Table S8 Genome-wide Association Study Results with No Covariates (A)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	α-Carotene/Zeinoxanthin	ss196425306	55K	1	86,844,203	3.47E-10	3.36E-05	0.31	196	0.40	0.28	0.17	0.35	0.06	-0.25	-0.22
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	Zeinoxanthin/Lutein	ss196425306	55K	1	86,844,203	4.97E-08	7.19E-03	0.29	195	0.40	0.28	0.09	0.24	-0.19	-0.35	0.84
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	Zeinoxanthin	ss196425306	55K	1	86,844,203	8.95E-08	1.30E-02	0.30	198	0.40	0.28	0.10	0.24	-0.11	-0.25	0.62
			α-Carotene/Zeinoxanthin	ss196425308	55K	1	86,945,134	3.47E-10	3.36E-05	0.31	196	0.40	0.27	0.17	0.35	0.06	-0.25	-0.22
			Zeinoxanthin/Lutein	ss196425308	55K	1	86,945,134	4.97E-08	7.19E-03	0.29	195	0.40	0.27	0.09	0.24	-0.19	-0.35	0.84
			Zeinoxanthin	ss196425308	55K	1	86,945,134	8.95E-08	1.30E-02	0.30	198	0.40	0.27	0.10	0.24	-0.11	-0.25	0.62
			Lutein	S1_96310268	GBS	1	96,310,268	3.71E-07	3.61E-02	0.17	200	0.06	0.21	0.17	0.28	1.19	0.80	1.67
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448432	GBS	2	44,448,432	2.22E-09	3.22E-04	0.11	196	0.29	0.09	0.05	0.24	-0.34	0.35	-0.69
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448432	GBS	2	44,448,432	1.66E-08	2.41E-03	0.11	195	0.29	0.09	0.05	0.22	-0.43	0.40	-0.76
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448432	GBS	2	44,448,432	4.82E-08	2.80E-03	0.11	196	0.29	0.09	0.15	0.29	0.13	-0.40	-0.26
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448438	GBS	2	44,448,438	2.22E-09	3.22E-04	0.11	196	0.29	0.09	0.05	0.24	0.34	0.35	1.31
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448438	GBS	2	44,448,438	1.66E-08	2.41E-03	0.11	195	0.29	0.09	0.05	0.22	0.43	0.40	1.46
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448438	GBS	2	44,448,438	4.82E-08	2.80E-03	0.11	196	0.29	0.09	0.15	0.29	-0.13	-0.40	0.42
			Zeaxanthin	S2_44473748	GBS	2	44,473,748	1.47E-06	4.27E-02	0.14	196	0.25	0.12	0.05	0.17	0.24	0.35	0.86
			β-Xanthophylls/α-Xanthophylls	S2_44473748	GBS	2	44,473,748	5.21E-06	9.00E-02	0.14	196	0.25	0.12	0.15	0.24	-0.09	-0.40	0.28
			Zeaxanthin	S2_44473758	GBS	2	44,473,758	1.47E-06	4.27E-02	0.14	196	0.24	0.12	0.05	0.17	-0.24	0.35	-0.55
			β-Xanthophylls/α-Xanthophylls	S2_44473758	GBS	2	44,473,758	5.21E-06	9.00E-02	0.14	196	0.24	0.12	0.15	0.24	0.09	-0.40	-0.20
			Zeaxanthin	S2_44473801	GBS	2	44,473,801	1.47E-06	4.27E-02	0.14	196	0.24	0.12	0.05	0.17	0.24	0.35	0.86
			β-Xanthophylls/α-Xanthophylls	S2_44473801	GBS	2	44,473,801	5.21E-06	9.00E-02	0.14	196	0.24	0.12	0.15	0.24	-0.09	-0.40	0.28
			β-Xanthophylls/α-Xanthophylls	S2_44474139	GBS	2	44,474,139	7.57E-06	9.64E-02	0.14	196	0.29	0.13	0.15	0.24	0.09	-0.40	-0.20
			Zeaxanthin	S2_44474308	GBS	2	44,474,308	1.19E-06	4.27E-02	0.21	196	0.38	0.28	0.05	0.17	0.21	0.35	0.73
			β-Xanthophylls/α-Xanthophylls	S2_44474308	GBS	2	44,474,308	7.03E-06	9.64E-02	0.21	196	0.38	0.28	0.15	0.24	-0.08	-0.40	0.24
			Zeaxanthin	S3_169734997	GBS	3	169,734,997	1.16E-06	4.27E-02	0.06	196	0.25	0.07	0.05	0.17	-0.42	0.35	-0.79
			Total β-Xanthophylls	S3_169734997	GBS	3	169,734,997	1.04E-06	5.00E-02	0.06	195	0.25	0.07	0.05	0.18	-0.58	0.40	-0.89
			Total α-Xanthophylls	ss196456701	55K	4	146,977,283	1.00E-06	9.76E-02	0.12	200	0.38	0.08	0.10	0.22	-0.87	0.70	-0.95
			β-Cryptoxanthin	S7_13843351	GBS	7	13,843,351	1.66E-07	4.84E-02	0.15	199	0.10	0.16	0.11	0.24	-0.04	0.10	-0.33
			Zeinoxanthin	S7_15282645	GBS	7	15,282,645	2.34E-07	2.27E-02	0.17	198	0.42	0.20	0.10	0.23	-0.12	-0.25	0.65
			β-Xanthophylls/α-Xanthophylls	ss196477160	55K	7	51,472,566	5.57E-06	9.00E-02	0.43	196	0.43	0.43	0.15	0.24	0.07	-0.40	-0.16
			β-Xanthophylls/α-Xanthophylls	S8_129072699	GBS	8	129,072,699	6.48E-06	9.40E-02	0.36	196	0.50	0.35	0.15	0.24	0.07	-0.40	-0.15
			β-Xanthophylls/α-Xanthophylls	S8_129124626	GBS	8	129,124,626	8.20E-06	9.91E-02	0.29	196	0.27	0.31	0.15	0.24	-0.07	-0.40	0.20
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Total α-Xanthophylls	*lcyE* 5'TE	Additonal Markers	8	138,882,481	4.37E-09	6.39E-04	NA	NA	NA	NA	.10	.43	NA	0.70	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Lutein	*lcyE* 5'TE	Additonal Markers	8	138,882,481	1.75E-08	2.56E-03	NA	NA	NA	NA	.11	.49	NA	0.80	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	ss196504160	55K	8	138,882,711	1.11E-09	1.61E-04	0.35	196	0.48	0.34	0.15	0.33	0.11	-0.40	-0.22

Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**ss196504160**	**55K**	**8**	**138,882,711**	**2.08E-09**	**6.00E-04**	**0.36**	**190**	**0.48**	**0.34**	**0.18**	**0.35**	**0.12**	**-0.85**	**-0.12**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882711**	**GBS**	**8**	**138,882,711**	**8.85E-07**	**2.37E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.15**	**0.26**	**-0.09**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Total β-Xanthophylls	ss196504160	55K	8	138,882,711	1.36E-06	5.61E-02	0.35	195	0.48	0.34	0.05	0.18	-0.26	0.40	-0.53
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Zeaxanthin	ss196504160	55K	8	138,882,711	2.30E-06	6.05E-02	0.35	196	0.48	0.34	0.05	0.16	-0.19	0.35	-0.45
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882747**	**GBS**	**8**	**138,882,747**	**8.85E-07**	**2.37E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.15**	**0.26**	**-0.09**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882751**	**GBS**	**8**	**138,882,751**	**8.85E-07**	**2.37E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.15**	**0.26**	**-0.09**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882798**	**GBS**	**8**	**138,882,798**	**8.99E-07**	**2.37E-02**	**0.31**	**196**	**0.21**	**0.36**	**0.15**	**0.26**	**-0.08**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**9.76E-08**	**4.72E-03**	**0.43**	**196**	**0.12**	**0.44**	**0.15**	**0.28**	**-0.08**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**6.03E-08**	**8.70E-03**	**0.44**	**190**	**0.12**	**0.44**	**0.18**	**0.32**	**-0.10**	**-0.85**	**0.13**
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	S8_138883026	GBS	8	138,883,026	5.90E-06	9.00E-02	0.40	196	0.18	0.48	0.15	0.24	0.07	-0.40	-0.16
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	S8_138883056	GBS	8	138,883,056	5.90E-06	9.00E-02	0.40	196	0.18	0.48	0.15	0.24	-0.07	-0.40	0.21
Carotenoid Degradation																		
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**5.05E-16**	**1.46E-10**	**NA**	**NA**	**NA**	**NA**	**.10**	**.24**	**NA**	**-0.40**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**4.62E-10**	**1.35E-04**	**NA**	**NA**	**NA**	**NA**	**.10**	**.40**	**NA**	**0.70**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Lutein**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**6.28E-09**	**1.84E-03**	**NA**	**NA**	**NA**	**NA**	**.11**	**.45**	**NA**	**0.80**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total β-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**1.65E-07**	**1.20E-02**	**NA**	**NA**	**NA**	**NA**	**.06**	**.30**	**NA**	**0.40**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	PZB00665.1	4K	8	138,886,137	3.82E-06	8.52E-02	0.35	196	0.05	0.38	0.15	0.25	0.08	-0.40	-0.17
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**2.52E-08**	**2.44E-03**	**0.47**	**196**	**0.19**	**0.42**	**0.15**	**0.30**	**-0.09**	**-0.40**	**0.28**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**1.82E-07**	**1.75E-02**	**0.47**	**190**	**0.19**	**0.42**	**0.18**	**0.31**	**-0.10**	**-0.85**	**0.13**
			β-Xanthophylls/α-Xanthophylls	**ss196508843**	**55K**	**8**	**139,143,878**	**8.80E-07**	**2.37E-02**	**0.29**	**196**	**0.38**	**0.26**	**0.15**	**0.26**	**0.08**	**-0.40**	**-0.18**
			β-Carotenoids/α-Carotenoids	S8_140192724	GBS	8	140,192,724	9.64E-07	6.95E-02	0.34	190	0.19	0.28	0.18	0.29	-0.09	-0.85	0.12
			β-Xanthophylls/α-Xanthophylls	S8_140192724	GBS	8	140,192,724	3.49E-06	8.43E-02	0.33	196	0.19	0.28	0.15	0.25	-0.08	-0.40	0.22
			Total β-Xanthophylls	**S8_171705545**	**GBS**	**8**	**171,705,545**	**5.15E-07**	**2.98E-02**	**0.10**	**195**	**0.14**	**0.14**	**0.05**	**0.19**	**-0.40**	**0.40**	**-0.72**

			Zeaxanthin	**S8_171705545**	**GBS**	**8**	**171,705,545**	**8.40E-07**	**4.27E-02**	**0.11**	**196**	**0.14**	**0.14**	**0.05**	**0.17**	**-0.28**	**0.35**	**-0.61**
			Total β-Xanthophylls	**S8_171705574**	**GBS**	**8**	**171,705,574**	**1.61E-07**	**1.20E-02**	**0.10**	**195**	**0.25**	**0.13**	**0.05**	**0.20**	**-0.42**	**0.40**	**-0.74**
			Zeaxanthin	**S8_171705574**	**GBS**	**8**	**171,705,574**	**2.39E-07**	**2.31E-02**	**0.11**	**196**	**0.25**	**0.13**	**0.05**	**0.19**	**-0.29**	**0.35**	**-0.63**
			α-Carotene/Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**3.31E-10**	**3.36E-05**	**0.31**	**196**	**0.37**	**0.29**	**0.17**	**0.35**	**-0.06**	**-0.25**	**0.30**
			Zeinoxanthin/Lutein	**ss196491114**	**55K**	**9**	**69,215,031**	**9.80E-08**	**9.46E-03**	**0.28**	**195**	**0.37**	**0.29**	**0.09**	**0.23**	**0.19**	**-0.35**	**-0.39**
			Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**3.76E-07**	**2.74E-02**	**0.30**	**198**	**0.37**	**0.29**	**0.10**	**0.23**	**0.11**	**-0.25**	**-0.34**
			β-Xanthophylls/α-Xanthophylls	ss196493105	55K	9	118,437,281	7.64E-06	9.64E-02	0.29	196	0.19	0.42	0.15	0.24	-0.09	-0.40	0.25
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	*crtRB1* InDel4	Additonal Markers	10	136,059,748	2.23E-07	5.10E-02	NA	NA	NA	NA	.06	.11	NA	-0.25	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	ss196501627	55K	10	136,060,033	3.51E-07	5.10E-02	0.19	196	0.00	0.22	0.04	0.18	0.12	-0.25	-0.36
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Zeaxanthin**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**1.11E-06**	**4.27E-02**	**NA**	**NA**	**NA**	**NA**	**.05**	**.17**	**NA**	**0.35**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Total β-Xanthophylls	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.97E-06	7.13E-02	NA	NA	NA	NA	.06	.18	NA	0.40	NA

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits without any markers tagging peak GWAS signals included as covariates. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font.

Table S8 Genome-wide Association Study Results with Covariate from *zep1* (B)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**α-Carotene/Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**3.47E-10**	**3.36E-05**	**0.31**	**196**	**0.40**	**0.28**	**0.17**	**0.35**	**0.06**	**-0.25**	**-0.22**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin/Lutein**	**ss196425306**	**55K**	**1**	**86,844,203**	**4.97E-08**	**7.19E-03**	**0.29**	**195**	**0.40**	**0.28**	**0.09**	**0.24**	**-0.19**	**-0.35**	**0.84**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**8.95E-08**	**1.30E-02**	**0.30**	**198**	**0.40**	**0.28**	**0.10**	**0.24**	**-0.11**	**-0.25**	**0.62**
			α-Carotene/Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**3.47E-10**	**3.36E-05**	**0.31**	**196**	**0.40**	**0.27**	**0.17**	**0.35**	**0.06**	**-0.25**	**-0.22**
			Zeinoxanthin/Lutein	**ss196425308**	**55K**	**1**	**86,945,134**	**4.97E-08**	**7.19E-03**	**0.29**	**195**	**0.40**	**0.27**	**0.09**	**0.24**	**-0.19**	**-0.35**	**0.84**
			Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**8.95E-08**	**1.30E-02**	**0.30**	**198**	**0.40**	**0.27**	**0.10**	**0.24**	**-0.11**	**-0.25**	**0.62**
			Lutein	**S1_96310268**	**GBS**	**1**	**96,310,268**	**3.30E-07**	**3.22E-02**	**0.17**	**200**	**0.06**	**0.21**	**0.12**	**0.24**	**1.23**	**0.80**	**1.73**
			β-Carotene/β-Cryptoxanthin	S2_228979822	GBS	2	228,979,822	5.38E-07	7.85E-02	0.08	198	0.30	0.05	0.10	0.22	-0.17	-0.70	0.31
			Total α-Xanthophylls	ss196456701	55K	4	146,977,283	1.00E-06	9.76E-02	0.12	200	0.38	0.08	0.10	0.22	-0.87	0.70	-0.95
			β-Cryptoxanthin	**S7_13843351**	**GBS**	**7**	**13,843,351**	**1.66E-07**	**4.84E-02**	**0.15**	**199**	**0.10**	**0.16**	**0.11**	**0.24**	**-0.04**	**0.10**	**-0.33**
			Zeinoxanthin	**S7_15282645**	**GBS**	**7**	**15,282,645**	**2.34E-07**	**2.27E-02**	**0.17**	**198**	**0.42**	**0.20**	**0.10**	**0.23**	**-0.12**	**-0.25**	**0.65**
			β-Xanthophylls/α-Xanthophylls	ss196477156	55K	7	51,471,492	1.02E-05	7.84E-02	0.40	196	0.43	0.39	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	**ss196477160**	**55K**	**7**	**51,472,566**	**1.06E-06**	**2.56E-02**	**0.43**	**196**	**0.43**	**0.43**	**0.29**	**0.38**	**0.07**	**-0.40**	**-0.16**
			β-Xanthophylls/α-Xanthophylls	ss196477229	55K	7	51,645,966	1.04E-05	7.84E-02	0.49	196	0.43	0.49	0.29	0.37	-0.06	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	ss196477237	55K	7	51,806,575	1.04E-05	7.84E-02	0.49	196	0.43	0.50	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	ss196477251	55K	7	51,981,502	1.04E-05	7.84E-02	0.49	196	0.43	0.50	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	ss196477253	55K	7	51,997,363	1.04E-05	7.84E-02	0.49	196	0.43	0.49	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	ss196477265	55K	7	52,248,496	1.04E-05	7.84E-02	0.49	196	0.43	0.48	0.29	0.37	-0.06	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	ss196477269	55K	7	52,290,305	1.04E-05	7.84E-02	0.49	196	0.43	0.50	0.29	0.37	-0.06	-0.40	0.18
			Total β-Xanthophylls	S8_27117706	GBS	8	27,117,706	1.52E-06	6.30E-02	0.17	195	0.25	0.17	0.22	0.32	-0.29	0.40	-0.57
			Zeaxanthin	S8_27117706	GBS	8	27,117,706	2.00E-06	8.27E-02	0.17	196	0.25	0.17	0.24	0.33	-0.21	0.35	-0.48
			β-Xanthophylls/α-Xanthophylls	PZB01094.1	4K	8	27,117,892	5.82E-06	7.04E-02	0.21	196	0.29	0.21	0.29	0.37	-0.08	-0.40	0.22
			Total β-Xanthophylls	S8_27118357	GBS	8	27,118,357	1.86E-06	6.74E-02	0.19	195	0.48	0.18	0.22	0.32	-0.27	0.40	-0.55
			Zeaxanthin	S8_27118357	GBS	8	27,118,357	2.91E-06	9.36E-02	0.19	196	0.48	0.18	0.24	0.33	-0.19	0.35	-0.46
			β-Xanthophylls/α-Xanthophylls	**S8_111289041**	**GBS**	**8**	**111,289,041**	**3.06E-06**	**4.94E-02**	**0.40**	**196**	**0.05**	**0.34**	**0.29**	**0.38**	**0.07**	**-0.40**	**-0.16**
			β-Carotenoids/α-Carotenoids	**S8_112713556**	**GBS**	**8**	**112,713,556**	**2.23E-06**	**4.28E-02**	**0.18**	**189**	**0.27**	**0.17**	**0.29**	**0.38**	**0.10**	**-0.85**	**-0.11**
			β-Xanthophylls/α-Xanthophylls	ss196516758	55K	8	112,713,556	4.09E-06	5.65E-02	0.20	196	0.45	0.17	0.29	0.37	-0.08	-0.40	0.24
			β-Carotenoids/α-Carotenoids	ss196516758	55K	8	112,713,556	4.34E-06	7.81E-02	0.21	189	0.45	0.17	0.29	0.37	-0.09	-0.85	0.12
			β-Xanthophylls/α-Xanthophylls	S8_112713556	GBS	8	112,713,556	8.41E-06	7.84E-02	0.17	196	0.27	0.17	0.29	0.37	0.08	-0.40	-0.18
			β-Xanthophylls/α-Xanthophylls	S8_123811152	GBS	8	123,811,152	1.02E-05	7.84E-02	0.18	196	0.47	0.19	0.29	0.37	0.07	-0.40	-0.16
			β-Carotenoids/α-Carotenoids	S8_123811152	GBS	8	123,811,152	5.18E-06	8.78E-02	0.19	189	0.47	0.19	0.29	0.37	0.09	-0.85	-0.09
			β-Xanthophylls/α-Xanthophylls	**ss196516738**	**55K**	**8**	**124,488,144**	**1.43E-06**	**3.19E-02**	**0.20**	**196**	**0.00**	**0.24**	**0.29**	**0.38**	**-0.09**	**-0.40**	**0.28**
			β-Carotenoids/α-Carotenoids	ss196516738	55K	8	124,488,144	6.21E-06	9.94E-02	0.21	189	0.00	0.24	0.29	0.37	-0.10	-0.85	0.14
			β-Xanthophylls/α-Xanthophylls	**S8_129072699**	**GBS**	**8**	**129,072,699**	**2.05E-06**	**3.88E-02**	**0.36**	**196**	**0.50**	**0.35**	**0.29**	**0.38**	**0.07**	**-0.40**	**-0.15**
			β-Xanthophylls/α-Xanthophylls	S8_129080393	GBS	8	129,080,393	5.19E-06	6.55E-02	0.47	196	0.21	0.38	0.29	0.37	-0.06	-0.40	0.17
			β-Xanthophylls/α-Xanthophylls	S8_129080428	GBS	8	129,080,428	1.46E-05	9.64E-02	0.39	196	0.21	0.49	0.29	0.36	-0.06	-0.40	0.16
			β-Xanthophylls/α-Xanthophylls	S8_129122614	GBS	8	129,122,614	8.88E-06	7.84E-02	0.47	196	0.20	0.39	0.29	0.37	-0.06	-0.40	0.16
			β-Xanthophylls/α-Xanthophylls	S8_129122646	GBS	8	129,122,646	8.88E-06	7.84E-02	0.47	196	0.20	0.39	0.29	0.37	-0.06	-0.40	0.16

			β-Xanthophylls/α-Xanthophylls	S8_129124046	GBS	8	129,124,046	3.63E-06	5.55E-02	0.34	196	0.50	0.35	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	**S8_129124626**	**GBS**	**8**	**129,124,626**	**2.42E-06**	**4.13E-02**	**0.29**	**196**	**0.27**	**0.31**	**0.29**	**0.38**	**-0.07**	**-0.40**	**0.19**
			β-Xanthophylls/α-Xanthophylls	S8_129135865	GBS	8	129,135,865	1.45E-05	9.64E-02	0.32	196	0.47	0.34	0.29	0.36	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	S8_129137347	GBS	8	129,137,347	6.90E-06	7.84E-02	0.41	196	0.15	0.48	0.29	0.37	0.06	-0.40	-0.14
			β-Xanthophylls/α-Xanthophylls	ss196512938	55K	8	129,291,444	1.08E-05	7.84E-02	0.34	196	0.14	0.36	0.29	0.37	-0.06	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	S8_129313857	GBS	8	129,313,857	1.36E-05	9.41E-02	0.29	196	0.05	0.34	0.29	0.36	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	S8_130513659	GBS	8	130,513,659	1.31E-05	9.27E-02	0.14	196	0.33	0.14	0.29	0.36	-0.08	-0.40	0.23
			β-Xanthophylls/α-Xanthophylls	S8_130930928	GBS	8	130,930,928	4.37E-06	5.76E-02	0.09	196	0.42	0.05	0.29	0.37	0.11	-0.40	-0.24
			β-Carotenoids/α-Carotenoids	**ss196486757**	**55K**	**8**	**131,113,149**	**2.15E-06**	**4.28E-02**	**0.41**	**189**	**0.33**	**0.44**	**0.29**	**0.38**	**-0.08**	**-0.85**	**0.10**
			β-Xanthophylls/α-Xanthophylls	ss196486757	55K	8	131,113,149	7.62E-06	7.84E-02	0.42	196	0.33	0.44	0.29	0.37	-0.06	-0.40	0.17
			β-Xanthophylls/α-Xanthophylls	ss196486759	55K	8	131,124,166	1.06E-05	7.84E-02	0.34	196	0.19	0.36	0.29	0.37	-0.06	-0.40	0.17
			β-Carotenoids/α-Carotenoids	**S8_131533827**	**GBS**	**8**	**131,533,827**	**8.54E-07**	**3.51E-02**	**0.30**	**189**	**0.13**	**0.37**	**0.29**	**0.39**	**0.09**	**-0.85**	**-0.10**
			β-Xanthophylls/α-Xanthophylls	S8_131533827	GBS	8	131,533,827	3.86E-06	5.60E-02	0.29	196	0.13	0.37	0.29	0.37	0.07	-0.40	-0.16
			Zeaxanthin	S8_137047040	GBS	8	137,047,040	2.68E-06	9.36E-02	0.32	196	0.15	0.36	0.24	0.33	0.17	0.35	0.55
			β-Xanthophylls/α-Xanthophylls	**ss196501608**	**55K**	**8**	**138,514,315**	**2.05E-06**	**3.88E-02**	**0.41**	**196**	**0.40**	**0.44**	**0.29**	**0.38**	**-0.07**	**-0.40**	**0.19**
			β-Carotenoids/α-Carotenoids	**ss196501608**	**55K**	**8**	**138,514,315**	**2.06E-06**	**4.28E-02**	**0.41**	**189**	**0.40**	**0.44**	**0.29**	**0.38**	**-0.08**	**-0.85**	**0.10**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**7.24E-14**	**2.10E-08**	**NA**	**196**	**NA**	**NA**	**.21**	**.30**	**NA**	**-0.40**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**4.85E-09**	**7.09E-04**	**NA**	**200**	**NA**	**NA**	**.09**	**.43**	**NA**	**0.70**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Lutein**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**1.92E-08**	**2.81E-03**	**NA**	**200**	**NA**	**NA**	**.11**	**.49**	**NA**	**0.80**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Zeaxanthin**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**1.19E-07**	**1.30E-02**	**NA**	**196**	**NA**	**NA**	**.24**	**.38**	**NA**	**0.35**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total β-Xanthophylls**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**3.22E-07**	**2.33E-02**	**NA**	**195**	**NA**	**NA**	**.22**	**.40**	**NA**	**0.40**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**ss196504160**	**55K**	**8**	**138,882,711**	**1.32E-10**	**1.91E-05**	**0.35**	**196**	**0.48**	**0.34**	**0.29**	**0.46**	**0.10**	**-0.40**	**-0.22**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**ss196504160**	**55K**	**8**	**138,882,711**	**4.23E-10**	**1.22E-04**	**0.37**	**189**	**0.48**	**0.34**	**0.29**	**0.45**	**0.11**	**-0.85**	**-0.12**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882711**	**GBS**	**8**	**138,882,711**	**2.59E-07**	**7.52E-03**	**0.28**	**196**	**0.41**	**0.30**	**0.29**	**0.40**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Zeaxanthin**	**ss196504160**	**55K**	**8**	**138,882,711**	**1.37E-07**	**1.30E-02**	**0.35**	**196**	**0.48**	**0.34**	**0.24**	**0.36**	**-0.19**	**0.35**	**-0.45**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total β-Xanthophylls**	**ss196504160**	**55K**	**8**	**138,882,711**	**1.19E-07**	**1.73E-02**	**0.35**	**195**	**0.48**	**0.34**	**0.22**	**0.35**	**-0.27**	**0.40**	**-0.54**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882711**	**GBS**	**8**	**138,882,711**	**1.85E-06**	**4.28E-02**	**0.29**	**189**	**0.41**	**0.30**	**0.29**	**0.38**	**-0.09**	**-0.85**	**0.11**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882747**	**GBS**	**8**	**138,882,747**	**2.59E-07**	**7.52E-03**	**0.28**	**196**	**0.41**	**0.30**	**0.29**	**0.40**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882747**	**GBS**	**8**	**138,882,747**	**1.85E-06**	**4.28E-02**	**0.29**	**189**	**0.41**	**0.30**	**0.29**	**0.38**	**-0.09**	**-0.85**	**0.11**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882751**	**GBS**	**8**	**138,882,751**	**2.59E-07**	**7.52E-03**	**0.28**	**196**	**0.41**	**0.30**	**0.29**	**0.40**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882751**	**GBS**	**8**	**138,882,751**	**1.85E-06**	**4.28E-02**	**0.29**	**189**	**0.41**	**0.30**	**0.29**	**0.38**	**-0.09**	**-0.85**	**0.11**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882798**	**GBS**	**8**	**138,882,798**	**8.75E-08**	**4.68E-03**	**0.31**	**196**	**0.21**	**0.36**	**0.29**	**0.40**	**-0.08**	**-0.40**	**0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882798**	**GBS**	**8**	**138,882,798**	**4.77E-07**	**2.29E-02**	**0.31**	**189**	**0.21**	**0.36**	**0.29**	**0.39**	**-0.09**	**-0.85**	**0.12**

Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**1.52E-08**	**1.10E-03**	**0.43**	**196**	**0.12**	**0.44**	**0.29**	**0.42**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**1.27E-08**	**1.83E-03**	**0.43**	**189**	**0.12**	**0.44**	**0.29**	**0.42**	**-0.10**	**-0.85**	**0.13**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138883026**	**GBS**	**8**	**138,883,026**	**1.13E-07**	**4.68E-03**	**0.40**	**196**	**0.18**	**0.48**	**0.29**	**0.40**	**0.08**	**-0.40**	**-0.17**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138883026**	**GBS**	**8**	**138,883,026**	**2.13E-07**	**1.23E-02**	**0.40**	**189**	**0.18**	**0.48**	**0.29**	**0.40**	**0.09**	**-0.85**	**-0.10**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138883056**	**GBS**	**8**	**138,883,056**	**1.13E-07**	**4.68E-03**	**0.40**	**196**	**0.18**	**0.48**	**0.29**	**0.40**	**-0.08**	**-0.40**	**0.23**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138883056**	**GBS**	**8**	**138,883,056**	**2.13E-07**	**1.23E-02**	**0.40**	**189**	**0.18**	**0.48**	**0.29**	**0.40**	**-0.09**	**-0.85**	**0.12**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**4.71E-10**	**1.38E-04**	**NA**	**200**	**NA**	**NA**	**.09**	**.40**	**NA**	**0.70**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Zeaxanthin**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**1.57E-09**	**4.54E-04**	**NA**	**196**	**NA**	**NA**	**.24**	**.39**	**NA**	**0.35**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total β-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**5.83E-09**	**1.69E-03**	**NA**	**195**	**NA**	**NA**	**.22**	**.40**	**NA**	**0.40**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Lutein**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**6.78E-09**	**1.98E-03**	**NA**	**200**	**NA**	**NA**	**.11**	**.45**	**NA**	**0.80**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	PZB00665.1	4K	8	138,886,137	1.03E-05	7.84E-02	0.35	196	0.05	0.38	0.29	0.37	0.07	-0.40	-0.15
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**2.25E-09**	**2.17E-04**	**0.47**	**196**	**0.19**	**0.42**	**0.29**	**0.44**	**-0.09**	**-0.40**	**0.28**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**3.13E-08**	**3.01E-03**	**0.47**	**189**	**0.19**	**0.42**	**0.29**	**0.41**	**-0.10**	**-0.85**	**0.13**
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Zeaxanthin	S8_138888278	GBS	8	138,888,278	3.36E-06	9.74E-02	0.46	196	0.19	0.42	0.24	0.33	0.16	0.35	0.53
			β-Xanthophylls/α-Xanthophylls	**ss196508843**	**55K**	**8**	**139,143,878**	**4.62E-07**	**1.22E-02**	**0.29**	**196**	**0.38**	**0.26**	**0.29**	**0.39**	**0.08**	**-0.40**	**-0.17**
			β-Carotenoids/α-Carotenoids	**ss196508843**	**55K**	**8**	**139,143,878**	**1.95E-06**	**4.28E-02**	**0.31**	**189**	**0.38**	**0.26**	**0.29**	**0.38**	**0.08**	**-0.85**	**-0.09**
			β-Xanthophylls/α-Xanthophylls	**S8_140192724**	**GBS**	**8**	**140,192,724**	**2.14E-06**	**3.88E-02**	**0.33**	**196**	**0.19**	**0.28**	**0.29**	**0.38**	**-0.07**	**-0.40**	**0.20**
			β-Carotenoids/α-Carotenoids	**S8_140192724**	**GBS**	**8**	**140,192,724**	**1.45E-06**	**4.28E-02**	**0.34**	**189**	**0.19**	**0.28**	**0.29**	**0.38**	**-0.08**	**-0.85**	**0.11**
			Total β-Xanthophylls	**S8_171705545**	**GBS**	**8**	**171,705,545**	**7.56E-07**	**3.65E-02**	**0.10**	**195**	**0.14**	**0.14**	**0.22**	**0.33**	**-0.36**	**0.40**	**-0.67**
			Zeaxanthin	S8_171705545	GBS	8	171,705,545	1.04E-06	5.03E-02	0.11	196	0.14	0.14	0.24	0.34	-0.25	0.35	-0.56
			Zeaxanthin	**S8_171705574**	**GBS**	**8**	**171,705,574**	**2.84E-07**	**1.64E-02**	**0.11**	**196**	**0.25**	**0.13**	**0.24**	**0.35**	**-0.26**	**0.35**	**-0.58**
			Total β-Xanthophylls	**S8_171705574**	**GBS**	**8**	**171,705,574**	**2.31E-07**	**2.23E-02**	**0.10**	**195**	**0.25**	**0.13**	**0.22**	**0.34**	**-0.38**	**0.40**	**-0.69**
			α-Carotene/Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**3.31E-10**	**3.36E-05**	**0.31**	**196**	**0.37**	**0.29**	**0.17**	**0.35**	**-0.06**	**-0.25**	**0.30**
			Zeinoxanthin/Lutein	**ss196491114**	**55K**	**9**	**69,215,031**	**9.80E-08**	**9.46E-03**	**0.28**	**195**	**0.37**	**0.29**	**0.09**	**0.23**	**0.19**	**-0.35**	**-0.39**
			Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**3.76E-07**	**2.74E-02**	**0.30**	**198**	**0.37**	**0.29**	**0.10**	**0.23**	**0.11**	**-0.25**	**-0.34**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	*crtRB1* InDel4	Additonal Markers	10	136,059,748	2.14E-07	5.10E-02	NA	196	NA	NA	.04	.09	NA	-0.25	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/β-Cryptoxanthin	*crtRB1* InDel4	Additonal Markers	10	136,059,748	5.29E-07	7.85E-02	NA	198	NA	NA	.07	.07	NA	-0.70	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	ss196501627	55K	10	136,060,033	3.51E-07	5.10E-02	0.19	196	0.00	0.22	0.04	0.18	0.12	-0.25	-0.36
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Zeaxanthin**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**1.79E-07**	**1.30E-02**	**NA**	**196**	**NA**	**NA**	**.24**	**.31**	**NA**	**0.35**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Total β-Xanthophylls**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**7.09E-07**	**3.65E-02**	**NA**	**195**	**NA**	**NA**	**.22**	**.29**	**NA**	**0.40**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Total Carotenes/Total Xanthophylls	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.89E-07	5.43E-02	NA	188	NA	NA	.05	.15	NA	-0.55	NA

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with the peak SNP tagging the GWAS signal from *zep1* included as a covariate. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font. Note that addition of the significant marker crtRB1 InDel4 did not improve the partial R-square value of the model for the β-Carotene/β-Cryptoxanthin trait due to taxa that had missing data for the marker state.

Table S8 Genome-wide Association Study Results with Covariate from *lut1* (C)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
			Lutein	S1_96310268	GBS	1	96,310,268	3.32E-07	3.23E-02	0.17	200	0.06	0.21	0.12	0.25	1.23	0.80	1.73
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448432	GBS	2	44,448,432	2.06E-09	2.98E-04	0.11	196	0.29	0.09	0.04	0.24	-0.34	0.35	-0.69
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448432	GBS	2	44,448,432	1.57E-08	2.28E-03	0.11	195	0.29	0.09	0.05	0.22	-0.43	0.40	-0.76
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448432	GBS	2	44,448,432	5.29E-07	1.28E-02	0.11	196	0.29	0.09	0.11	0.24	0.12	-0.40	-0.24
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Carotenoids/α-Carotenoids	S2_44448432	GBS	2	44,448,432	9.29E-07	4.88E-02	0.12	189	0.29	0.09	0.20	0.31	0.13	-0.85	-0.13
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448438	GBS	2	44,448,438	2.06E-09	2.98E-04	0.11	196	0.29	0.09	0.04	0.24	0.34	0.35	1.31
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448438	GBS	2	44,448,438	1.57E-08	2.28E-03	0.11	195	0.29	0.09	0.05	0.22	0.43	0.40	1.46
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448438	GBS	2	44,448,438	5.29E-07	1.28E-02	0.11	196	0.29	0.09	0.11	0.24	-0.12	-0.40	0.37
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Carotenoids/α-Carotenoids	S2_44448438	GBS	2	44,448,438	9.29E-07	4.88E-02	0.12	189	0.29	0.09	0.20	0.31	-0.13	-0.85	0.17
			Zeaxanthin	S2_44473748	GBS	2	44,473,748	1.32E-06	3.82E-02	0.14	196	0.25	0.12	0.04	0.17	0.24	0.35	0.86
			β-Xanthophylls/α-Xanthophylls	S2_44473748	GBS	2	44,473,748	1.65E-05	9.94E-02	0.14	196	0.25	0.12	0.11	0.20	-0.09	-0.40	0.27
			Zeaxanthin	S2_44473758	GBS	2	44,473,758	1.32E-06	3.82E-02	0.14	196	0.24	0.12	0.04	0.17	-0.24	0.35	-0.55
			β-Xanthophylls/α-Xanthophylls	S2_44473758	GBS	2	44,473,758	1.65E-05	9.94E-02	0.14	196	0.24	0.12	0.11	0.20	0.09	-0.40	-0.19
			Zeaxanthin	S2_44473801	GBS	2	44,473,801	1.32E-06	3.82E-02	0.14	196	0.24	0.12	0.04	0.17	0.24	0.35	0.86
			β-Xanthophylls/α-Xanthophylls	S2_44473801	GBS	2	44,473,801	1.65E-05	9.94E-02	0.14	196	0.24	0.12	0.11	0.20	-0.09	-0.40	0.27
			Zeaxanthin	S2_44474308	GBS	2	44,474,308	1.09E-06	3.82E-02	0.21	196	0.38	0.28	0.04	0.17	0.21	0.35	0.73
			β-Xanthophylls/α-Xanthophylls	S2_44474308	GBS	2	44,474,308	1.55E-05	9.94E-02	0.21	196	0.38	0.28	0.11	0.20	-0.08	-0.40	0.23
			Zeaxanthin	S3_169734997	GBS	3	169,734,997	9.39E-07	3.82E-02	0.06	196	0.25	0.07	0.04	0.17	-0.42	0.35	-0.79
			Total β-Xanthophylls	S3_169734997	GBS	3	169,734,997	7.99E-07	3.85E-02	0.06	195	0.25	0.07	0.05	0.18	-0.58	0.40	-0.89
			β-Xanthophylls/α-Xanthophylls	S3_169734997	GBS	3	169,734,997	1.53E-05	9.94E-02	0.06	196	0.25	0.07	0.11	0.20	0.16	-0.40	-0.31
			Zeaxanthin	S3_172380629	GBS	3	172,380,629	3.84E-06	9.28E-02	0.05	196	0.15	0.05	0.04	0.16	-0.42	0.35	-0.78
			β-Xanthophylls/α-Xanthophylls	ss196415633	55K	3	216,418,000	1.11E-05	8.55E-02	0.07	196	0.33	0.04	0.11	0.21	0.12	-0.40	-0.25
			β-Cryptoxanthin	S7_13843351	GBS	7	13,843,351	3.40E-08	9.94E-03	0.15	199	0.10	0.16	0.15	0.29	-0.04	0.10	-0.34
			Zeinoxanthin	S7_15282645	GBS	7	15,282,645	3.40E-07	9.89E-02	0.17	198	0.42	0.20	0.25	0.36	-0.11	-0.25	0.57
			β-Xanthophylls/α-Xanthophylls	ss196477160	55K	7	51,472,566	1.69E-05	9.94E-02	0.43	196	0.43	0.43	0.11	0.20	0.07	-0.40	-0.15
			β-Xanthophylls/α-Xanthophylls	S8_21700838	GBS	8	21,700,838	7.67E-06	7.92E-02	0.45	196	0.17	0.38	0.11	0.21	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	PZD00025.1	4K	8	22,245,644	8.90E-06	7.92E-02	0.15	196	0.24	0.14	0.11	0.21	0.10	-0.40	-0.21
			β-Xanthophylls/α-Xanthophylls	S8_27118357	GBS	8	27,118,357	1.09E-05	8.55E-02	0.19	196	0.48	0.18	0.11	0.21	0.08	-0.40	-0.18
			β-Xanthophylls/α-Xanthophylls	ss196485943	55K	8	113,211,580	9.06E-06	7.92E-02	0.30	196	0.29	0.25	0.11	0.21	-0.07	-0.40	0.21
			β-Xanthophylls/α-Xanthophylls	ss196485947	55K	8	113,283,478	5.25E-06	6.35E-02	0.10	196	0.38	0.07	0.11	0.21	-0.13	-0.40	0.40
			β-Xanthophylls/α-Xanthophylls	S8_113350643	GBS	8	113,350,643	1.17E-05	8.67E-02	0.10	196	0.47	0.09	0.11	0.21	0.12	-0.40	-0.24
			β-Xanthophylls/α-Xanthophylls	ss196503032	55K	8	120,970,129	1.37E-05	9.94E-02	0.40	196	0.00	0.45	0.11	0.20	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	ss196503028	55K	8	120,970,146	1.73E-05	9.94E-02	0.39	196	0.00	0.44	0.11	0.20	0.07	-0.40	-0.15
			β-Xanthophylls/α-Xanthophylls	ss196486295	55K	8	121,437,490	1.78E-05	9.94E-02	0.33	196	0.00	0.36	0.11	0.20	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	ss196486297	55K	8	121,437,794	1.78E-05	9.94E-02	0.33	196	0.00	0.36	0.11	0.20	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	ss196516738	55K	8	124,488,144	5.06E-06	6.35E-02	0.20	196	0.00	0.24	0.11	0.21	-0.09	-0.40	0.27
			β-Xanthophylls/α-	S8_128602581	GBS	8	128,602,581	1.57E-05	9.94E-02	0.36	196	0.18	0.47	0.11	0.20	-0.07	-0.40	0.19

			Xanthophylls															
			β-Xanthophylls/α-Xanthophylls	S8_128947357	GBS	8	128,947,357	1.60E-05	9.94E-02	0.31	196	0.37	0.36	0.11	0.20	0.07	-0.40	-0.16
			β-Xanthophylls/α-Xanthophylls	S8_129072699	GBS	8	129,072,699	1.41E-06	2.55E-02	0.36	196	0.50	0.35	0.11	0.23	0.07	-0.40	-0.16
			β-Xanthophylls/α-Xanthophylls	S8_129075429	GBS	8	129,075,429	7.91E-06	7.92E-02	0.42	196	0.50	0.44	0.11	0.21	0.07	-0.40	-0.15
			β-Xanthophylls/α-Xanthophylls	S8_129080393	GBS	8	129,080,393	6.40E-06	7.43E-02	0.47	196	0.21	0.38	0.11	0.21	-0.07	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	S8_129122614	GBS	8	129,122,614	8.84E-06	7.92E-02	0.47	196	0.20	0.39	0.11	0.21	-0.06	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	S8_129122646	GBS	8	129,122,646	8.84E-06	7.92E-02	0.47	196	0.20	0.39	0.11	0.21	-0.06	-0.40	0.18
			β-Xanthophylls/α-Xanthophylls	S8_129124046	GBS	8	129,124,046	3.27E-06	4.75E-02	0.34	196	0.50	0.35	0.11	0.22	0.07	-0.40	-0.16
			β-Xanthophylls/α-Xanthophylls	S8_129124626	GBS	8	129,124,626	1.85E-06	2.83E-02	0.29	196	0.27	0.31	0.11	0.22	-0.08	-0.40	0.22
			β-Xanthophylls/α-Xanthophylls	S8_129137347	GBS	8	129,137,347	4.09E-06	5.39E-02	0.41	196	0.15	0.48	0.11	0.22	0.07	-0.40	-0.15
			β-Xanthophylls/α-Xanthophylls	ss196512938	55K	8	129,291,444	9.28E-06	7.92E-02	0.34	196	0.14	0.36	0.11	0.21	-0.07	-0.40	0.20
			β-Xanthophylls/α-Xanthophylls	S8_129313857	GBS	8	129,313,857	1.49E-05	9.94E-02	0.29	196	0.05	0.34	0.11	0.20	-0.07	-0.40	0.20
			β-Xanthophylls/α-Xanthophylls	ss196486728	55K	8	130,510,859	8.61E-06	7.92E-02	0.17	196	0.33	0.16	0.11	0.21	0.08	-0.40	-0.18
			β-Xanthophylls/α-Xanthophylls	S8_130513659	GBS	8	130,513,659	7.07E-06	7.88E-02	0.14	196	0.33	0.14	0.11	0.21	-0.09	-0.40	0.27
			β-Xanthophylls/α-Xanthophylls	S8_130930928	GBS	8	130,930,928	1.69E-06	2.73E-02	0.09	196	0.42	0.05	0.11	0.22	0.13	-0.40	-0.26
			β-Xanthophylls/α-Xanthophylls	ss196486759	55K	8	131,124,166	1.12E-05	8.55E-02	0.34	196	0.19	0.36	0.11	0.21	-0.07	-0.40	0.19
			β-Xanthophylls/α-Xanthophylls	S8_131533827	GBS	8	131,533,827	1.02E-05	8.47E-02	0.29	196	0.13	0.37	0.11	0.21	0.07	-0.40	-0.16
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Total α-Xanthophylls	*lcyE* 5'TE	Additonal Markers	8	138,882,481	4.97E-09	7.26E-04	NA	200	NA	NA	.09	.43	NA	0.70	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Lutein	*lcyE* 5'TE	Additonal Markers	8	138,882,481	2.24E-08	3.27E-03	NA	200	NA	NA	.12	.49	NA	0.80	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	ss196504160	55K	8	138,882,711	4.03E-10	5.84E-05	0.35	196	0.48	0.34	0.11	0.31	0.11	-0.40	-0.23
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	ss196504160	55K	8	138,882,711	2.75E-09	7.92E-04	0.37	189	0.48	0.34	0.20	0.36	0.12	-0.85	-0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138882711	GBS	8	138,882,711	3.23E-07	1.04E-02	0.28	196	0.41	0.30	0.11	0.24	-0.09	-0.40	0.26
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138882711	GBS	8	138,882,711	1.71E-06	5.46E-02	0.29	189	0.41	0.30	0.20	0.30	-0.09	-0.85	0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Total β-Xanthophylls	ss196504160	55K	8	138,882,711	1.77E-06	6.40E-02	0.35	195	0.48	0.34	0.05	0.17	-0.26	0.40	-0.53
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Zeaxanthin	ss196504160	55K	8	138,882,711	2.80E-06	7.37E-02	0.35	196	0.48	0.34	0.04	0.16	-0.19	0.35	-0.44
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138882747	GBS	8	138,882,747	3.23E-07	1.04E-02	0.28	196	0.41	0.30	0.11	0.24	-0.09	-0.40	0.26
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138882747	GBS	8	138,882,747	1.71E-06	5.46E-02	0.29	189	0.41	0.30	0.20	0.30	-0.09	-0.85	0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138882751	GBS	8	138,882,751	3.23E-07	1.04E-02	0.28	196	0.41	0.30	0.11	0.24	-0.09	-0.40	0.26
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138882751	GBS	8	138,882,751	1.71E-06	5.46E-02	0.29	189	0.41	0.30	0.20	0.30	-0.09	-0.85	0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138882798	GBS	8	138,882,798	2.65E-07	1.04E-02	0.31	196	0.21	0.36	0.11	0.24	-0.09	-0.40	0.26
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138882798	GBS	8	138,882,798	2.59E-06	6.88E-02	0.31	189	0.21	0.36	0.20	0.30	-0.09	-0.85	0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138882897	GBS	8	138,882,897	1.55E-08	1.12E-03	0.43	196	0.12	0.44	0.11	0.27	-0.09	-0.40	0.26

Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138882897	GBS	8	138,882,897	6.73E-08	9.69E-03	0.43	189	0.12	0.44	0.20	0.33	-0.10	-0.85	0.13
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138883026	GBS	8	138,883,026	1.04E-06	2.02E-02	0.40	196	0.18	0.48	0.11	0.23	0.08	-0.40	-0.17
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138883056	GBS	8	138,883,056	1.04E-06	2.02E-02	0.40	196	0.18	0.48	0.11	0.23	-0.08	-0.40	0.22
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	*lcyE* SNP216	Additonal Markers	8	138,883,206	7.15E-16	2.07E-10	NA	196	NA	NA	.08	.22	NA	-0.40	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Total α-Xanthophylls	*lcyE* SNP216	Additonal Markers	8	138,883,206	5.37E-10	1.57E-04	NA	200	NA	NA	.09	.40	NA	0.70	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Lutein	*lcyE* SNP216	Additonal Markers	8	138,883,206	6.44E-09	1.88E-03	NA	200	NA	NA	.12	.45	NA	0.80	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	Total β-Xanthophylls	*lcyE* SNP216	Additonal Markers	8	138,883,206	1.64E-07	1.19E-02	NA	195	NA	NA	.05	.29	NA	0.40	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	PZB00665.1	4K	8	138,886,137	5.28E-07	1.28E-02	0.35	196	0.05	0.38	0.11	0.24	0.08	-0.40	-0.18
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Xanthophylls/α-Xanthophylls	S8_138888278	GBS	8	138,888,278	2.98E-09	2.88E-04	0.47	196	0.19	0.42	0.11	0.29	-0.10	-0.40	0.30
Carotenoid Synthesis and Degradation	GRMZM2G012966	lcyE	β-Carotenoids/α-Carotenoids	S8_138888278	GBS	8	138,888,278	1.80E-07	1.73E-02	0.47	189	0.19	0.42	0.20	0.32	-0.10	-0.85	0.13
			β-Xanthophylls/α-Xanthophylls	ss196508843	55K	8	139,143,878	1.33E-07	7.74E-03	0.29	196	0.38	0.26	0.11	0.25	0.09	-0.40	-0.19
			β-Carotenoids/α-Carotenoids	ss196508843	55K	8	139,143,878	1.02E-06	4.88E-02	0.31	189	0.38	0.26	0.20	0.31	0.09	-0.85	-0.10
			β-Xanthophylls/α-Xanthophylls	ss196507132	55K	8	139,300,073	3.68E-06	5.09E-02	0.39	196	0.18	0.49	0.11	0.22	-0.07	-0.40	0.22
			β-Xanthophylls/α-Xanthophylls	S8_140192724	GBS	8	140,192,724	6.19E-07	1.38E-02	0.33	196	0.19	0.28	0.11	0.23	-0.08	-0.40	0.24
			β-Carotenoids/α-Carotenoids	S8_140192724	GBS	8	140,192,724	2.63E-06	6.88E-02	0.34	189	0.19	0.28	0.20	0.30	-0.09	-0.85	0.11
			Total β-Xanthophylls	S8_171705545	GBS	8	171,705,545	3.98E-07	2.30E-02	0.10	195	0.14	0.14	0.05	0.18	-0.40	0.40	-0.72
			Zeaxanthin	S8_171705545	GBS	8	171,705,545	6.85E-07	3.82E-02	0.11	196	0.14	0.14	0.04	0.17	-0.28	0.35	-0.61
			Total β-Xanthophylls	S8_171705574	GBS	8	171,705,574	1.27E-07	1.19E-02	0.10	195	0.25	0.13	0.05	0.20	-0.42	0.40	-0.74
			Zeaxanthin	S8_171705574	GBS	8	171,705,574	1.98E-07	1.91E-02	0.11	196	0.25	0.13	0.04	0.19	-0.30	0.35	-0.63
			β-Xanthophylls/α-Xanthophylls	ss196493105	55K	9	118,437,281	1.54E-06	2.63E-02	0.29	196	0.19	0.42	0.11	0.22	-0.09	-0.40	0.28
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	*crtRB1* InDel4	Additonal Markers	10	136,059,748	1.72E-07	5.00E-02	NA	196	NA	NA	.03	.08	NA	-0.25	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	ss196501627	55K	10	136,060,033	3.67E-07	5.33E-02	0.19	196	0.00	0.22	0.04	0.18	0.12	-0.25	-0.36
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Total Carotenes/Total Xanthophylls	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.33E-07	3.82E-02	NA	188	NA	NA	.02	.14	NA	-0.55	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Zeaxanthin	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.12E-06	3.82E-02	NA	196	NA	NA	.04	.15	NA	0.35	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Total β-Xanthophylls	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.77E-06	6.40E-02	NA	195	NA	NA	.05	.17	NA	0.40	NA

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with the peak SNP tagging the GWAS signal from *lut1* included as a covariate. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font.

Table S8 Genome-wide Association Study Results with Covariates for *lcyE* (D)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
			Zeaxanthin	S1_2940079	**GBS**	1	2,940,079	3.37E-06	9.80E-02	0.05	176	0.50	0.03	0.18	0.29	-0.37	0.35	-0.74
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**α-Carotene/Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**7.23E-10**	**7.03E-05**	**0.33**	**178**	**0.40**	**0.28**	**0.16**	**0.37**	**0.07**	**-0.25**	**-0.22**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**4.28E-08**	**4.15E-03**	**0.32**	**178**	**0.40**	**0.28**	**0.10**	**0.27**	**-0.12**	**-0.25**	**0.67**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin/Lutein**	**ss196425306**	**55K**	**1**	**86,844,203**	**4.98E-08**	**4.80E-03**	**0.31**	**175**	**0.40**	**0.28**	**0.08**	**0.25**	**-0.21**	**-0.35**	**0.93**
			α-Carotene/Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**7.23E-10**	**7.03E-05**	**0.33**	**178**	**0.40**	**0.27**	**0.16**	**0.37**	**0.07**	**-0.25**	**-0.22**
			Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**4.28E-08**	**4.15E-03**	**0.32**	**178**	**0.40**	**0.27**	**0.10**	**0.27**	**-0.12**	**-0.25**	**0.67**
			Zeinoxanthin/Lutein	**ss196425308**	**55K**	**1**	**86,945,134**	**4.98E-08**	**4.80E-03**	**0.31**	**175**	**0.40**	**0.27**	**0.08**	**0.25**	**-0.21**	**-0.35**	**0.93**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Zeaxanthin**	**S2_44448432**	**GBS**	**2**	**44,448,432**	**7.43E-09**	**1.08E-03**	**0.11**	**176**	**0.29**	**0.09**	**0.18**	**0.36**	**-0.32**	**0.35**	**-0.67**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Total β-Xanthophylls**	**S2_44448432**	**GBS**	**2**	**44,448,432**	**8.43E-08**	**1.22E-02**	**0.11**	**175**	**0.29**	**0.09**	**0.20**	**0.34**	**-0.40**	**0.40**	**-0.73**
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448432	**GBS**	2	44,448,432	5.10E-07	7.40E-02	0.11	176	0.29	0.09	0.45	0.54	0.10	-0.40	-0.22
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Zeaxanthin**	**S2_44448438**	**GBS**	**2**	**44,448,438**	**7.43E-09**	**1.08E-03**	**0.11**	**176**	**0.29**	**0.09**	**0.18**	**0.36**	**0.32**	**0.35**	**1.22**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Total β-Xanthophylls**	**S2_44448438**	**GBS**	**2**	**44,448,438**	**8.43E-08**	**1.22E-02**	**0.11**	**175**	**0.29**	**0.09**	**0.20**	**0.34**	**0.40**	**0.40**	**1.34**
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448438	**GBS**	2	44,448,438	5.10E-07	7.40E-02	0.11	176	0.29	0.09	0.45	0.54	-0.10	-0.40	0.32
			Zeaxanthin	S5_216074707	**GBS**	5	216,074,707	2.89E-06	9.80E-02	0.14	176	0.17	0.17	0.18	0.29	-0.23	0.35	-0.52
			β-Cryptoxanthin	**S7_13843351**	**GBS**	**7**	**13,843,351**	**1.40E-07**	**4.09E-02**	**0.16**	**179**	**0.10**	**0.16**	**0.19**	**0.33**	**-0.04**	**0.10**	**-0.33**
			Zeinoxanthin	S7_15282645	**GBS**	7	15,282,645	9.69E-07	7.05E-02	0.18	178	0.42	0.20	0.10	0.23	-0.12	-0.25	0.65
			Total β-Xanthophylls	**ss196478758**	**55K**	**7**	**103,626,333**	**6.37E-07**	**4.60E-02**	**0.41**	**175**	**0.19**	**0.44**	**0.20**	**0.32**	**-0.24**	**0.40**	**-0.50**
			Zeaxanthin	ss196478758	**55K**	7	103,626,333	7.39E-07	5.35E-02	0.41	176	0.19	0.44	0.18	0.31	-0.18	0.35	-0.42
			Zeinoxanthin	S7_107111687	**GBS**	7	107,111,687	1.48E-06	7.19E-02	0.16	178	0.23	0.25	0.10	0.23	0.12	-0.25	-0.36
			Zeinoxanthin	S7_107111713	**GBS**	7	107,111,713	1.48E-06	7.19E-02	0.16	178	0.23	0.25	0.10	0.23	0.12	-0.25	-0.36
			Total β-Xanthophylls	S7_108788777	**GBS**	7	108,788,777	1.08E-06	6.23E-02	0.49	175	0.29	0.43	0.20	0.32	-0.23	0.40	-0.47
			Zeaxanthin	S7_108788777	**GBS**	7	108,788,777	3.13E-06	9.80E-02	0.49	176	0.29	0.43	0.18	0.29	-0.16	0.35	-0.39
			Total Carotenoids	S7_121184182	**GBS**	7	121,184,182	9.65E-07	9.10E-02	0.08	181	0.14	0.08	0.06	0.19	-1.41	0.65	-1.26
			Total Carotenoids	S7_121184311	**GBS**	7	121,184,311	8.11E-07	9.10E-02	0.08	181	0.13	0.09	0.06	0.19	-1.42	0.65	-1.27
			Total Carotenoids	S7_121185458	**GBS**	7	121,185,458	1.37E-06	9.66E-02	0.06	181	0.13	0.07	0.06	0.19	-1.55	0.65	-1.40
			Total β-Xanthophylls	**S7_121185500**	**GBS**	**7**	**121,185,500**	**1.99E-07**	**1.91E-02**	**0.09**	**175**	**0.19**	**0.09**	**0.20**	**0.33**	**0.40**	**0.40**	**1.33**
			Zeaxanthin	**S7_121185500**	**GBS**	**7**	**121,185,500**	**4.13E-07**	**3.99E-02**	**0.09**	**176**	**0.19**	**0.09**	**0.18**	**0.31**	**0.29**	**0.35**	**1.08**
			Total Carotenoids	S7_121185500	**GBS**	7	121,185,500	3.67E-07	9.10E-02	0.08	181	0.19	0.09	0.06	0.20	1.42	0.65	2.88
			Total β-Xanthophylls	S8_171705574	**GBS**	8	171,705,574	1.57E-06	7.28E-02	0.11	175	0.25	0.13	0.20	0.31	-0.36	0.40	-0.68
			Zeaxanthin	S8_171705574	**GBS**	8	171,705,574	1.50E-06	7.77E-02	0.11	176	0.25	0.13	0.18	0.30	-0.26	0.35	-0.58
			α-Carotene/Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**7.23E-10**	**7.03E-05**	**0.33**	**178**	**0.37**	**0.29**	**0.16**	**0.37**	**-0.07**	**-0.25**	**0.31**
			Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**4.28E-08**	**4.15E-03**	**0.32**	**178**	**0.37**	**0.29**	**0.10**	**0.27**	**0.12**	**-0.25**	**-0.37**
			Zeinoxanthin/Lutein	**ss196491114**	**55K**	**9**	**69,215,031**	**4.98E-08**	**4.80E-03**	**0.31**	**175**	**0.37**	**0.29**	**0.08**	**0.25**	**0.21**	**-0.35**	**-0.41**
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Total Carotenes/Total Xanthophylls**	***crtRB1* InDel4**	**Additonal Markers**	**10**	**136,059,748**	**3.98E-08**	**5.72E-03**	**NA**	**188**	**NA**	**NA**	**.06**	**.19**	**NA**	**-0.55**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Zeaxanthin	*crtRB1* InDel4	Additonal Markers	10	136,059,748	3.38E-06	9.80E-02	NA	196	NA	NA	.24	.32	NA	0.35	NA
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**β-Carotene/(β-Cryptoxanthin+Zeaxanthin)**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**2.13E-10**	**6.21E-05**	**NA**	**196**	**NA**	**NA**	**.04**	**.10**	**NA**	**-0.25**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Total Carotenes/Total Xanthophylls**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**3.30E-09**	**9.49E-04**	**NA**	**188**	**NA**	**NA**	**.06**	**.22**	**NA**	**-0.55**	**NA**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Total β-Xanthophylls	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.76E-06	7.28E-02	NA	195	NA	NA	.29	.38	NA	0.40	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	Zeaxanthin	*crtRB1* 3'TE	Additonal Markers	10	136,061,719	1.61E-06	7.77E-02	NA	196	NA	NA	.24	.33	NA	0.35	NA

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with the markers tagging *lcyE* identified in the multi-locus mixed model included as covariates. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are

demarcated with boldface font and those significant only at 10% FDR without boldface font.

Table S8 Genome-wide Association Study Results with S8_171705574 Covariate (E)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**α-Carotene/Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**5.23E-10**	**5.06E-05**	**0.31**	**196**	**0.40**	**0.28**	**0.17**	**0.35**	**0.06**	**-0.25**	**-0.22**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin/Lutein**	**ss196425306**	**55K**	**1**	**86,844,203**	**4.34E-08**	**6.28E-03**	**0.29**	**195**	**0.40**	**0.28**	**0.09**	**0.24**	**-0.19**	**-0.35**	**0.84**
Carotenoid Synthesis and Degradation	**GRMZM2G143202**	**lut1**	**Zeinoxanthin**	**ss196425306**	**55K**	**1**	**86,844,203**	**7.31E-08**	**1.06E-02**	**0.30**	**198**	**0.40**	**0.28**	**0.10**	**0.25**	**-0.11**	**-0.25**	**0.62**
			α-Carotene/Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**5.23E-10**	**5.06E-05**	**0.31**	**196**	**0.40**	**0.27**	**0.17**	**0.35**	**0.06**	**-0.25**	**-0.22**
			Zeinoxanthin/Lutein	**ss196425308**	**55K**	**1**	**86,945,134**	**4.34E-08**	**6.28E-03**	**0.29**	**195**	**0.40**	**0.27**	**0.09**	**0.24**	**-0.19**	**-0.35**	**0.84**
			Zeinoxanthin	**ss196425308**	**55K**	**1**	**86,945,134**	**7.31E-08**	**1.06E-02**	**0.30**	**198**	**0.40**	**0.27**	**0.10**	**0.25**	**-0.11**	**-0.25**	**0.62**
			Lutein	S1_96310268	**GBS**	1	96,310,268	5.53E-07	5.39E-02	0.17	200	0.06	0.21	0.13	0.25	1.21	0.80	1.70
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Zeaxanthin**	**S2_44448432**	**GBS**	**2**	**44,448,432**	**2.15E-09**	**3.11E-04**	**0.11**	**196**	**0.29**	**0.09**	**0.19**	**0.35**	**-0.32**	**0.35**	**-0.66**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Total β-Xanthophylls**	**S2_44448432**	**GBS**	**2**	**44,448,432**	**1.75E-08**	**2.54E-03**	**0.11**	**195**	**0.29**	**0.09**	**0.20**	**0.34**	**-0.40**	**0.40**	**-0.72**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**β-Xanthophylls/α-Xanthophylls**	**S2_44448432**	**GBS**	**2**	**44,448,432**	**1.31E-07**	**7.61E-03**	**0.11**	**196**	**0.29**	**0.09**	**0.19**	**0.31**	**0.12**	**-0.40**	**-0.25**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Zeaxanthin**	**S2_44448438**	**GBS**	**2**	**44,448,438**	**2.15E-09**	**3.11E-04**	**0.11**	**196**	**0.29**	**0.09**	**0.19**	**0.35**	**0.32**	**0.35**	**1.19**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**Total β-Xanthophylls**	**S2_44448438**	**GBS**	**2**	**44,448,438**	**1.75E-08**	**2.54E-03**	**0.11**	**195**	**0.29**	**0.09**	**0.20**	**0.34**	**0.40**	**0.40**	**1.32**
Carotenoid Synthesis and Degradation	**GRMZM2G127139**	**zep1**	**β-Xanthophylls/α-Xanthophylls**	**S2_44448438**	**GBS**	**2**	**44,448,438**	**1.31E-07**	**7.61E-03**	**0.11**	**196**	**0.29**	**0.09**	**0.19**	**0.31**	**-0.12**	**-0.40**	**0.39**
			Zeaxanthin	**S2_44473748**	**GBS**	**2**	**44,473,748**	**1.72E-07**	**9.98E-03**	**0.14**	**196**	**0.25**	**0.12**	**0.19**	**0.31**	**0.24**	**0.35**	**0.87**
			Total β-Xanthophylls	**S2_44473748**	**GBS**	**2**	**44,473,748**	**5.64E-07**	**3.26E-02**	**0.14**	**195**	**0.25**	**0.12**	**0.20**	**0.31**	**0.32**	**0.40**	**0.99**
			β-Xanthophylls/α-Xanthophylls	S2_44473748	**GBS**	2	44,473,748	2.75E-06	5.71E-02	0.14	196	0.25	0.12	0.19	0.28	-0.10	-0.40	0.28
			Zeaxanthin	**S2_44473758**	**GBS**	**2**	**44,473,758**	**1.72E-07**	**9.98E-03**	**0.14**	**196**	**0.24**	**0.12**	**0.19**	**0.31**	**-0.24**	**0.35**	**-0.55**
			Total β-Xanthophylls	**S2_44473758**	**GBS**	**2**	**44,473,758**	**5.64E-07**	**3.26E-02**	**0.14**	**195**	**0.24**	**0.12**	**0.20**	**0.31**	**-0.32**	**0.40**	**-0.61**
			β-Xanthophylls/α-Xanthophylls	S2_44473758	**GBS**	2	44,473,758	2.75E-06	5.71E-02	0.14	196	0.24	0.12	0.19	0.28	0.10	-0.40	-0.20
			Zeaxanthin	**S2_44473801**	**GBS**	**2**	**44,473,801**	**1.72E-07**	**9.98E-03**	**0.14**	**196**	**0.24**	**0.12**	**0.19**	**0.31**	**0.24**	**0.35**	**0.87**
			Total β-Xanthophylls	**S2_44473801**	**GBS**	**2**	**44,473,801**	**5.64E-07**	**3.26E-02**	**0.14**	**195**	**0.24**	**0.12**	**0.20**	**0.31**	**0.32**	**0.40**	**0.99**
			β-Xanthophylls/α-Xanthophylls	S2_44473801	**GBS**	2	44,473,801	2.75E-06	5.71E-02	0.14	196	0.24	0.12	0.19	0.28	-0.10	-0.40	0.28
			Zeaxanthin	**S2_44474139**	**GBS**	**2**	**44,474,139**	**9.65E-07**	**4.36E-02**	**0.14**	**196**	**0.29**	**0.13**	**0.19**	**0.29**	**-0.23**	**0.35**	**-0.52**
			β-Xanthophylls/α-Xanthophylls	S2_44474139	**GBS**	2	44,474,139	4.99E-06	8.52E-02	0.14	196	0.29	0.13	0.19	0.28	0.09	-0.40	-0.20
			Zeaxanthin	**S2_44474308**	**GBS**	**2**	**44,474,308**	**1.09E-06**	**4.36E-02**	**0.21**	**196**	**0.38**	**0.28**	**0.19**	**0.29**	**0.20**	**0.35**	**0.67**
			Total α-Xanthophylls	ss196456701	**55K**	4	146,977,283	7.48E-07	7.29E-02	0.12	200	0.38	0.08	0.11	0.23	-0.89	0.70	-0.95
			β-Cryptoxanthin	S7_13843351	**GBS**	7	13,843,351	2.78E-07	8.12E-02	0.15	199	0.10	0.16	0.17	0.29	-0.04	0.10	-0.32
			Zeinoxanthin	**S7_15282645**	**GBS**	**7**	**15,282,645**	**1.18E-07**	**1.14E-02**	**0.17**	**198**	**0.42**	**0.20**	**0.10**	**0.24**	**-0.12**	**-0.25**	**0.69**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**3.99E-09**	**5.83E-04**	**NA**	**200**	**NA**	**NA**	**.10**	**.43**	**NA**	**0.70**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Lutein**	***lcyE* 5'TE**	**Additonal Markers**	**8**	**138,882,481**	**1.52E-08**	**2.22E-03**	**NA**	**200**	**NA**	**NA**	**.11**	**.49**	**NA**	**0.80**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**ss196504160**	**55K**	**8**	**138,882,711**	**3.69E-09**	**5.35E-04**	**0.35**	**196**	**0.48**	**0.34**	**0.19**	**0.35**	**0.10**	**-0.40**	**-0.21**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**ss196504160**	**55K**	**8**	**138,882,711**	**4.67E-09**	**1.34E-03**	**0.37**	**189**	**0.48**	**0.34**	**0.22**	**0.38**	**0.11**	**-0.85**	**-0.12**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882711**	**GBS**	**8**	**138,882,711**	**1.58E-06**	**4.57E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.19**	**0.29**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882747**	**GBS**	**8**	**138,882,747**	**1.58E-06**	**4.57E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.19**	**0.29**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882751**	**GBS**	**8**	**138,882,751**	**1.58E-06**	**4.57E-02**	**0.28**	**196**	**0.41**	**0.30**	**0.19**	**0.29**	**-0.08**	**-0.40**	**0.24**
Carotenoid Synthesis and	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	S8_138882798	**GBS**	8	138,882,798	2.66E-06	5.71E-02	0.31	196	0.21	0.36	0.19	0.28	-0.08	-0.40	0.23

Degradation																		
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**2.15E-07**	**1.04E-02**	**0.43**	**196**	**0.12**	**0.44**	**0.19**	**0.31**	**-0.08**	**-0.40**	**0.23**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138882897**	**GBS**	**8**	**138,882,897**	**1.14E-07**	**1.64E-02**	**0.43**	**189**	**0.12**	**0.44**	**0.22**	**0.35**	**-0.09**	**-0.85**	**0.12**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**2.78E-15**	**8.06E-10**	**NA**	**196**	**NA**	**NA**	**.13**	**.26**	**NA**	**-0.40**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**3.24E-10**	**9.48E-05**	**NA**	**200**	**NA**	**NA**	**.10**	**.40**	**NA**	**0.70**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Lutein**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**4.75E-09**	**1.39E-03**	**NA**	**200**	**NA**	**NA**	**.11**	**.45**	**NA**	**0.80**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**PZB00665.1**	**4K**	**8**	**138,886,137**	**1.47E-06**	**4.57E-02**	**0.35**	**196**	**0.05**	**0.38**	**0.19**	**0.29**	**0.08**	**-0.40**	**-0.18**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**1.58E-08**	**1.53E-03**	**0.47**	**196**	**0.19**	**0.42**	**0.19**	**0.33**	**-0.09**	**-0.40**	**0.28**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**2.43E-07**	**2.33E-02**	**0.47**	**189**	**0.19**	**0.42**	**0.22**	**0.34**	**-0.10**	**-0.85**	**0.13**
			β-Xanthophylls/α-Xanthophylls	ss196508843	**55K**	8	139,143,878	3.32E-06	6.02E-02	0.29	196	0.38	0.26	0.19	0.28	0.08	-0.40	-0.17
			β-Xanthophylls/α-Xanthophylls	S8_140192724	**GBS**	8	140,192,724	2.98E-06	5.77E-02	0.33	196	0.19	0.28	0.19	0.28	-0.08	-0.40	0.22
			β-Carotenoids/α-Carotenoids	S8_140192724	**GBS**	8	140,192,724	1.29E-06	9.31E-02	0.34	189	0.19	0.28	0.22	0.32	-0.09	-0.85	0.11
			α-Carotene/Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**5.01E-10**	**5.06E-05**	**0.31**	**196**	**0.37**	**0.29**	**0.17**	**0.35**	**-0.06**	**-0.25**	**0.30**
			Zeinoxanthin/Lutein	**ss196491114**	**55K**	**9**	**69,215,031**	**8.52E-08**	**8.23E-03**	**0.28**	**195**	**0.37**	**0.29**	**0.09**	**0.24**	**0.19**	**-0.35**	**-0.39**
			Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**3.07E-07**	**2.23E-02**	**0.30**	**198**	**0.37**	**0.29**	**0.10**	**0.23**	**0.11**	**-0.25**	**-0.34**
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	*crtRB1* InDel4	Additonal Markers	10	136,059,748	2.87E-07	5.79E-02	NA	196	NA	NA	.04	.08	NA	-0.25	NA
Carotenoid Synthesis and Degradation	GRMZM2G152135	crtRB1	β-Carotene/(β-Cryptoxanthin+Zeaxanthin)	ss196501627	55K	10	136,060,033	3.99E-07	5.79E-02	0.19	196	0.00	0.22	0.04	0.18	0.12	-0.25	-0.36
Carotenoid Synthesis and Degradation	**GRMZM2G152135**	**crtRB1**	**Zeaxanthin**	***crtRB1* 3'TE**	**Additonal Markers**	**10**	**136,061,719**	**1.20E-06**	**4.36E-02**	**NA**	**196**	**NA**	**NA**	**.17**	**.27**	**NA**	**0.35**	**NA**

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with SNP S8_171705574 included as a covariate. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font.

Table S8 Genome-wide Association Study Results with Covariate for *crtRB1* (F)

a priori candidate gene pathway	RefGen_v2 Gene ID	Annotated gene containing associated SNP or gene within 3kb of associated SNP	Trait	SNP ID	SNP Source	Chr	Position in RefGen_v2	*P*-value	FDR-Adjusted *P*-value	Minor Allele Frequency (MAF)	Sample Size	MAF Tropical (8% of 201 Lines)	MAF Temperate (92% of 201 Lines)	R-square_LR from Model without SNP	R-square_LR from Model with SNP	Effect Size	Lambda from Box-Cox Procedure	Back-Transformed Effect Estimates
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	α-Carotene/Zeinoxanthin	ss196425306	55K	1	86,844,203	8.94E-10	8.59E-05	0.32	190	0.40	0.28	0.17	0.36	0.06	-0.25	-0.21
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	Zeinoxanthin/Lutein	ss196425306	55K	1	86,844,203	5.87E-08	8.43E-03	0.30	189	0.40	0.28	0.09	0.25	-0.19	-0.35	0.85
Carotenoid Synthesis and Degradation	GRMZM2G143202	lut1	Zeinoxanthin	ss196425306	55K	1	86,844,203	1.21E-07	1.74E-02	0.31	192	0.40	0.28	0.10	0.24	-0.11	-0.25	0.62
			α-Carotene/Zeinoxanthin	ss196425308	55K	1	86,945,134	8.94E-10	8.59E-05	0.32	190	0.40	0.27	0.17	0.36	0.06	-0.25	-0.21
			Zeinoxanthin/Lutein	ss196425308	55K	1	86,945,134	5.87E-08	8.43E-03	0.30	189	0.40	0.27	0.09	0.25	-0.19	-0.35	0.85
			Zeinoxanthin	ss196425308	55K	1	86,945,134	1.21E-07	1.74E-02	0.31	192	0.40	0.27	0.10	0.24	-0.11	-0.25	0.62
			Lutein	S1_96310268	GBS	1	96,310,268	2.24E-07	3.24E-02	0.17	194	0.06	0.21	0.12	0.26	1.28	0.80	1.81
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448432	GBS	2	44,448,432	2.71E-09	3.89E-04	0.11	190	0.29	0.09	0.12	0.30	-0.32	0.35	-0.67
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448432	GBS	2	44,448,432	2.34E-08	3.35E-03	0.11	189	0.29	0.09	0.12	0.28	-0.41	0.40	-0.74
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448432	GBS	2	44,448,432	8.21E-08	7.61E-03	0.11	190	0.29	0.09	0.18	0.31	0.13	-0.40	-0.26
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Zeaxanthin	S2_44448438	GBS	2	44,448,438	2.71E-09	3.89E-04	0.11	190	0.29	0.09	0.12	0.30	0.32	0.35	1.22
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	Total β-Xanthophylls	S2_44448438	GBS	2	44,448,438	2.34E-08	3.35E-03	0.11	189	0.29	0.09	0.12	0.28	0.41	0.40	1.37
Carotenoid Synthesis and Degradation	GRMZM2G127139	zep1	β-Xanthophylls/α-Xanthophylls	S2_44448438	GBS	2	44,448,438	8.21E-08	7.61E-03	0.11	190	0.29	0.09	0.18	0.31	-0.13	-0.40	0.41
			Zeaxanthin	S2_44473748	GBS	2	44,473,748	3.89E-07	1.60E-02	0.13	190	0.25	0.12	0.12	0.25	0.25	0.35	0.89
			Total β-Xanthophylls	S2_44473748	GBS	2	44,473,748	1.41E-06	4.49E-02	0.13	189	0.25	0.12	0.12	0.24	0.32	0.40	1.01
			β-Xanthophylls/α-Xanthophylls	S2_44473748	GBS	2	44,473,748	1.76E-06	6.32E-02	0.13	190	0.25	0.12	0.18	0.28	-0.10	-0.40	0.31
			Zeaxanthin	S2_44473758	GBS	2	44,473,758	3.89E-07	1.60E-02	0.13	190	0.24	0.12	0.12	0.25	-0.25	0.35	-0.56
			Total β-Xanthophylls	S2_44473758	GBS	2	44,473,758	1.41E-06	4.49E-02	0.13	189	0.24	0.12	0.12	0.24	-0.32	0.40	-0.62
			β-Xanthophylls/α-Xanthophylls	S2_44473758	GBS	2	44,473,758	1.76E-06	5.05E-02	0.13	190	0.24	0.12	0.18	0.28	0.10	-0.40	-0.21
			Zeaxanthin	S2_44473801	GBS	2	44,473,801	3.89E-07	1.60E-02	0.13	190	0.24	0.12	0.12	0.25	0.25	0.35	0.89
			Total β-Xanthophylls	S2_44473801	GBS	2	44,473,801	1.41E-06	4.49E-02	0.13	189	0.24	0.12	0.12	0.24	0.32	0.40	1.01
			β-Xanthophylls/α-Xanthophylls	S2_44473801	GBS	2	44,473,801	1.76E-06	5.05E-02	0.13	190	0.24	0.12	0.18	0.28	-0.10	-0.40	0.31
			Zeaxanthin	S2_44474139	GBS	2	44,474,139	1.48E-06	4.26E-02	0.14	190	0.29	0.13	0.12	0.24	-0.23	0.35	-0.53
			β-Xanthophylls/α-Xanthophylls	S2_44474139	GBS	2	44,474,139	2.48E-06	6.49E-02	0.14	190	0.29	0.13	0.18	0.28	0.10	-0.40	-0.21
			Zeaxanthin	S2_44474308	GBS	2	44,474,308	1.63E-06	4.26E-02	0.21	190	0.38	0.28	0.12	0.24	0.20	0.35	0.68
			Zeaxanthin	S3_169734997	GBS	3	169,734,997	1.04E-06	3.33E-02	0.06	190	0.25	0.07	0.12	0.24	-0.39	0.35	-0.75
			Total β-Xanthophylls	S3_169734997	GBS	3	169,734,997	8.48E-07	4.06E-02	0.06	189	0.25	0.07	0.12	0.24	-0.54	0.40	-0.86
			Zeaxanthin	S3_172380629	GBS	3	172,380,629	3.87E-06	9.20E-02	0.05	190	0.15	0.05	0.12	0.23	-0.38	0.35	-0.75
			β-Cryptoxanthin	S7_13843351	GBS	7	13,843,351	1.77E-07	5.11E-02	0.16	193	0.10	0.16	0.13	0.27	-0.04	0.10	-0.33
			Zeinoxanthin	S7_15282645	GBS	7	15,282,645	2.70E-07	2.59E-02	0.18	192	0.42	0.20	0.10	0.23	-0.12	-0.25	0.66
			Zeaxanthin	S8_2511818	GBS	8	2,511,818	4.16E-06	9.20E-02	0.05	190	0.45	0.11	0.12	0.23	-0.33	0.35	-0.69
			β-Xanthophylls/α-Xanthophylls	PZD00025.1	4K	8	22,245,644	2.97E-06	7.12E-02	0.14	190	0.24	0.14	0.18	0.28	0.10	-0.40	-0.21
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	*lcyE* 5'TE	Additonal Markers	8	138,882,481	2.43E-13	3.49E-08	NA	196	NA	NA	.04	.24	NA	NA	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Carotenoids/α-Carotenoids	*lcyE* 5'TE	Additonal Markers	8	138,882,481	1.35E-13	3.86E-08	NA	189	NA	NA	.01	.28	NA	NA	NA
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	ss196504160	55K	8	138,882,711	6.86E-09	6.58E-04	0.35	190	0.48	0.34	0.18	0.34	0.10	-0.40	-0.21
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Carotenoids/α-Carotenoids	ss196504160	55K	8	138,882,711	7.10E-09	1.01E-03	0.36	184	0.48	0.34	0.20	0.37	0.11	-0.85	-0.12
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Carotenoids/α-Carotenoids	S8_138882897	GBS	8	138,882,897	1.28E-07	1.22E-02	0.43	184	0.12	0.44	0.20	0.34	-0.10	-0.85	0.13
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	β-Xanthophylls/α-Xanthophylls	S8_138882897	GBS	8	138,882,897	4.03E-07	1.66E-02	0.43	190	0.12	0.44	0.18	0.30	-0.08	-0.40	0.24
Carotenoid Synthesis and Degradation	GRMZM2G012966	lycE	Lutein	*lcyE* SNP216	Additonal Markers	8	138,883,206	1.08E-09	3.12E-04	NA	200	NA	NA	.12	.49	NA	NA	NA

Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Zeaxanthin**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**1.02E-06**	**3.33E-02**	**NA**	**196**	**NA**	**NA**	**.17**	**.34**	**NA**	**NA**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total β-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**8.01E-07**	**4.06E-02**	**NA**	**195**	**NA**	**NA**	**.18**	**.39**	**NA**	**NA**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**Total α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**1.39E-10**	**4.03E-05**	**NA**	**200**	**NA**	**NA**	**.09**	**.42**	**NA**	**NA**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	***lcyE* SNP216**	**Additonal Markers**	**8**	**138,883,206**	**1.86E-14**	**5.35E-09**	**NA**	**196**	**NA**	**NA**	**.04**	**.25**	**NA**	**NA**	**NA**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Xanthophylls/α-Xanthophylls**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**1.06E-07**	**5.07E-03**	**0.47**	**190**	**0.19**	**0.42**	**0.18**	**0.31**	**-0.09**	**-0.40**	**0.27**
Carotenoid Synthesis and Degradation	**GRMZM2G012966**	**lycE**	**β-Carotenoids/α-Carotenoids**	**S8_138888278**	**GBS**	**8**	**138,888,278**	**3.97E-07**	**2.83E-02**	**0.47**	**184**	**0.19**	**0.42**	**0.20**	**0.32**	**-0.10**	**-0.85**	**0.13**
			β-Xanthophylls/α-Xanthophylls	S8_140192724	GBS	8	140,192,724	3.36E-06	7.44E-02	0.34	190	0.19	0.28	0.18	0.28	-0.08	-0.40	0.22
			β-Carotenoids/α-Carotenoids	S8_140192724	GBS	8	140,192,724	1.27E-06	7.22E-02	0.35	184	0.19	0.28	0.20	0.31	-0.09	-0.85	0.12
			Zeaxanthin	**S8_171705545**	**GBS**	**8**	**171,705,545**	**2.95E-07**	**1.60E-02**	**0.11**	**190**	**0.14**	**0.14**	**0.12**	**0.25**	**-0.28**	**0.35**	**-0.61**
			Total β-Xanthophylls	**S8_171705545**	**GBS**	**8**	**171,705,545**	**2.80E-07**	**2.01E-02**	**0.10**	**189**	**0.14**	**0.14**	**0.12**	**0.26**	**-0.40**	**0.40**	**-0.72**
			Zeaxanthin	**S8_171705574**	**GBS**	**8**	**171,705,574**	**9.09E-08**	**8.71E-03**	**0.11**	**190**	**0.25**	**0.13**	**0.12**	**0.27**	**-0.29**	**0.35**	**-0.63**
			Total β-Xanthophylls	**S8_171705574**	**GBS**	**8**	**171,705,574**	**9.66E-08**	**9.24E-03**	**0.10**	**189**	**0.25**	**0.13**	**0.12**	**0.27**	**-0.41**	**0.40**	**-0.74**
			α-Carotene/Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**8.69E-10**	**8.59E-05**	**0.32**	**190**	**0.37**	**0.29**	**0.17**	**0.36**	**-0.06**	**-0.25**	**0.29**
			Zeinoxanthin/Lutein	**ss196491114**	**55K**	**9**	**69,215,031**	**1.13E-07**	**1.08E-02**	**0.29**	**189**	**0.37**	**0.29**	**0.09**	**0.24**	**0.19**	**-0.35**	**-0.39**
			Zeinoxanthin	**ss196491114**	**55K**	**9**	**69,215,031**	**4.90E-07**	**3.53E-02**	**0.30**	**192**	**0.37**	**0.29**	**0.10**	**0.23**	**0.11**	**-0.25**	**-0.34**

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with the peak marker tagging the GWAS signal from *crtRB1* included as a covariate. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font.

Table S8 Genome-wide Association Study Results with Covariates for *lut1*, *zep1*, *lcyE* and *crtRB1* (G)

***a priori* candidate gene pathway**	**RefGen_v2 Gene ID**	**Annotated gene containing associated SNP or gene within 3kb of associated SNP**	**Trait**	**SNP ID**	**SNP Source**	**Chr**	**Position in RefGen_v2**	***P*-value**	**FDR-Adjusted *P*-value**	**Minor Allele Frequency (MAF)**	**Sample Size**	**MAF Tropical (8% of 201 Lines)**	**MAF Temperate (92% of 201 Lines)**	**R-square_LR from Model without SNP**	**R-square_LR from Model with SNP**	**Effect Size**	**Lambda from Box-Cox Procedure**	**Back-Transformed Effect Estimates**
			β-Cryptoxanthin	**S7_13843351**	**GBS**	**7**	**13,843,351**	**4.86E-08**	**1.42E-02**	**0.16**	**177**	**0.10**	**0.16**	**0.24**	**0.39**	**-0.04**	**0.10**	**-0.33**
			Total Carotenoids	S7_121184182	GBS	7	121,184,182	3.30E-07	9.66E-02	0.08	179	0.14	0.08	0.16	0.29	-1.41	0.65	-1.26
			Total β-Xanthophylls	S7_121185500	GBS	7	121,185,500	5.90E-07	8.50E-02	0.09	173	0.19	0.09	0.41	0.51	0.34	0.40	1.07
			Zeaxanthin	**S8_171705574**	**GBS**	**8**	**171,705,574**	**1.54E-07**	**4.44E-02**	**0.11**	**174**	**0.25**	**0.13**	**0.42**	**0.53**	**-0.25**	**0.35**	**-0.56**
			Total β-Xanthophylls	S8_171705574	GBS	8	171,705,574	3.92E-07	8.50E-02	0.10	173	0.25	0.13	0.41	0.51	-0.34	0.40	-0.65

Statistically significant results from genome-wide association studies on 24 grain carotenoid traits with markers tagging the signals at *lut1*, *zep1*, *lcyE*, and *crtRB1* included as covariates. Markers (Column E) that were significantly associated with the indicated trait (Column D) at 5% false discovery rate (FDR) are demarcated with boldface font and those significant only at 10% FDR without boldface font.