	0.19
27	F4-28	0.804±0.05	0.504±0.03	0.28	9.60±0.60	7.58±0.67	0.33	58.5±4.1	55.2±3.6	0.17
28	Aifeng99	0.813±0.05	0.488±0.04	0.19	11.74±0.71	8.43±0.73	0.25	60.4±4.2	51.4±3.7	0.15
29	Baomai1	0.802±0.07	0.593±0.02	0.35	12.43±0.74	7.60±0.74	0.33	62.4±5.0	50.4±3.4	0.07
30	Dekang961	0.818±0.05	0.538±0.03	0.23	12.90±0.77	8.35±0.72	0.25	62.4±5.0	54.5±3.7	0.15
31	Jimai22	0.790±0.05	0.442±0.03	0.08	9.77±0.61	6.53±0.67	0.32	67.2±5.2	59.4±4.0	0.17
32	Lian118	0.799±0.06	0.543±0.03	0.20	10.15±0.63	8.45±0.73	0.21	65.2±5.1	50.4±3.5	0.15
33	Liangxing66	0.811±0.05	0.483±0.04	0.21	12.75±0.76	8.59±0.74	0.33	70.1±5.4	60.3±4.2	0.08
34	Liangxing77	0.813±0.05	0.622±0.03	0.34	12.57±0.75	9.42±0.79	0.34	67.4±5.2	57.3±3.9	0.15
35	Liangxing99	0.809±0.05	0.603±0.03	0.25	11.72±0.71	9.42±0.79	0.20	69.3±5.4	59.3±4.0	0.14
36	Shannong19	0.791±0.05	0.642±0.03	0.25	9.92±0.62	8.90±0.75	0.18	60.4±5.4	55.3±3.7	0.02
37	Shannong20	0.691±0.03	0.577±0.03	0.44	10.27±0.63	7.44±0.67	0.33	59.3±5.3	49.5±3.4	0.12

38	Shangrong3	0.807±0.05	0.534±0.04	0.34	9.95±0.62	6.53±0.61	0.17	58.4±5.3	49.5±3.4	0.11
39	Su533	0.808±0.03	0.588±0.03	0.19	11.16±0.68	8.99±0.76	0.10	60.4±5.4	48.2±3.3	0.08
40	Su7078	0.805±0.05	0.537±0.03	0.10	15.31±0.89	9.99±0.82	0.18	62.4±5.5	52.6±3.9	0.04
41	Xumai30	0.851±0.05	0.532±0.04	0.37	11.69±0.70	8.24±0.59	0.21	64.5±5.7	54.3±3.7	0.06
42	Xumai7086	0.803±0.02	0.533±0.04	0.37	10.55±0.65	8.78±0.75	0.30	70.0±6.0	62.1±4.1	0.16
43	Yannong19	0.802±0.03	0.642±0.02	0.31	10.62±0.65	8.43±0.73	0.16	68.5±5.9	58.0±3.9	0.05

Table 2. Effect of salt stress on grain yield and yield components of wheat cultivars (Mean ±SE, n=3).

NO.	Cultivar	Grain yield/plant (g)			Spike no./plant			Grain no./spike			Grain weight (mg)		
		Control	Salt	(Control-Slat)/Control	Control	Salt	(Control-Slat)/Control	Control	Salt	(Control-Slat)/Control	Control	Salt	(Control-Slat)/Control
1	0108	5.86±2.83	5.04±2.76	0.33	6.6±0.6	6.2±0.4	0.06	30.0±2.0	28.2±1.7	0.19	30.69±1.38	27.08±1.92	0.25
2	0192	8.45±4.07	7.20±3.80	0.25	7.2±0.6	7.0±0.5	0.10	36.6±2.1	34.3±2.0	0.13	32.87±1.48	27.95±1.53	0.24
3	0307	6.61±3.19	5.79±3.12	0.43	6.6±0.6	6.5±0.4	0.09	29.2±1.9	26.0±1.6	0.18	35.33±1.59	30.70±1.57	0.22
4	0317	4.16±2.00	2.93±1.74	0.31	5.0±0.5	4.8±0.3	0.03	27.5±1.5	22.0±1.5	0.16	31.69±1.43	26.14±1.33	0.20
5	0354	7.81±3.77	5.23±2.85	0.07	7.0±0.6	6.6±0.4	0.00	32.4±2.0	26.2±1.8	0.14	35.32±1.59	26.38±1.35	0.19
6	0356	6.59±3.18	5.49±2.98	0.38	6.6±0.6	6.2±0.4	0.08	30.0±1.7	25.0±1.7	0.15	34.30±1.54	29.98±1.53	0.19
7	0375	5.42±2.61	4.34±2.42	0.15	4.5±0.5	4.2±0.3	0.11	35.0±2.0	29.0±1.8	0.12	35.72±1.61	31.14±1.59	0.19
8	0104-2	5.88±2.84	3.22±1.88	0.05	5.4±0.5	4.0±0.3	0.11	31.2±1.7	27.0±1.8	0.13	36.13±1.63	30.32±1.55	0.19
9	0105-1	6.55±3.16	4.78±2.63	0.27	6.0±0.5	5.6±0.4	0.07	32.0±1.8	30.7±1.9	0.04	35.20±1.63	28.81±1.47	0.18
10	0106-3	6.33±3.05	3.91±2.22	0.30	6.0±0.5	5.5±0.4	0.04	30.5±1.7	26.0±1.7	0.20	35.72±1.66	28.86±1.59	0.18
11	0118-2	4.64±3.26	4.35±2.91	0.23	4.6±0.3	4.0±0.6	0.03	28.2±1.7	26.0±1.6	0.13	37.29±1.73	33.46±1.84	0.17
12	0109-1	8.17±5.74	5.25±2.86	0.39	8.0±0.5	6.0±0.6	0.05	29.1±1.5	24.5±1.6	0.22	35.93±1.67	31.77±1.75	0.17
13	09-192	3.87±2.72	3.59±1.73	0.22	4.0±0.3	4.0±0.5	0.09	30.3±1.8	26.0±1.8	0.13	33.59±1.56	27.08±1.49	0.16
14	09-351	5.08±3.57	3.86±1.86	0.45	5.0±0.3	4.6±0.5	0.26	30.0±1.8	27.2±1.7	0.13	35.19±1.63	29.87±1.65	0.16
15	B1	5.72±4.02	4.26±2.05	0.24	6.3±0.4	5.7±0.5	0.08	27.0±1.8	23.4±1.8	0.09	34.83±1.62	26.62±1.47	0.15
16	B2	4.87±3.42	4.16±2.01	0.18	5.6±0.4	5.0±0.5	0.13	28.0±1.7	24.6±1.9	0.06	32.44±1.51	26.30±1.45	0.15
17	B3	6.43±4.52	3.66±1.76	0.15	5.5±0.4	5.0±0.5	0.03	34.3±1.9	28.2±1.9	0.06	35.22±1.63	27.44±1.51	0.15
18	B4	8.10±5.70	5.59±2.79	0.23	7.2±0.5	7.0±0.5	0.08	32.3±1.6	27.1±1.9	0.11	35.77±1.66	28.49±1.57	0.14
19	B5	7.26±4.84	5.37±2.68	0.10	7.0±0.4	6.8±0.6	0.07	33.0±2.0	27.0±1.8	0.07	32.38±1.50	30.30±1.67	0.14
20	C0108-1	6.43±4.28	4.56±2.28	0.40	5.6±0.4	5.0±0.5	0.09	34.0±2.0	30.0±1.7	0.23	34.93±1.62	31.67±1.62	0.14
21	C39	5.69±3.79	5.31±2.85	0.35	5.6±0.5	5.2±0.4	0.09	29.4±1.6	27.0±1.9	0.24	35.83±1.66	31.92±1.73	0.14
22	F2-116	5.51±3.67	4.28±2.14	0.12	4.8±0.5	4.2±0.3	0.02	36.5±2.0	28.4±2.1	0.11	32.67±1.52	31.48±1.61	0.13
23	F4-06	9.82±6.54	5.87±2.93	0.20	8.0±0.6	7.3±0.5	0.07	35.0±2.0	27.0±1.8	0.17	35.82±1.66	30.87±1.57	0.13
24	F4-1	5.09±3.39	4.22±2.11	0.03	5.7±0.5	5.2±0.4	0.05	33.0±1.7	26.0±1.9	0.07	28.21±1.32	26.44±1.45	0.13
25	F4-116	5.53±3.69	3.61±1.80	0.17	5.5±0.5	5.0±0.4	0.06	37.0±1.8	28.0±1.4	0.17	28.26±1.32	24.40±1.24	0.13
26	F4-21	5.85±3.90	3.55±2.05	0.28	6.3±0.6	6.0±0.4	0.06	32.4±1.6	25.3±1.8	0.12	29.72±1.38	24.63±1.26	0.12
27	F4-28	5.88±3.92	5.37±3.10	0.14	5.7±0.5	5.0±0.4	0.06	34.2±1.9	30.3±1.9	0.06	31.30±1.46	30.55±1.56	0.12
28	Aifeng99	3.18±2.12	3.03±2.04	0.36	4.5±0.5	4.0±0.4	0.25	24.6±1.4	21.3±1.4	0.16	30.71±1.43	24.94±1.32	0.12

29	Baomai1	6.34±4.46	4.56±2.63	0.07	6.4±0.6	6.0±0.4	0.07	33.0±1.9	29.0±1.8	0.08	31.02±1.40	27.29±1.44	0.11
30	Dekang961	4.95±3.29	3.82±2.21	0.26	6.0±0.4	5.5±0.4	0.12	27.0±1.5	24.0±1.7	0.05	31.61±1.42	27.19±1.44	0.11
31	Jimai22	7.76±5.17	4.19±2.42	0.06	7.2±0.5	5.8±0.5	0.13	35.6±2.0	26.0±1.7	0.08	30.96±1.73	29.19±1.54	0.10
32	Lian118	6.59±4.39	5.90±3.41	0.10	5.6±0.4	5.2±0.5	0.09	36.7±2.0	34.2±2.1	0.08	32.89±1.84	28.33±1.60	0.10
33	Liangxing66	4.96±3.30	4.07±2.35	0.29	4.8±0.3	4.2±0.5	0.11	34.0±1.9	32.0±2.0	0.12	31.53±1.77	26.80±1.42	0.09
34	Liangxing77	6.83±4.55	5.02±2.90	0.18	6.6±0.4	5.8±0.5	0.08	33.0±1.9	31.4±2.0	0.02	32.22±1.80	28.78±1.52	0.08
35	Liangxing99	9.76±6.50	7.76±5.46	0.20	7.4±0.5	6.8±0.6	0.08	37.0±2.1	35.0±2.2	0.05	36.33±2.03	33.52±1.71	0.08
36	Shannong19	6.72±4.48	6.61±4.40	0.26	5.6±0.4	5.2±0.5	0.03	34.3±1.9	33.0±2.1	0.18	35.99±2.38	34.48±1.76	0.06
37	Shannong20	8.07±5.38	7.81±5.47	0.46	6.3±0.4	6.0±0.4	0.19	36.5±2.0	34.0±2.4	0.27	35.86±2.01	31.30±1.60	0.06
38	Shangrong3	9.93±4.95	8.17±5.44	0.21	7.8±0.5	7.2±0.5	0.12	35.2±2.1	34.5±2.0	0.20	36.79±2.06	33.77±1.72	0.06
39	Su533	6.64±3.31	5.19±3.45	0.02	5.5±0.4	5.0±0.4	0.07	38.0±2.1	33.0±2.1	0.04	32.58±1.82	27.32±1.39	0.04
40	Su7078	7.58±3.78	5.86±3.90	0.22	7.2±0.6	7.0±0.4	0.13	31.0±1.9	27.0±1.7	0.22	34.97±1.96	28.96±1.48	0.04
41	Xumai30	9.94±3.73	6.08±4.05	0.09	8.0±0.6	6.8±0.4	0.12	37.2±1.7	27.6±2.1	0.11	34.14±1.91	33.59±1.71	0.02
42	Xumai7086	6.21±3.58	4.89±3.26	0.39	5.7±0.5	5.0±0.4	0.15	35.0±2.0	28.0±1.8	0.26	32.22±1.80	30.39±1.55	0.02
43	Yannong19	6.48±3.74	5.82±3.88	0.17	5.5±0.5	5.0±0.4	0.09	38.0±2.1	35.0±2.2	0.21	32.05±1.79	28.77±1.47	0.06

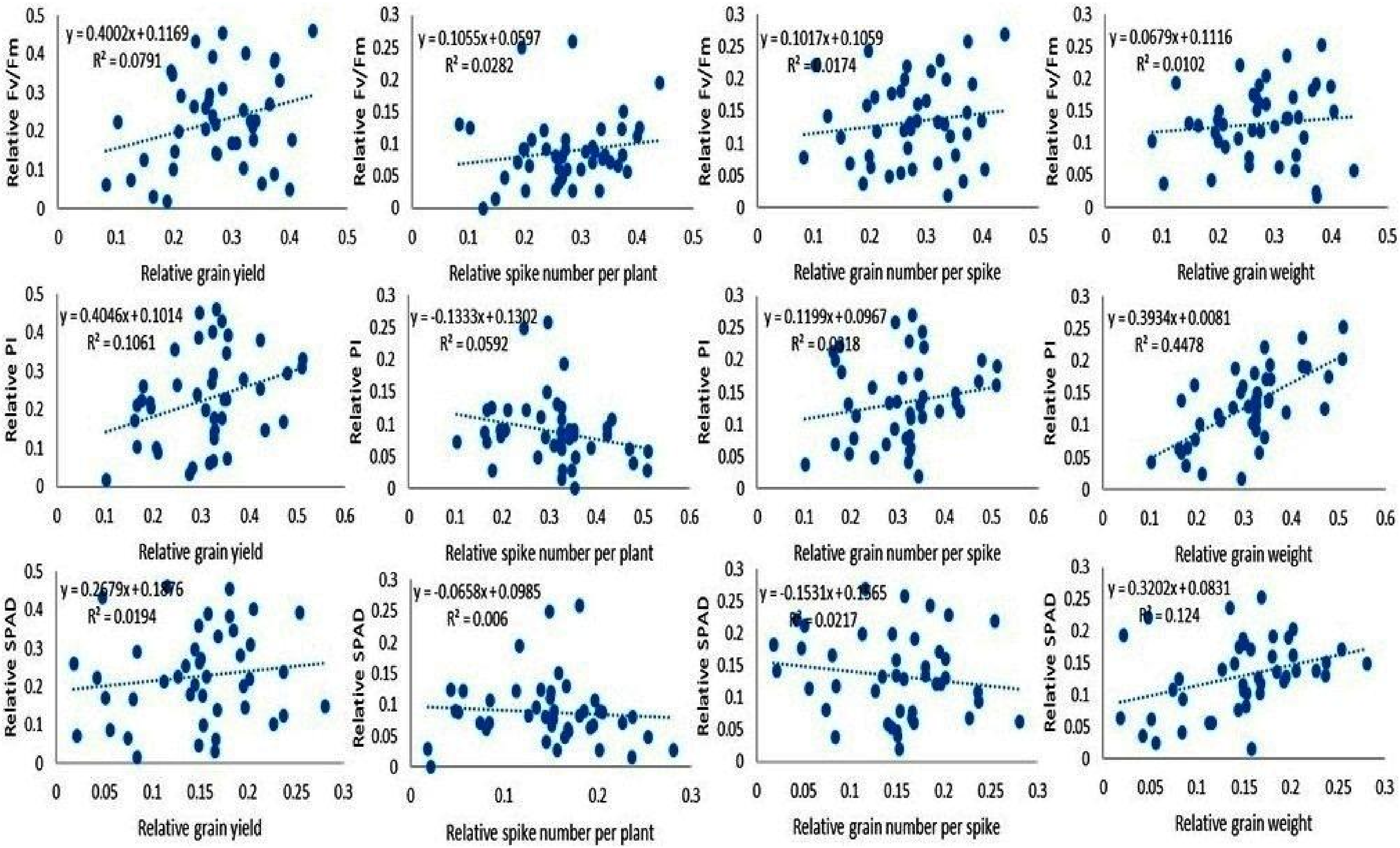

Figure 1. Linear correlations (Pearson's coefficients) of relative chlorophyll a fluorescence parameters, relative chlorophyll content to relative values of grain yield components of wheat cultivars under salt stress (Mean ±SE, n=3). The relative values were determined by calculating the ratio of the salt-induced reduction to the control for a given parameter.

lowest one in Xumai30 and line F4-28. In addition, depending on the changes in grain yield components, the salt-tolerant cultivars were Shannong19 and Shannong20, while the salt sensitive cultivars were Jimai22 and line 0104-2.

Relations between OJIP parameters and grain yield components: The relationships between the relative salt induced reduction of the measured parameters were shown in Figure 1. Significant positive linear relationships between relative PI and relative values of grain yield and grain weight were found among 43 wheat cultivars. The coefficient between relative PI and relative grain yield and grain weight was 0.106^{**} and 0.448^{**}, respectively. However, no significant linear relation was found between Fv/Fm and the yield components. Various studies have documented that Fv/Fm could be used to evaluate the salt tolerance (Mehta *et al*. 2010; El-Hendawy *et al*. 2017). Here, we found that it cannot well reflect the changes in grain yield in wheat exposed to salt stress. It has been reported that PI has a significant positive linear relationship with the grain production under water deficit in Lathyrus genus (Silvestre *et al*. 2014). Our results showed that PI was a good parameter for screening genotypes with higher grain weight and grain yield under salt stress.

Conclusion: It could be concluded that salt stress resulted in different reductions in chlorophyll content and chlorophyll a fluorescence parameters. The salt induced decrease in PI and Fv/Fm varied in a large range among 43 wheat cultivars. The grain yield loss induced by salt stress was mainly due to the decrease in grain weight in wheat. PI was a good parameter for screening genotypes with higher grain weight and grain yield under salt stress. In addition, the salt-tolerant cultivars were Shannong19 and Shannong20, while the salt sensitive cultivars were Jimai22 and line 0104-2.

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