

Rice (*Oryza sativa* L.) Grain Size, Shape, and Weight-Related QTLs Identified Using GWAS with Multiple GAPIT Models and High-Density SNP Chip DNA Markers

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Table S1. Normality test of grain traits (GL, GW, GT, LWR, and TGW)

Observations	Grain traits				
	GL	GW	GT	LWR	TGW
Mean	60.1	36.5	2.01	1.77	21.1
Std. Deviation	2.36	1.66	0.0664	0.123	1.29
Std. Error of Mean	0.192	0.135	0.0054	0.01	0.105
Sum	9077	5509	303	267	3189
Skewness	1.48	-1.15	-1.26	4.21	-0.41
Kurtosis	7.15	5.48	7.48	33.7	1.28
D'Agostino & Pearson normality test					
K2 (95.4% of data falls within two standard deviations of the mean)	65.7	49.7	59.6	174	10
P value	<.001	<.001	<.001	<.001	0.007
Passed normality test (alpha=0.05)?	No	No	No	No	No
P value summary	***	***	***	***	**
Shapiro-Wilk normality test					
W	0.885	0.916	0.909	0.722	0.976
P value	<.001	<.001	<.001	<.001	0.009
Passed normality test (alpha=0.05)?	No	No	No	No	No
P value summary	***	***	***	***	**

GL: grain length, GW: grain width, GT, grain thickness, LWR: grain length-to-width ratio, and TGW: thousand grain weight, *** $p < 0.001$, ** $p < 0.01$.

Table S2. Linked Markers to grain length, width, thickness, LWR, and thousand-grain weight.

Trait/QTL	SNP Chip Marker	Chr	Position (bp)	<i>P-value</i>	MAF	nobs	Effect	PVE (%)	Allele
GL	BLINK								
<i>qGL1-1^{BFSG}</i>	AX-95918134	1	3820526	4.27E-15	0.02	143	-3.54	72.5	TTWH1
<i>qGL11-1^{BFSG}</i>	AX-274862201	11	16356105	8.58E-24	0.06	143	2.35	31.9	Ilpum
<i>qGL2-1^{BFSG}</i>	AX-115751685	2	35100558	1.62E-10	0.34	143	-0.66	22.9	TTWH1
<i>qGL3-1^{BF}</i>	AX-154437636	3	2253428	1.72E-09	0.20	143	0.86	5.5	Ilpum
<i>qGL2-2^{BF}</i>	AX-154880023	2	35133528	2.88E-07	0.29	143	-0.70	3.1	TTWH1
<i>qGL7-1^{BFSG}</i>	AX-153903748	7	6690089	4.09E-12	0.44	143	-0.79	2.6	TTWH1
<i>qGL1-2^{BF}</i>	AX-279584700	1	41489588	6.18E-09	0.13	143	-1.29	1.7	TTWH1
<i>qGL5^{BFSG}</i>	AX-282746698	5	16169537	2.05E-09	0.19	143	0.72	1.4	Ilpum
	FarmCPU								
<i>qGL1-1^{BFSG}</i>	AX-95918134	1	3820526	2.49E-17	0.02	143	-3.72	65.5	TTWH1
<i>qGL11-1^{BFSG}</i>	AX-274862201	11	16356105	6.86E-23	0.06	143	2.26	34.5	Ilpum
<i>qGL11-2^{FSG}</i>	AX-115751092	11	2823622	3.79E-07	0.08	143	0.93	14.0	Ilpum
<i>qGL3-2^{Farm}</i>	AX-154551783	3	8242439	5.58E-08	0.17	143	-1.42	8.0	TTWH1
<i>qGL7-1^{BFSG}</i>	AX-153903748	7	6690089	2.67E-09	0.44	143	-0.73	7.6	TTWH1
<i>qGL2-1^{BFSG}</i>	AX-115751685	2	35100558	1.36E-07	0.34	143	-0.56	5.1	TTWH1
<i>qGL5-1^{BFSG}</i>	AX-282746698	5	16169537	1.27E-08	0.19	143	0.67	4.3	Ilpum
<i>qGL3-1^{BF}</i>	AX-154437636	3	2253428	3.00E-09	0.20	143	0.76	3.8	Ilpum
<i>qGL2-2^{BF}</i>	AX-154880023	2	35133528	1.23E-06	0.29	143	-0.64	3.2	TTWH1
<i>qGL1-2^{BF}</i>	AX-279584700	1	41489588	2.95E-08	0.13	143	-1.13	1.3	TTWH1
	SUPER								
<i>qGL1-1^{BFSG}</i>	AX-95918134	1	3820526	4.27E-15	0.02	143	-3.54	72.5	TTWH1
<i>qGL11-1^{BFSG}</i>	AX-274862201	11	16356105	6.86E-23	0.06	143	2.26	34.5	Ilpum
<i>qGL11-2^{FSG}</i>	AX-115751092	11	2823622	3.79E-07	0.08	143	0.93	14.0	Ilpum
<i>qGL7-1^{BFSG}</i>	AX-153903748	7	6690089	2.67E-09	0.44	143	-0.73	7.6	TTWH1
<i>qGL2-1^{BFSG}</i>	AX-115751685	2	35100558	1.36E-07	0.34	143	-0.56	5.1	TTWH1
<i>qGL5-1^{BFSG}</i>	AX-282746698	5	16169537	1.27E-08	0.18	143	0.67	4.3	Ilpum
	GLM								
<i>qGL1-1^{BFSG}</i>	AX-95918134	1	3820526	4.27E-15	0.02	143	-3.54	72.5	TTWH1
<i>qGL11-1^{BFSG}</i>	AX-274862201	11	16356105	6.86E-23	0.06	143	2.26	34.5	Ilpum
<i>qGL11-2^{FSG}</i>	AX-115751092	11	2823622	3.79E-07	0.08	143	0.93	14.0	Ilpum
<i>qGL7-1^{BFSG}</i>	AX-153903748	7	6690089	2.67E-09	0.44	143	-0.73	7.6	TTWH1
<i>qGL2-1^{BFSG}</i>	AX-115751685	2	35100558	1.36E-07	0.34	143	-0.56	5.1	TTWH1
<i>qGL5-1^{BFSG}</i>	AX-282746698	5	16169537	1.27E-08	0.18	143	0.67	4.3	Ilpum
GW	BLINK								
<i>qGW1-1^{BFSG}</i>	AX-273945773	1	5623288	8.36E-13	0.32	143	0.63	18.9	Ilpum
<i>qGW2-1^{Blink}</i>	AX-279699609	2	10805604	8.17E-18	0.10	143	-1.16	14.9	TTWH1
<i>qGW1-3^{BF}</i>	AX-115791785	1	43103625	9.44E-28	0.30	143	-1.01	8.8	TTWH1
<i>qGW1-4^{Blink}</i>	AX-281116133	1	20864932	1.52E-11	0.17	143	0.56	6.9	Ilpum
<i>qGW6-1^{BF}</i>	AX-115737727	6	28484619	5.27E-07	0.15	143	0.42	6.2	Ilpum
<i>qGW3-1^{Blink}</i>	AX-154073979	3	7895651	9.65E-08	0.33	143	0.46	4.8	Ilpum
<i>qGW3-2^{Blink}</i>	AX-115811160	3	14888685	6.12E-15	0.21	143	0.65	4.1	Ilpum
	FarmCPU								

$qGW1-1^{BFSG}$	AX-273945773	1	5623288	3.39E-09	0.32	143	0.57	15.5	Ilpum
$qGW6-2^{FSG}$	AX-273990782	6	13986482	2.45E-07	0.12	143	-0.44	14.9	TTWH1
$qGW1-6^{Farm}$	AX-280898927	1	2483022	2.66E-08	0.06	143	-0.66	9.4	TTWH1
$qGW1-3^{BF}$	AX-115791785	1	43103625	5.18E-10	0.30	143	-0.44	8.7	TTWH1
$qGW6-1^{BF}$	AX-115737727	6	28484619	5.27E-07	0.15	143	0.48	5.4	Ilpum
$qGW12-1^{FSG}$	AX-284265976	12	13013702	6.88E-08	0.10	143	-0.39	4.2	TTWH1
$qGW8-1^{FSG}$	AX-115796459	8	3875546	2.89E-08	0.21	143	0.40	3.7	Ilpum
$qGW2-3^{Farm}$	AX-279994820	2	35461009	2.02E-06	0.15	143	-0.68	3.5	TTWH1
$qGW2-4^{Farm}$	AX-154042022	2	24704256	1.30E-09	0.27	143	0.54	3.4	Ilpum
$qGW3-3^{Farm}$	AX-154797543	3	2973374	4.00E-07	0.31	143	0.39	1.2	Ilpum
SUPER									
$qGW1-1^{BFSG}$	AX-273945773	1	5623288	3.39E-09	0.32	143	0.57	15.5	Ilpum
$qGW6-2^{FSG}$	AX-273990782	6	13986482	2.45E-07	0.12	143	-0.44	14.9	TTWH1
$qGW12-1^{FSG}$	AX-284265976	12	13013702	6.88E-08	0.09	143	-0.39	4.2	TTWH1
$qGW8-1^{FSG}$	AX-115796459	8	3875546	2.89E-08	0.21	143	0.40	3.7	Ilpum
GLM									
$qGW1-1^{BFSG}$	AX-273945773	1	5623288	3.39E-09	0.32	143	0.57	15.5	Ilpum
$qGW6-2^{FSG}$	AX-273990782	6	13986482	2.45E-07	0.12	143	-0.44	14.9	TTWH1
$qGW12-1^{FSG}$	AX-284265976	12	13013702	6.88E-08	0.09	143	-0.39	4.2	TTWH1
$qGW8-1^{FSG}$	AX-115796459	8	3875546	2.89E-08	0.21	143	0.40	3.7	Ilpum
GT	BLINK								
$qGT1^{Blink}$	AX-279261704	1	18023142	3.10E-07	0.02	143	-0.07	74.9	TTWH1
FarmCPU									
$qGT2-1^{Farm}$	AX-154787777	2	2118477	3.09E-11	0.03	143	-0.13	54.9	TTWH1
$qGT2-2^{Farm}$	AX-154913392	2	25105471	7.77E-09	0.29	143	0.03	5.3	Ilpum
LWR	BLINK								
$qLWR10^{Blink}$	AX-115835839	10	22038978	5.11E-07	0.17	143	0.03	26.5	Ilpum
$qLWR2-1^{BFSG}$	AX-274833045	2	10000097	1.24E-07	0.06	143	-0.09	15.2	TTWH1
$qLWR1-1^{BF}$	AX-154960834	1	1595394	1.51E-12	0.41	143	-0.04	13.5	TTWH1
$qLWR1-2^{Blink}$	AX-115737888	1	600441	6.38E-09	0.15	143	-0.06	10.7	TTWH1
$qLWR3^{Blink}$	AX-154834762	3	8098398	6.51E-10	0.17	143	-0.08	6.9	TTWH1
FarmCPU									
$qLWR2-1^{BFSG}$	AX-274833045	2	10000097	1.38E-08	0.06	143	-0.11	32.9	TTWH1
$qLWR6-1^{FSG}$	AX-115851421	6	10178858	1.54E-16	0.08	143	0.07	30.5	Ilpum
$qLWR1-1^{BF}$	AX-154960834	1	1595394	9.97E-11	0.41	143	-0.04	13.2	TTWH1
$qLWR6-2^{FSG}$	AX-155522120	6	30842264	1.26E-06	0.15	143	-0.05	9.4	TTWH1
$qLWR8^{FSG}$	AX-154176130	8	5398451	4.47E-07	0.15	143	-0.04	5.9	TTWH1
SUPER									
$qLWR2-1^{BFSG}$	AX-274833045	2	10000097	1.24E-07	0.06	143	-0.09	15.2	TTWH1
$qLWR6-1^{FSG}$	AX-115851421	6	10178858	1.54E-16	0.08	143	0.07	30.5	Ilpum
$qLWR6-2^{FSG}$	AX-155522120	6	30842264	1.26E-06	0.15	143	-0.05	9.4	TTWH1
$qLWR8^{FSG}$	AX-154176130	8	5398451	4.47E-07	0.15	143	-0.04	5.9	TTWH1
GLM									
$qLWR2-1^{BFSG}$	AX-274833045	2	10000097	1.24E-07	0.06	143	-0.09	15.2	TTWH1
$qLWR6-1^{FSG}$	AX-115851421	6	10178858	1.54E-16	0.08	143	0.07	30.5	Ilpum
$qLWR6-2^{FSG}$	AX-155522120	6	30842264	1.26E-06	0.15	143	-0.05	9.3	TTWH1

<i>qLWR8^{FSG}</i>	AX-154176130	8	5398451	4.47E-07	0.15	143	-0.04	5.9	TTWH1
TGW	BLINK								
<i>qTGW6^{BFSG}</i>	AX-115737727	6	28484619	3.60E-10	0.15	143	0.88	32.8	Ilpum
<i>qTGW2-1^{BF}</i>	AX-279699609	2	10805604	4.19E-21	0.10	143	-1.33	18.6	TTWH1
<i>qTGW1-1^{Blink}</i>	AX-154298059	1	5644298	2.56E-06	0.30	143	0.37	11.6	Ilpum
<i>qTGW3-1^{BF}</i>	AX-154471576	3	15332432	1.08E-10	0.06	143	-0.93	10.7	TTWH1
<i>qTGW2-2^{BF}</i>	AX-154096541	2	10773042	1.05E-11	0.17	143	0.83	7.8	Ilpum
<i>qTGW1-2^{BFSG}</i>	AX-154333920	1	5860250	1.95E-10	0.30	143	0.40	4.9	Ilpum
<i>qTGW1-3^{BF}</i>	AX-154810092	1	42931550	2.15E-17	0.26	143	-0.62	4.03	TTWH1
	FarmCPU								
<i>qTGW6^{BFSG}</i>	AX-115737727	6	28484619	9.95E-08	0.15	143	0.71	54.0	Ilpum
<i>qTGW2-1^{BF}</i>	AX-279699609	2	10805604	5.49E-15	0.10	143	-0.98	27.9	TTWH1
<i>qTGW3-2^{Farm}</i>	AX-123153600	3	7887961	2.47E-19	0.33	143	0.84	13.9	Ilpum
<i>qTGW1-3^{BF}</i>	AX-154810092	1	42931550	4.87E-17	0.26	143	-0.58	8.3	TTWH1
<i>qTGW2-2^{BF}</i>	AX-154096541	2	10773042	3.38E-10	0.17	143	0.72	7.5	Ilpum
<i>qTGW3-1^{BF}</i>	AX-154471576	3	15332432	4.98E-09	0.06	143	-0.79	7.2	TTWH1
<i>qTGW1-2^{BFSG}</i>	AX-154333920	1	5860250	1.41E-11	0.30	143	0.57	6.2	Ilpum
	SUPER								
<i>qTGW6^{BFSG}</i>	AX-115737727	6	28484619	9.95E-08	0.15	143	0.71	54.0	Ilpum
<i>qTGW1-2^{BFSG}</i>	AX-154333920	1	5860250	1.41E-11	0.30	143	0.57	6.2	Ilpum
	GLM								
<i>qTGW6^{BFSG}</i>	AX-115737727	6	28484619	9.95E-08	0.15	143	0.71	54.0	Ilpum
<i>qTGW1-2^{BFSG}</i>	AX-154333920	1	5860250	1.41E-11	0.30	143	0.57	6.2	Ilpum

GL: grain length, GW: grain width, GT: grain thickness, LWR: Length-to-width ratio, and TGW: thousand-grain weight. Chr: chromosome, MAF: minor allelic frequency, nobs: number of observations, PVE: phenotype variance explained. *qTrait^{Blink}*: QTL detected by BLINK only, *qTrait^{Farm}*: QTL detected by FarmCPU only, GLM, *qTrait^{Glm}*: QTL detected by GLM only, *qTrait^{FSG}*: QTL co-detected by FarmCPU, SUPER, and GLM, *qTrait^{BFSG}*: QTL co-detected by BLINK, FarmCPU, SUPER, and GLM.

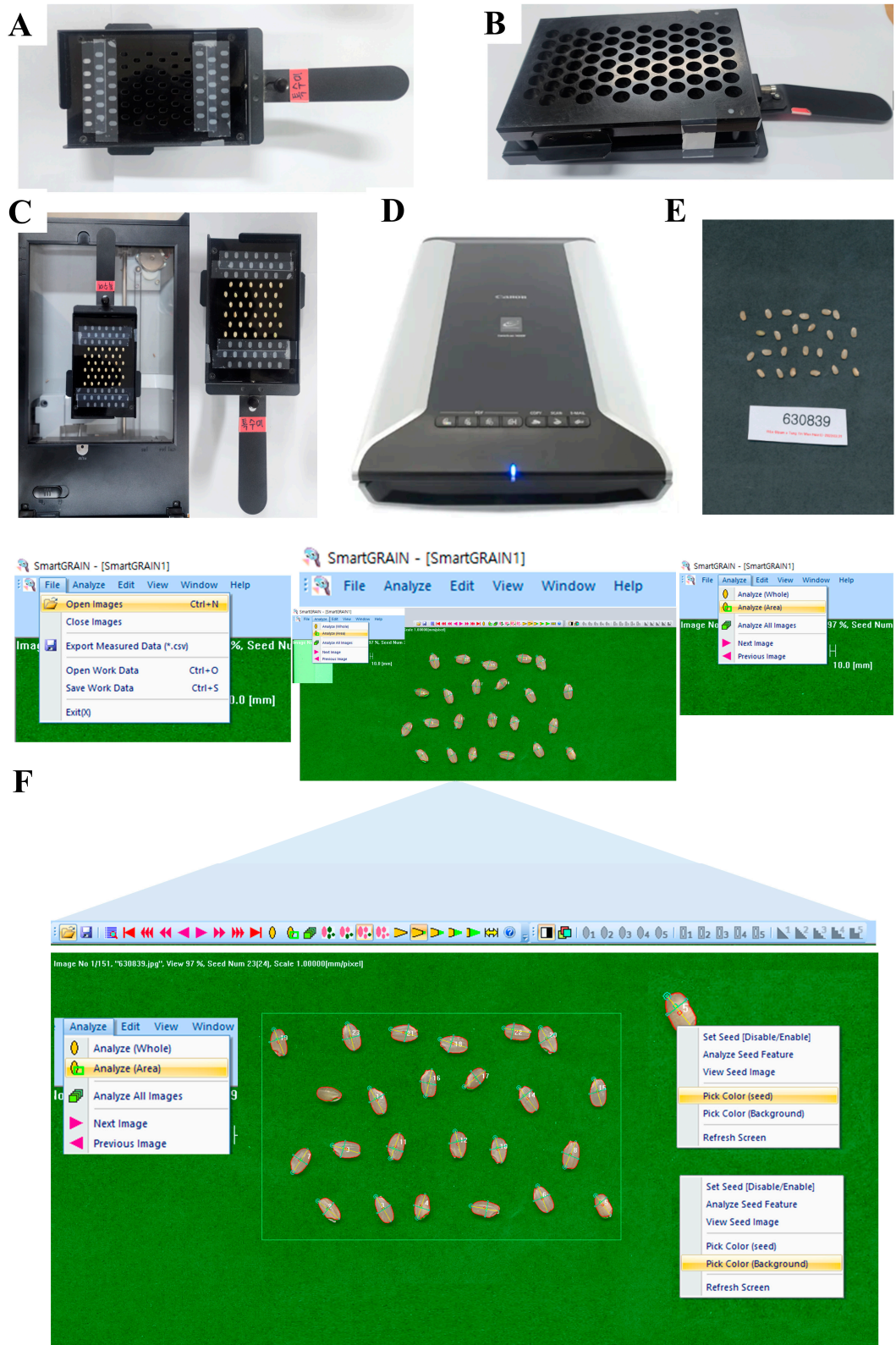


Figure S1. Illustration of rice grain length, width, and length-to-width ratio analysis using SMART GRAIN software. (A,B) Images of a rice grain dispenser, (C) A rice dispenser with rice grain on a scanner, (D,E) Scanner and scanned rice grains with a label, and (F) visualization of stepwise grain shape analysis.