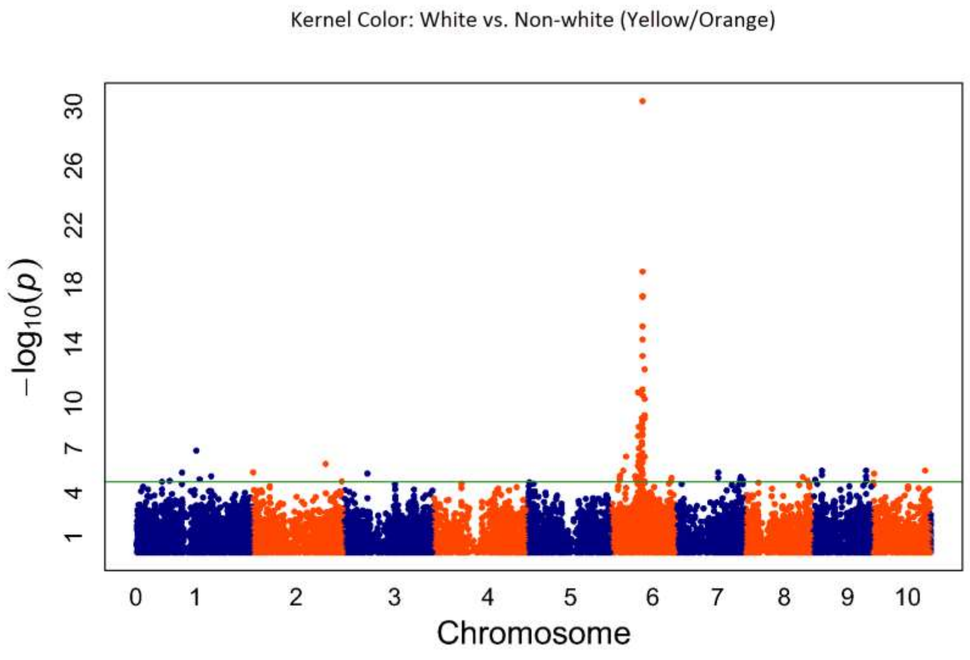
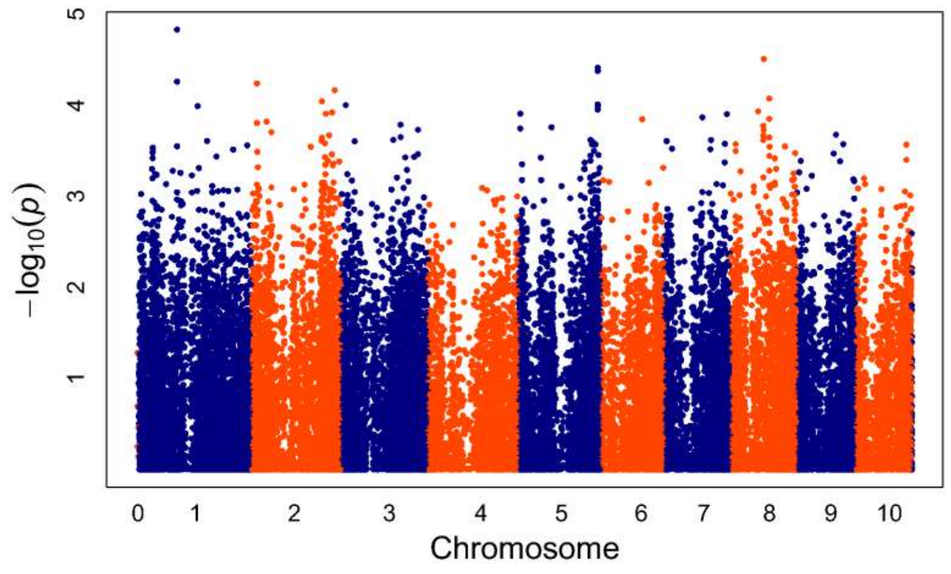
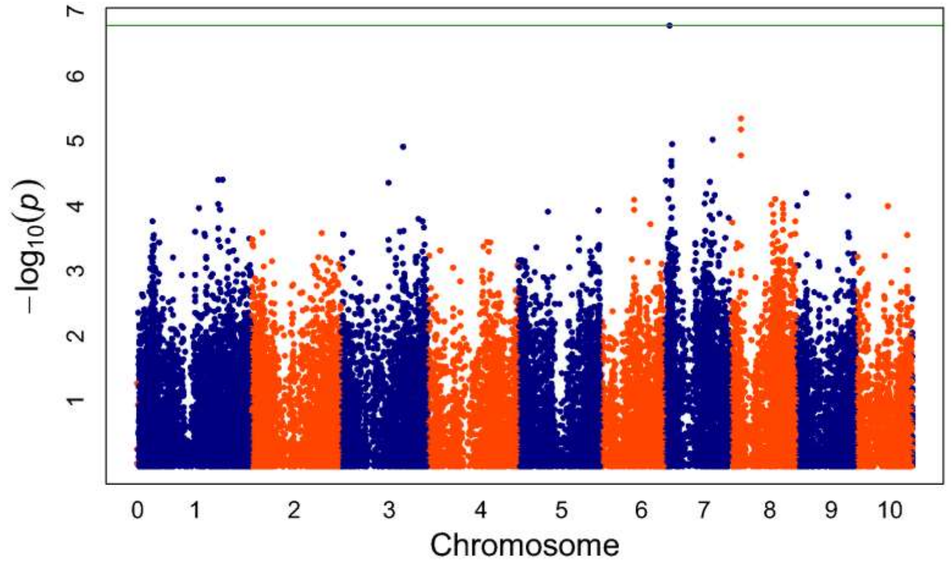



**Figure S1** Genome-wide association study (GWAS) of a binary kernel color trait: white vs. non-white. The non-white class included maize inbred lines ranging from yellow to dark orange in kernel color. Scatter plot of association results from a unified mixed model analysis of the kernel color trait. Negative $\log_{10}$-transformed *P*-values (y-axis) from GWAS are plotted against physical position (B73 RefGen_v2) on each of 10 chromosomes (x-axis). Chromosomes are alternatingly colored. The horizontal green line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% false discovery rate.

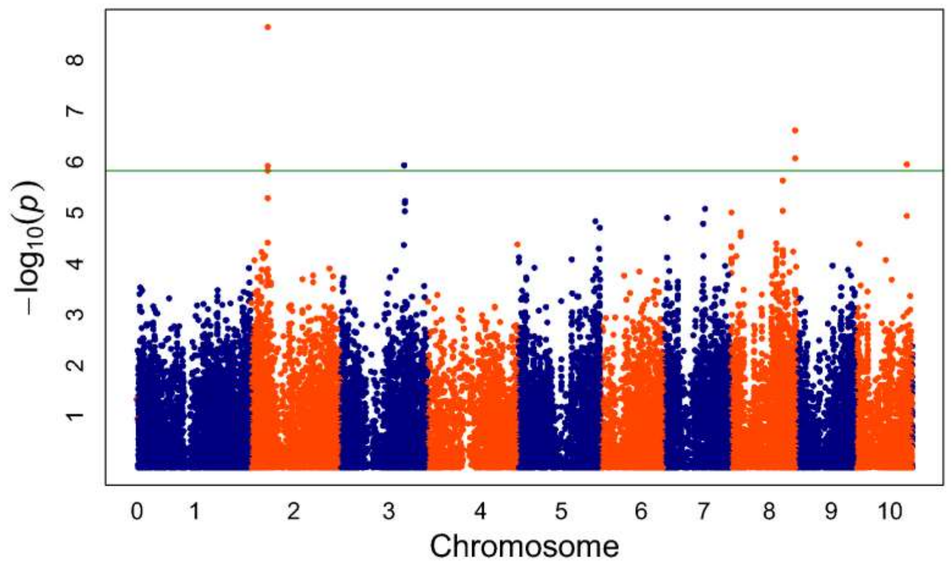
β-Carotene



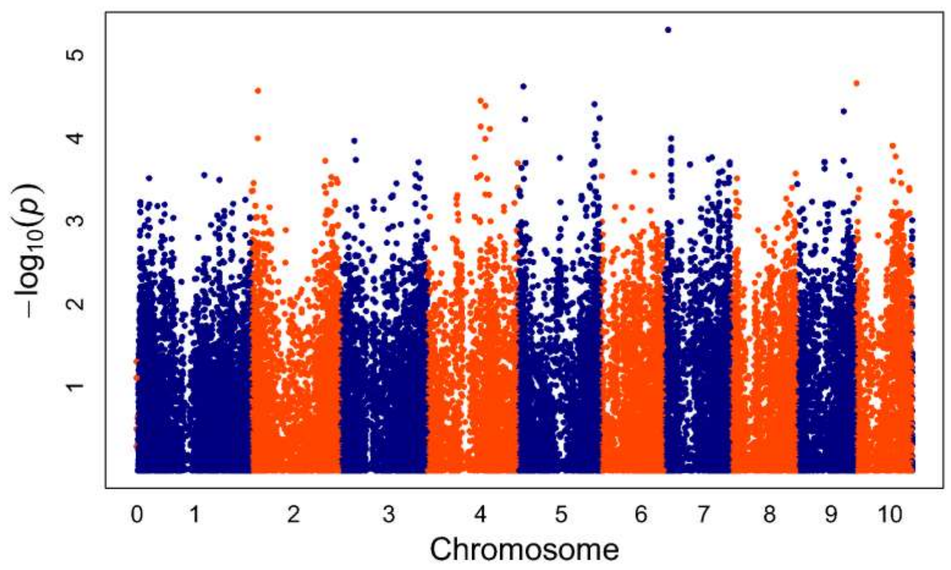

β-Cryptoxanthin



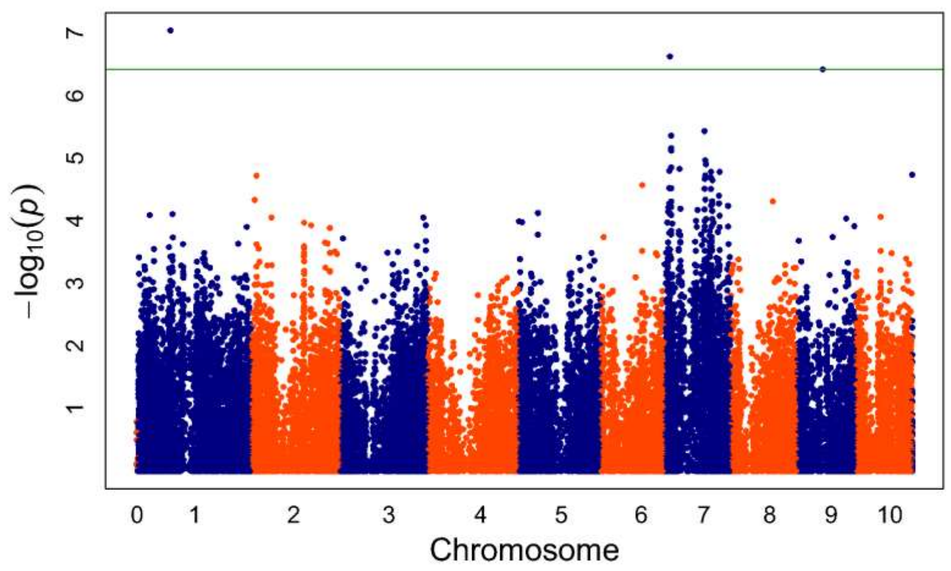
Zeaxanthin



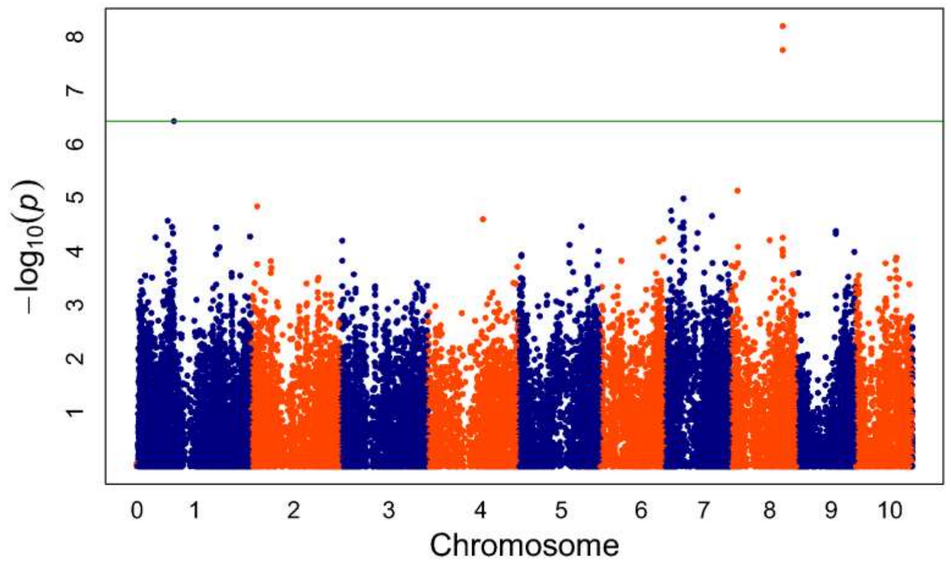

α-Carotene



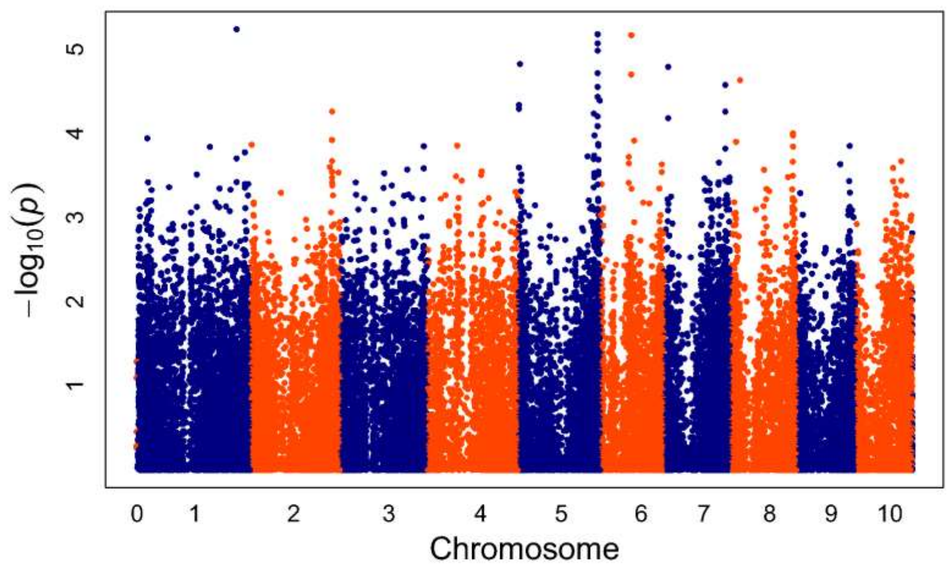

Zeinoxanthin



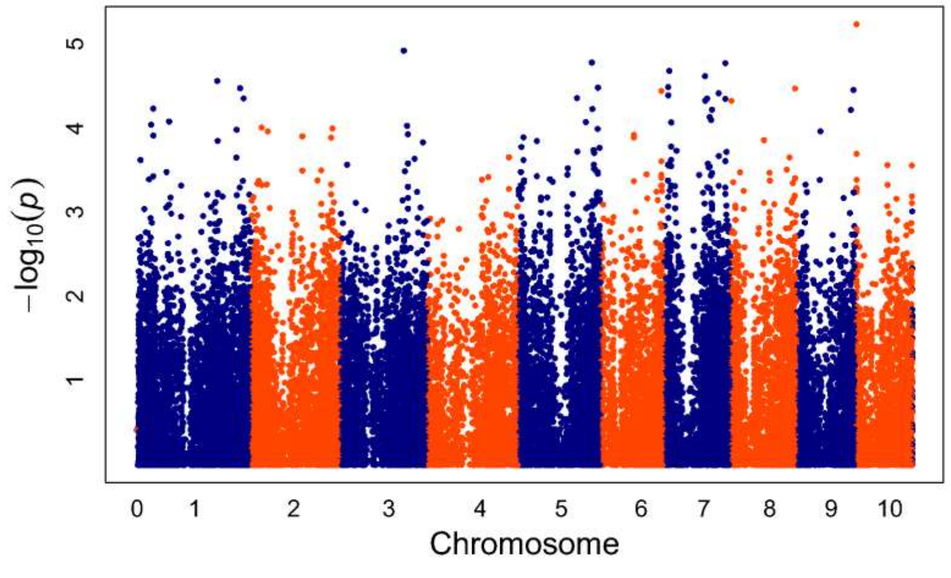
Lutein



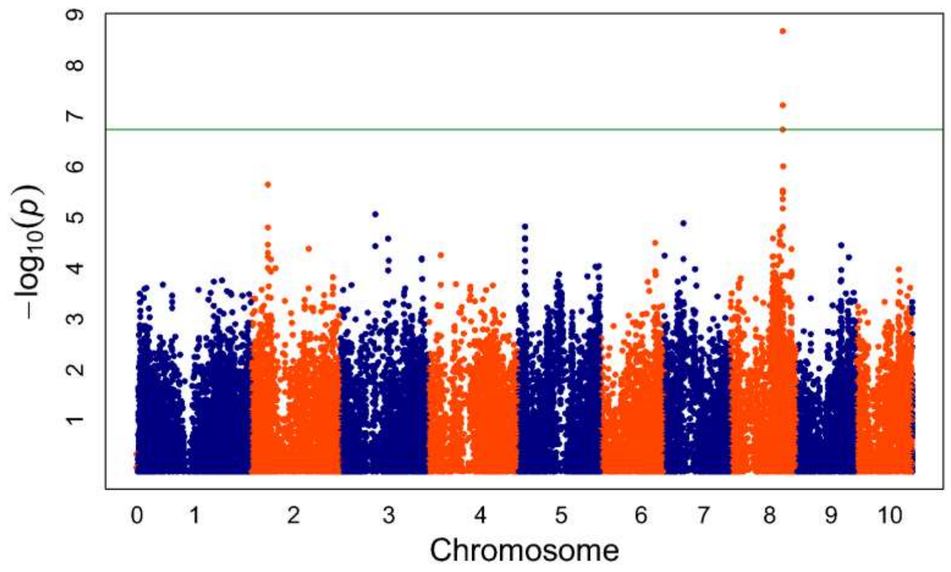

Acyclic and Monocyclic Carotenes



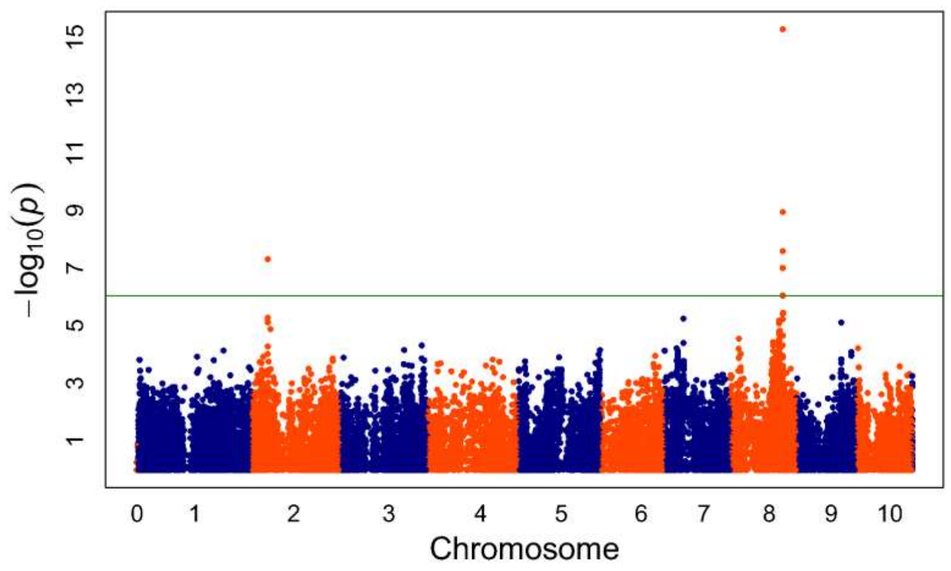

Total Carotenoids



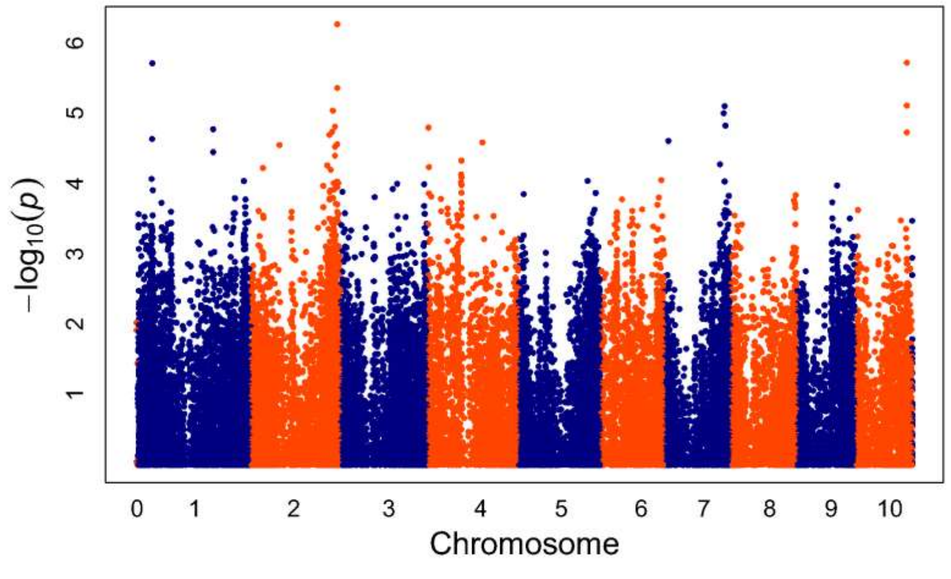
β-Carotenoids/α-Carotenoids

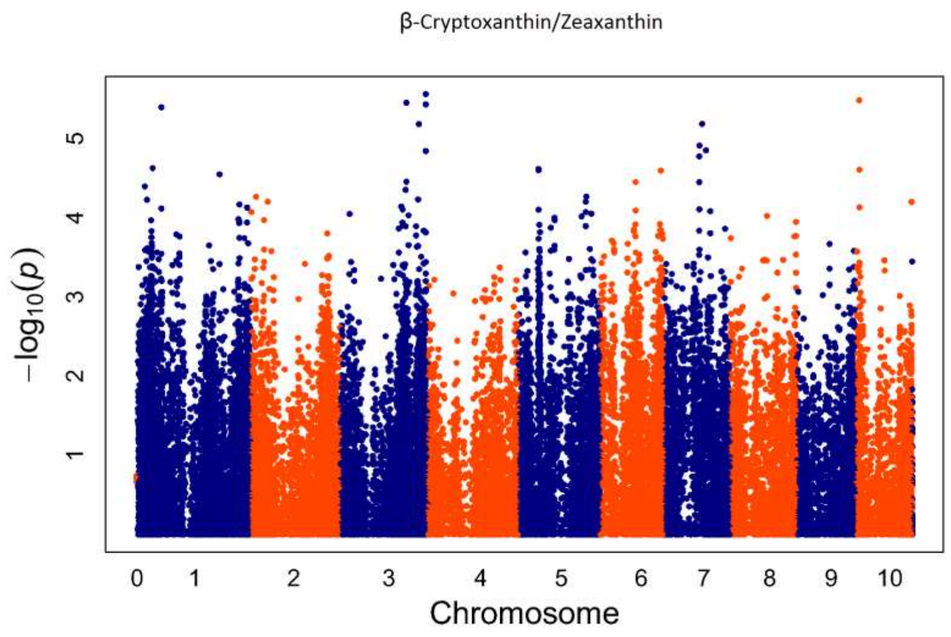


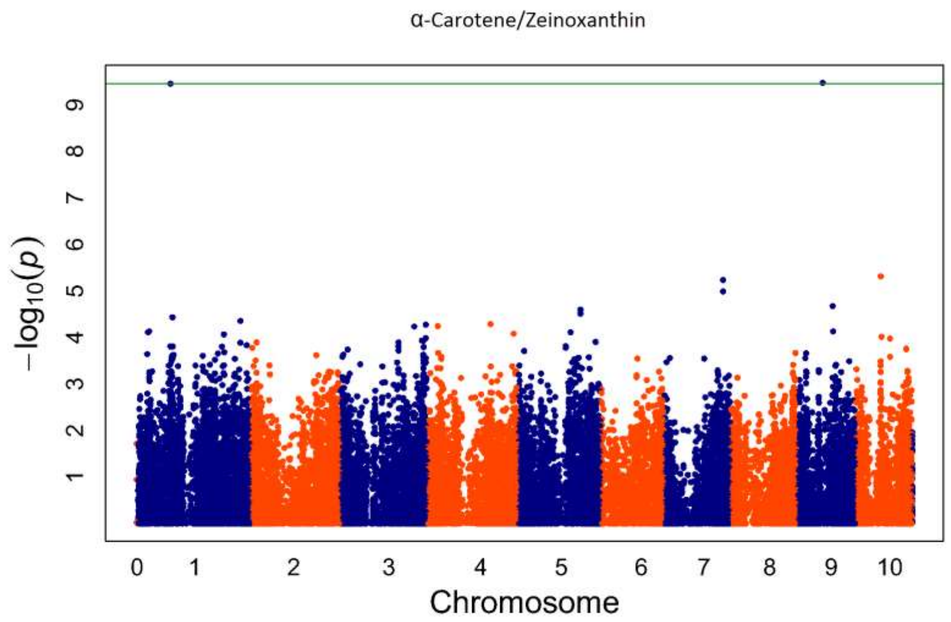

β-Xanthophylls/α-Xanthophylls



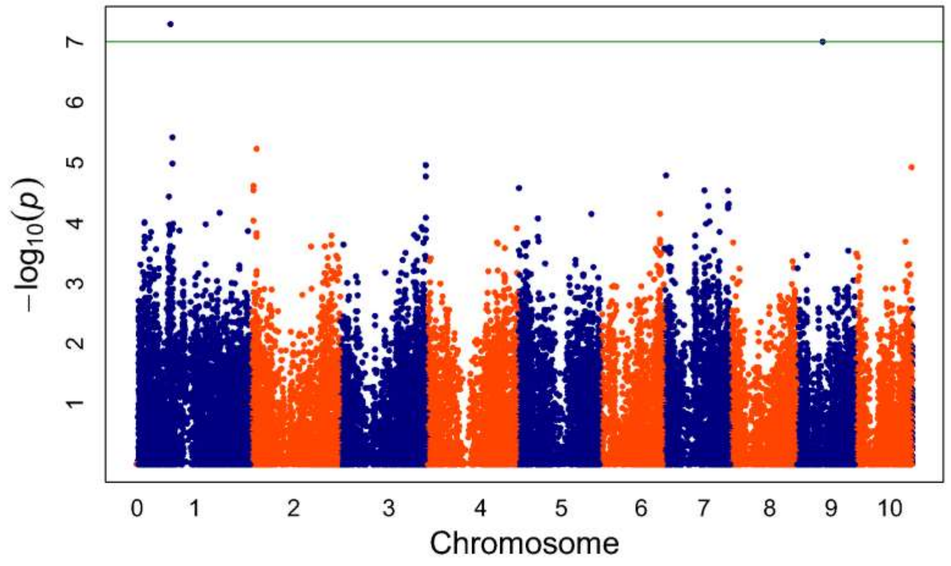

β-Carotene/β-Cryptoxanthin



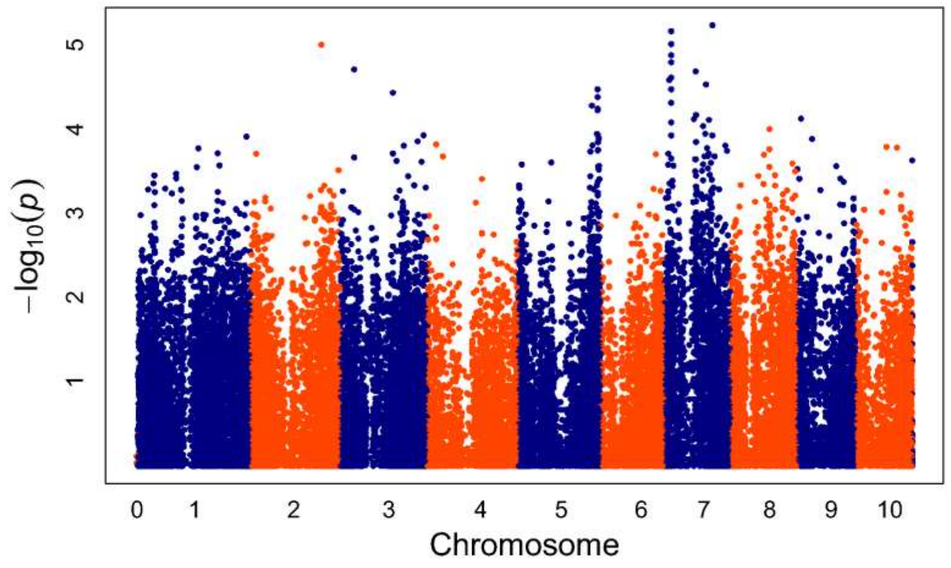

β-Cryptoxanthin/Zeaxanthin
$-\log_{10}(p)$
1
2
3
4
5
0
1
2
3
4
5
6
7
8
9
10
Chromosome


α-Carotene/Zeinoxanthin
$-\log_{10}(p)$
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
Chromosome

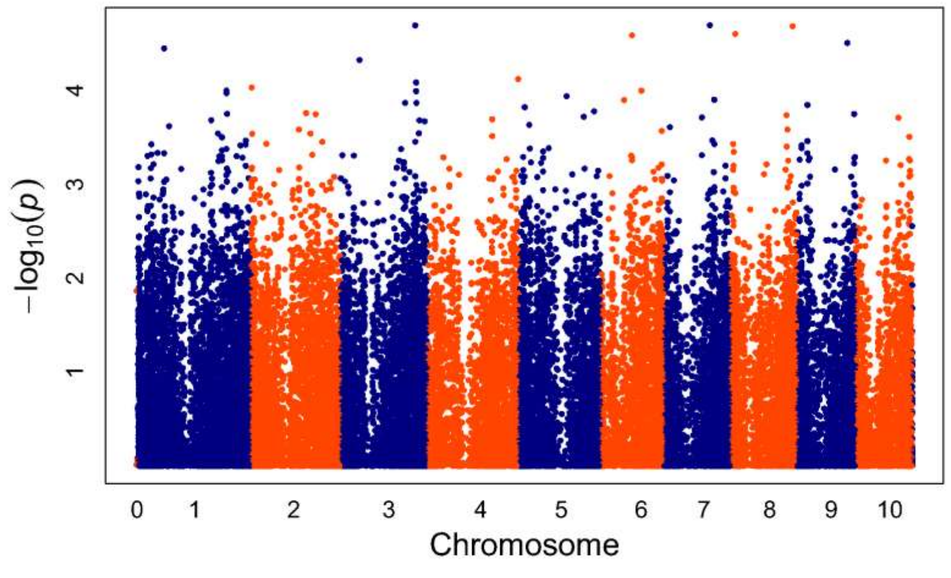
Zeinoxanthin/Lutein



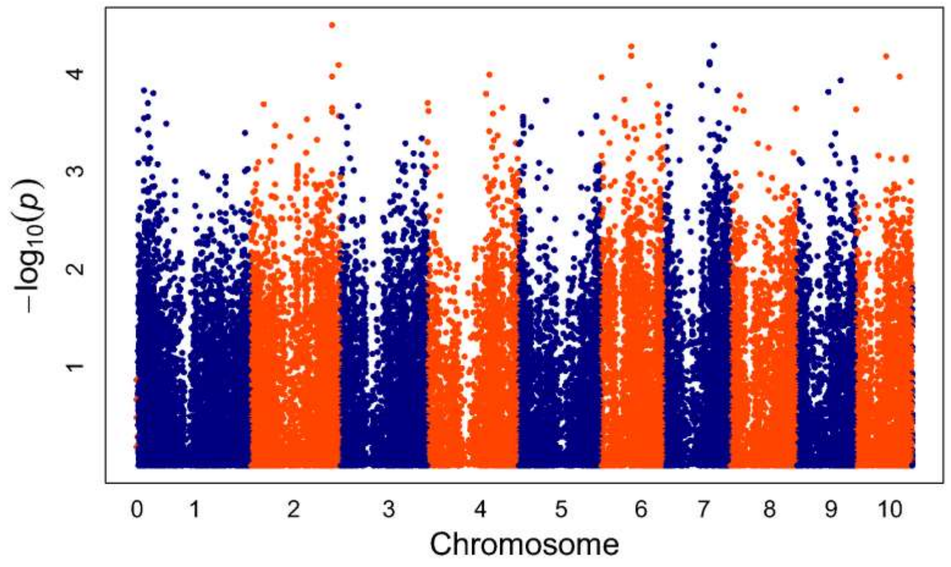

Provitamin A



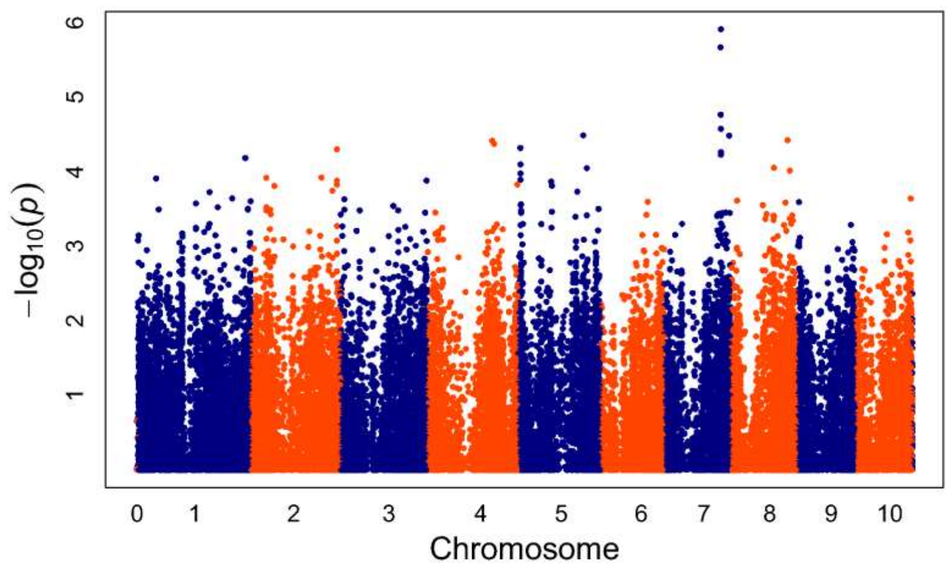

Phytofluene



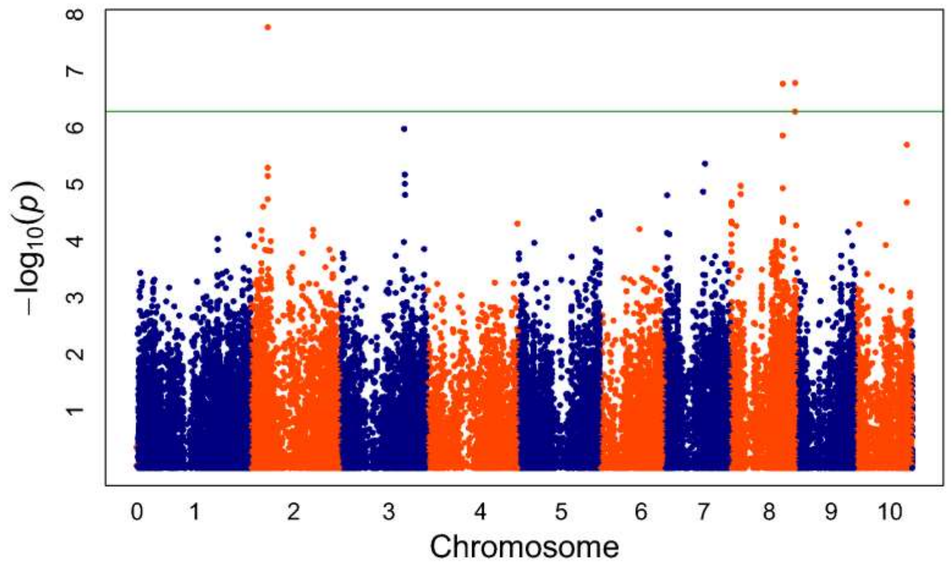
ζ-Carotene

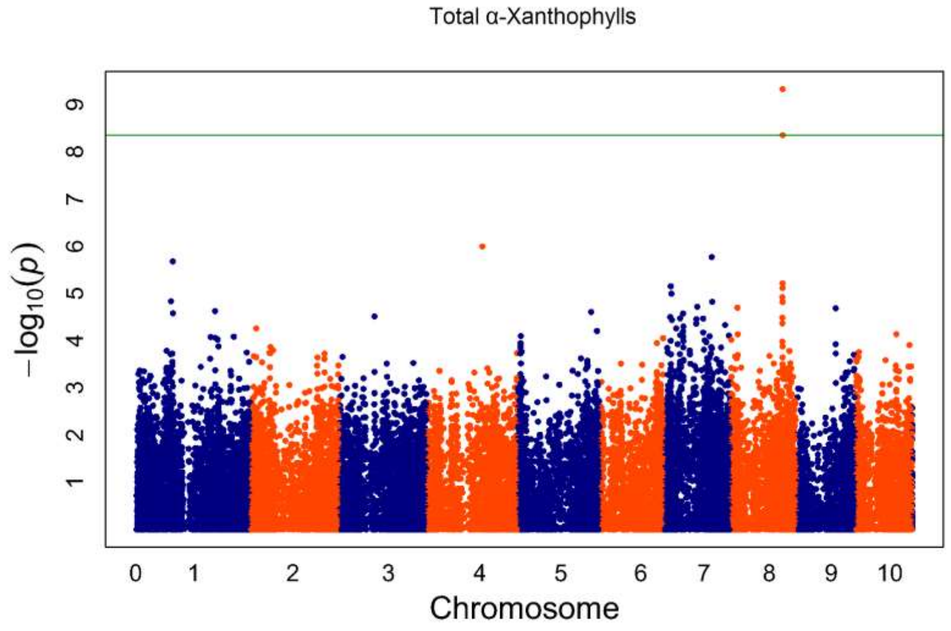


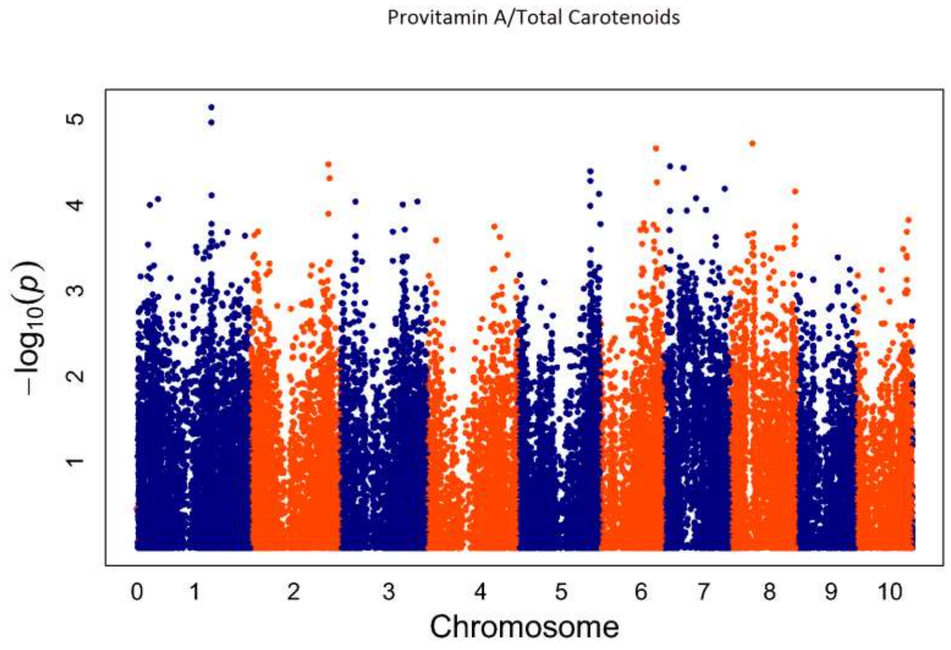

Tetrahydrolycopene

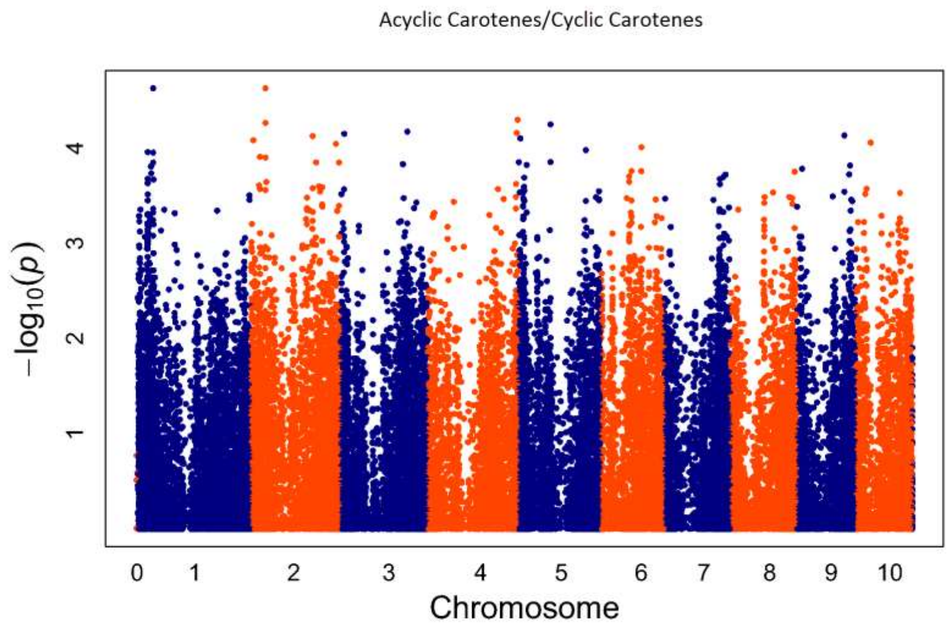


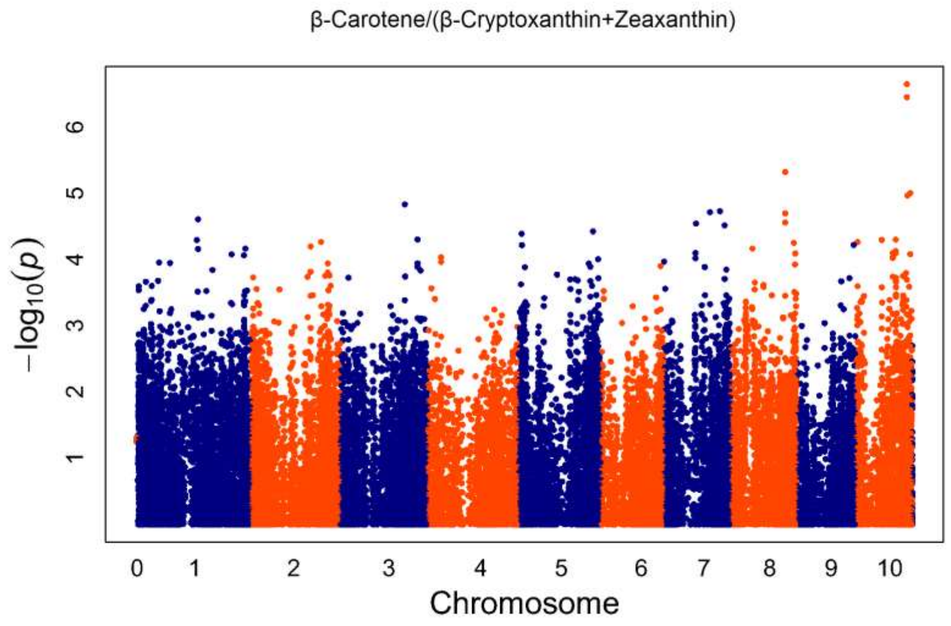

Total β-Xanthophylls




Total α-Xanthophylls
$-\log_{10}(p)$
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
Chromosome


Provitamin A/Total Carotenoids
$-\log_{10}(p)$
1
2
3
4
5
0
1
2
3
4
5
6
7
8
9
10
Chromosome


Acyclic Carotenes/Cyclic Carotenes
$-\log_{10}(p)$
1
2
3
4
0
1
2
3
4
5
6
7
8
9
10
Chromosome



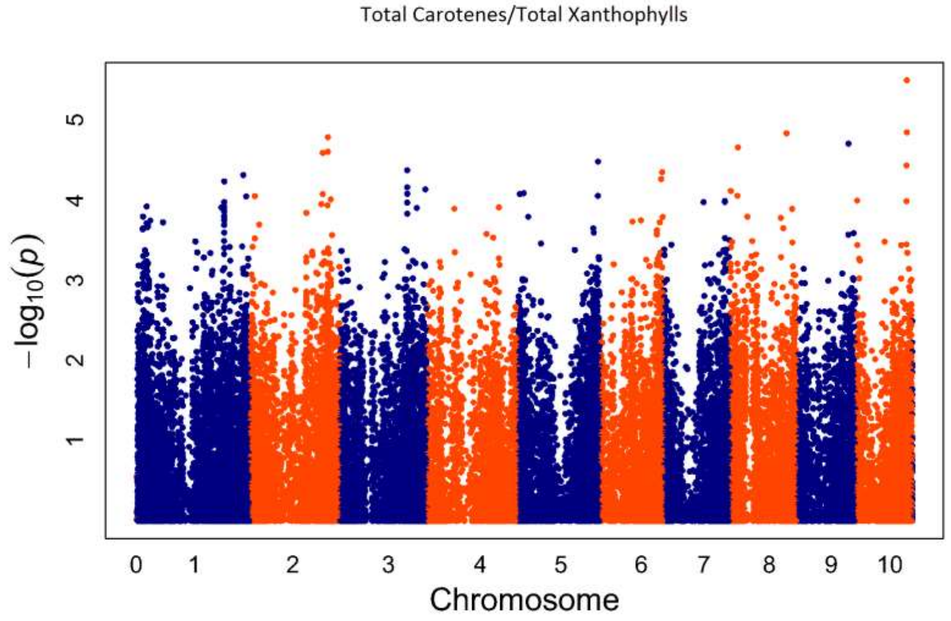




**Figure S2** Genome-wide association study (GWAS) of 24 carotenoid grain traits. Scatter plots of association results from a unified mixed model analysis of each carotenoid grain trait. Negative $\log_{10}$-transformed *P*-values (y-axis) from GWAS are plotted against physical position (B73 RefGen_v2) on each of 10 chromosomes (x-axis). Chromosomes are alternatingly colored. The horizontal green line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% false discovery rate (FDR). Additional information for all statistically significant markers at 5% and 10% FDR are provided in Table S8 (A).

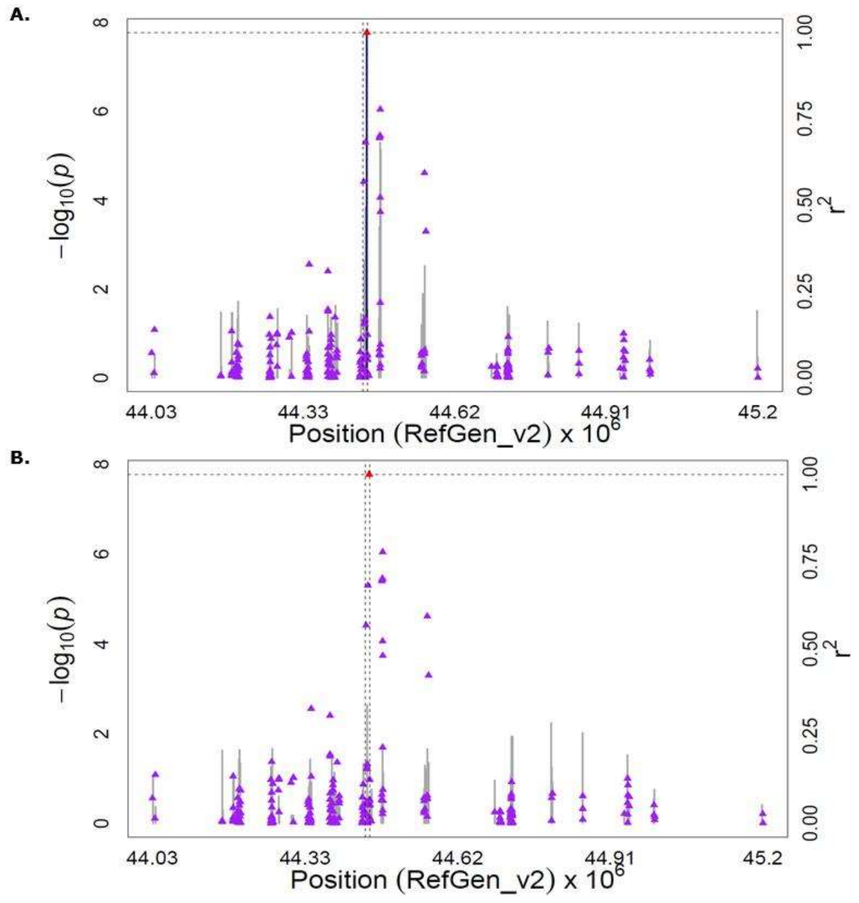



**Figure S3** Genome-wide association study (GWAS) for total β-xanthophylls content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of total β-xanthophylls and linkage disequilibrium (LD) estimates ($r^2$) across the *zep1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for total β-xanthophylls and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1.2 Mb region on chromosome 2 that encompasses *zep1*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for total β-xanthophylls at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 44,448,432 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *zep1* (GRMZM2G127139). (B) Scatter plot of association results from a conditional unified mixed model analysis of total β-xanthophylls and LD estimates ($r^2$) across the *zep1* chromosome region, as in (A). The peak SNP from the unconditional GWAS (S2_44448432; 44,448,432 bp) was included as a covariate in the unified mixed model to control for the *zep1* effect.

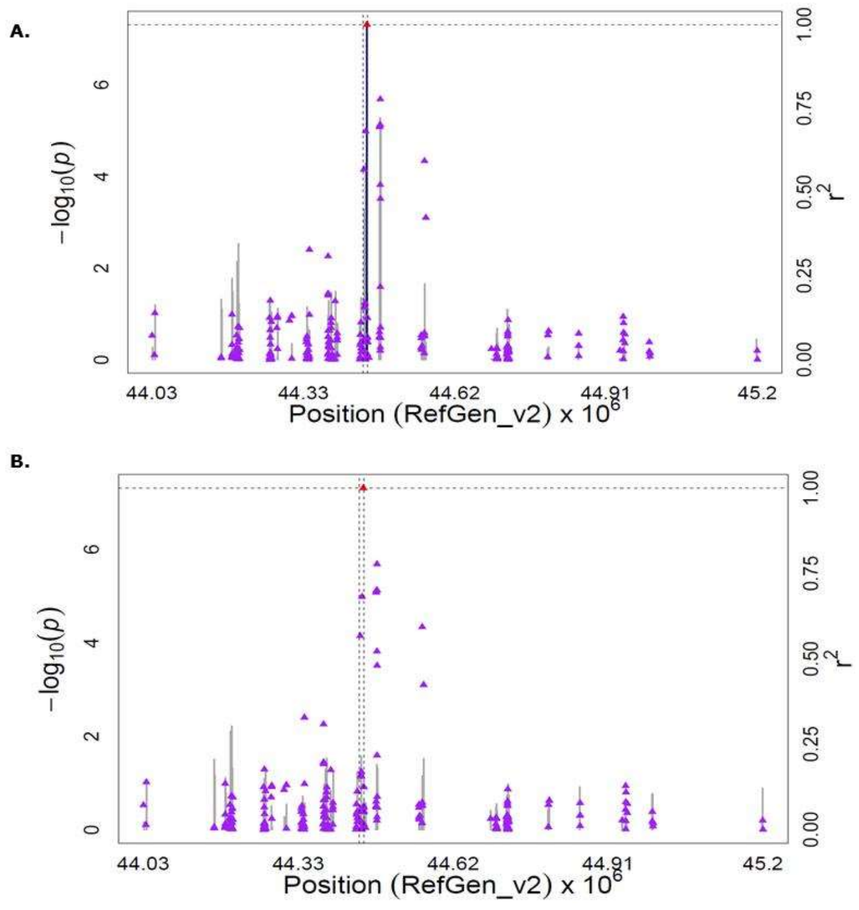



**Figure S4** Genome-wide association study (GWAS) for the ratio of total β-xanthophylls to total α-xanthophylls content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of the ratio of total β-xanthophylls to total α-xanthophylls and linkage disequilibrium (LD) estimates ($r^2$) across the *zep1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for the ratio of total β-xanthophylls to total α-xanthophylls and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1.2 Mb region on chromosome 2 that encompasses *zep1*. The blue vertical lines are $-\log_{10}$ P-values for SNPs that are statistically significant for the ratio of total β-xanthophylls to total α-xanthophylls at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 44,448,432 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *zep1* (GRMZM2G127139). (B) Scatter plot of association results from a conditional unified mixed model analysis of the ratio of total β-xanthophylls to total α-xanthophylls and LD estimates ($r^2$) across the *zep1* chromosome region, as in (A). The peak SNP from the unconditional GWAS (S2_44448432; 44,448,432 bp) was included as a covariate in the unified mixed model to control for the *zep1* effect.

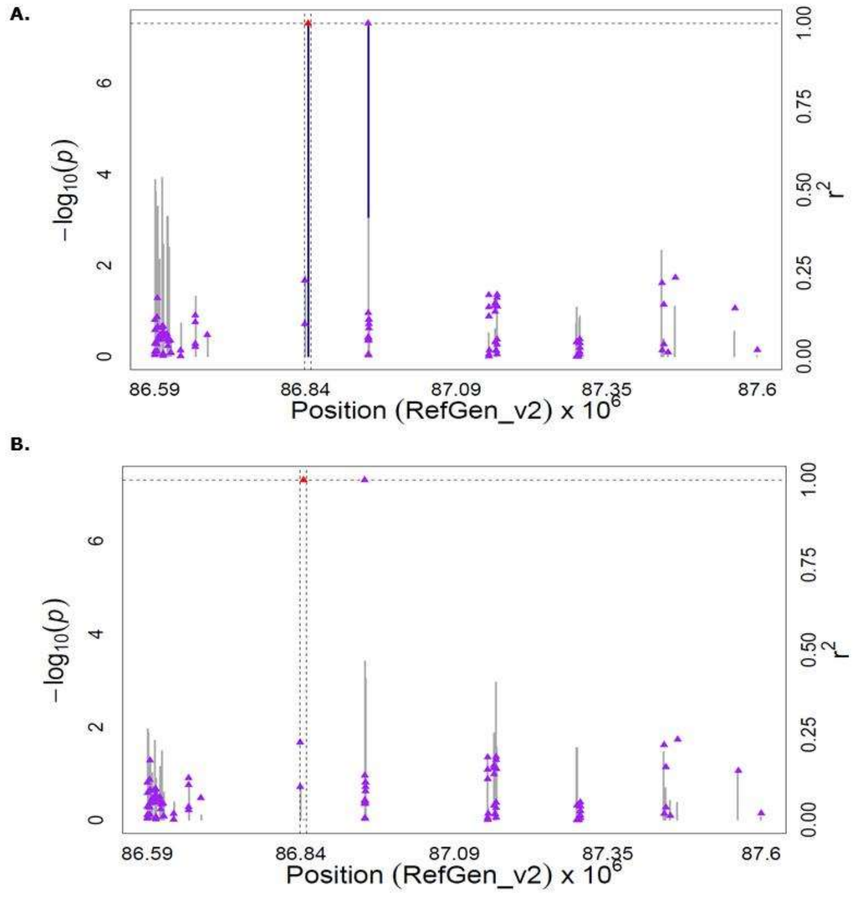



**Figure S5** Genome-wide association study (GWAS) for the ratio of zeinoxanthin to lutein content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of the ratio of zeinoxanthin to lutein and linkage disequilibrium (LD) estimates ($r^2$) across the *lut1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for the ratio of zeinoxanthin to lutein and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1 Mb region on chromosome 1 that encompasses *lut1*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for the ratio of zeinoxanthin to lutein at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 86,844,203 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lut1* (GRMZM2G14322.) (B) Scatter plot of association results from a conditional unified mixed model analysis of the ratio of zeinoxanthin to lutein and LD estimates ($r^2$) across the *lut1* chromosome region, as in (A). The peak SNP from the unconditional GWAS (ss196425306; 86,844,203 bp) was included as a covariate in the unified mixed model to control for the *lut1* effect.

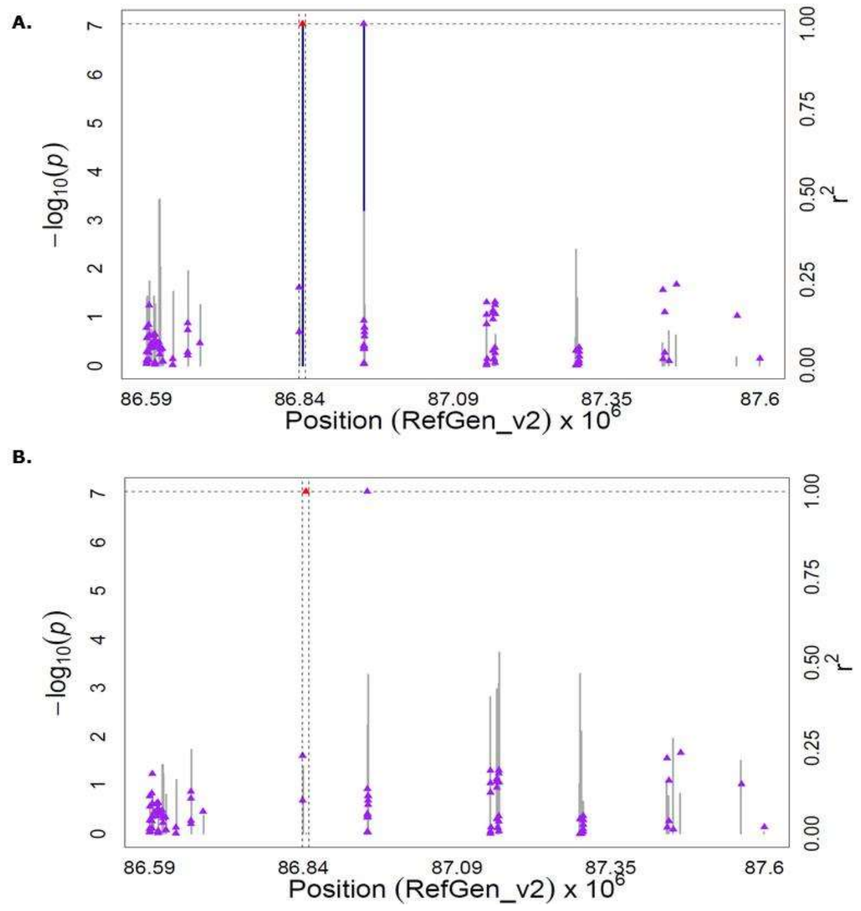



**Figure S6** Genome-wide association study (GWAS) for zeinoxanthin content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of zeinoxanthin and linkage disequilibrium (LD) estimates ($r^2$) across the *lut1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for zeinoxanthin and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1 Mb region on chromosome 1 that encompasses *lut1*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for zeinoxanthin at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 86,844,203 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lut1* (GRMZM2G14322.) (B) Scatter plot of association results from a conditional unified mixed model analysis of zeinoxanthin and LD estimates ($r^2$) across the *lut1* chromosome region, as in (A). The peak SNP from the unconditional GWAS (ss196425306; 86,844,203 bp) was included as a covariate in the unified mixed model to control for the *lut1* effect.

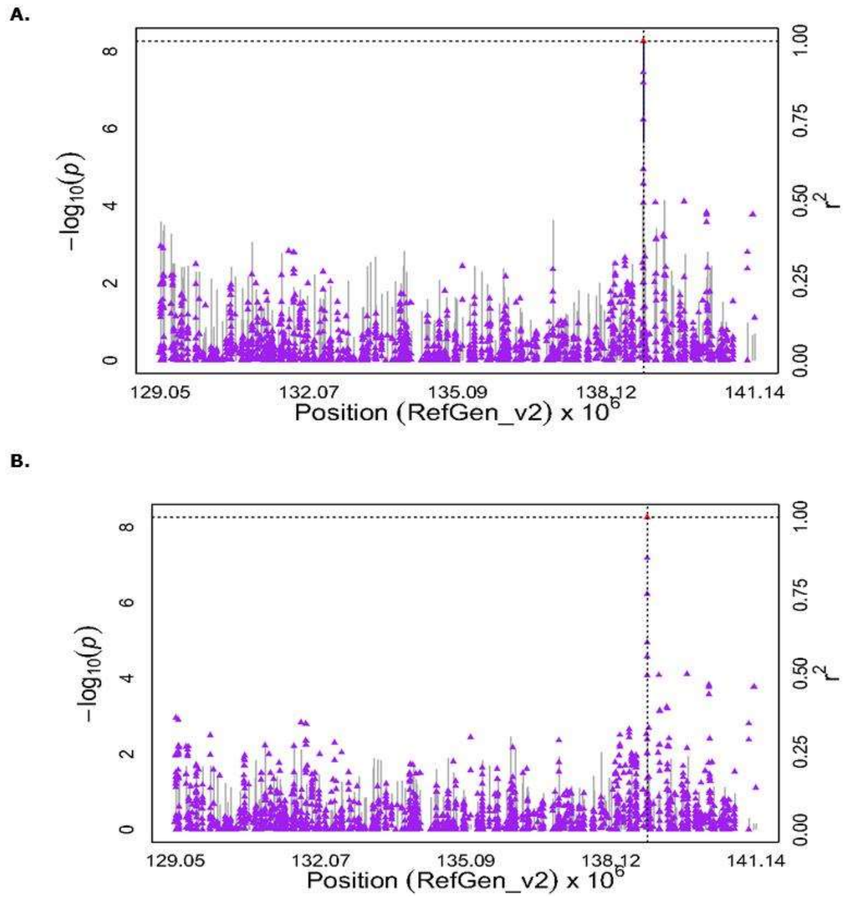



**Figure S7** Genome-wide association study (GWAS) for zeaxanthin content in maize grain. Scatter plot of association results from a unified mixed model analysis of zeaxanthin and linkage disequilibrium (LD) estimates ($r^2$) across the *lcyE* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for zeaxanthin and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 12 Mb region on chromosome 8 that encompasses *lcyE*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for zeaxanthin at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 138,883,206 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lcyE* (GRMZM2G12966). (B) Scatter plot of association results from a conditional unified mixed model analysis of zeaxanthin and LD estimates ($r^2$) across the *lcyE* chromosome region, as in (A). The two SNPs (*lcyE* SNP216 and S8_138882897) from the optimal multi-locus mixed model (MLMM) model were included as covariates in the unified mixed model to control for the *lcyE* effect.

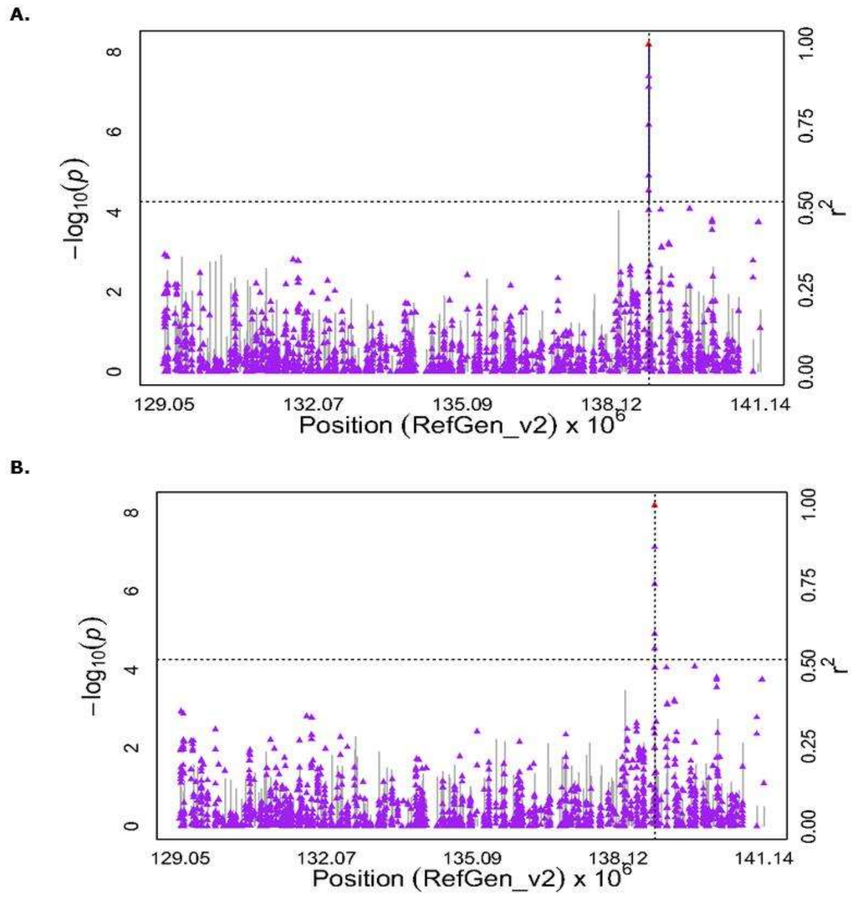



**Figure S8** Genome-wide association study (GWAS) for lutein content in maize grain. Scatter plot of association results from a unified mixed model analysis of lutein and linkage disequilibrium (LD) estimates ($r^2$) across the *lcyE* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for lutein and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 12 Mb region on chromosome 8 that encompasses *lcyE*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for lutein at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 138,883,206 bp. The black horizontal dashed line indicates the –log10 *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lcyE* (GRMZM2G12966). (B) Scatter plot of association results from a conditional unified mixed model analysis of lutein and LD estimates ($r^2$) across the *lcyE* chromosome region, as in (A). The two SNPs (*lcyE* SNP216 and S8_138882897) from the optimal multi-locus mixed model (MLMM) model were included as covariates in the unified mixed model to control for the *lcyE* effect.

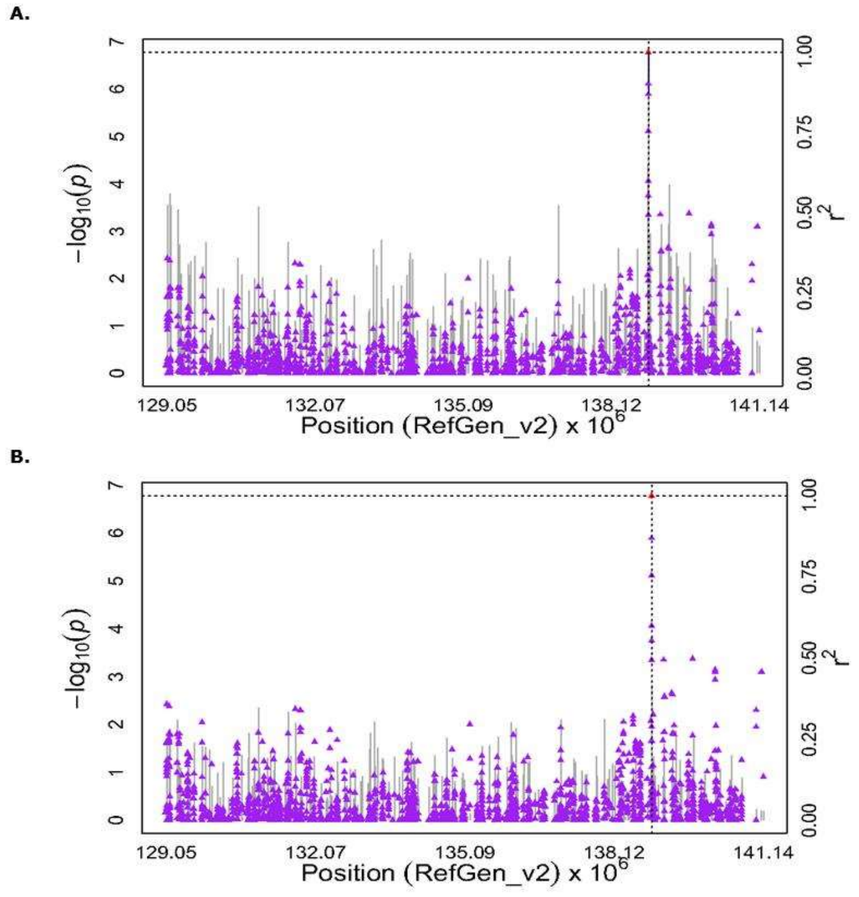



**Figure S9** Genome-wide association study (GWAS) for total β-xanthophyll content in maize grain. Scatter plot of association results from a unified mixed model analysis of total β-xanthophyll and linkage disequilibrium (LD) estimates ($r^2$) across the *lcyE* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for total β-xanthophyll and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 12 Mb region on chromosome 8 that encompasses *lcyE*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for total β-xanthophyll at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 138,883,206 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lcyE* (GRMZM2G12966). (B) Scatter plot of association results from a conditional unified mixed model analysis of total β-xanthophyll and LD estimates ($r^2$) across the *lcyE* chromosome region, as in (A). The two SNPs (*lcyE* SNP216 and S8_138882897) from the optimal multi-locus mixed model (MLMM) model were included as covariates in the unified mixed model to control for the *lcyE* effect.

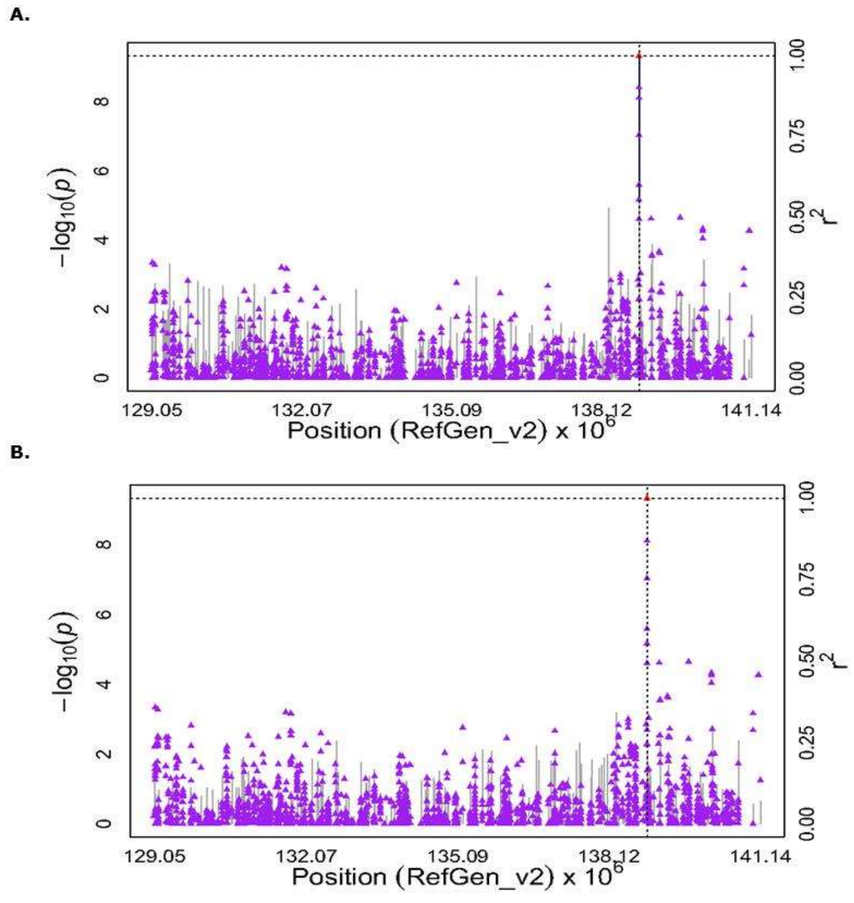



**Figure S10** Genome-wide association study (GWAS) for total α-xanthophyll content in maize grain. Scatter plot of association results from a unified mixed model analysis of total α-xanthophyll and linkage disequilibrium (LD) estimates ($r^2$) across the *lcyE* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for total α-xanthophyll and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 12 Mb region on chromosome 8 that encompasses *lcyE*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for total α-xanthophyll at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 138,883,206 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lcyE* (GRMZM2G12966). (B) Scatter plot of association results from a conditional unified mixed model analysis of total α-xanthophyll and LD estimates ($r^2$) across the *lcyE* chromosome region, as in (A). The two SNPs (*lcyE* SNP216 and S8_138882897) from the optimal multi-locus mixed model (MLMM) model were included as covariates in the unified mixed model to control for the *lcyE* effect.

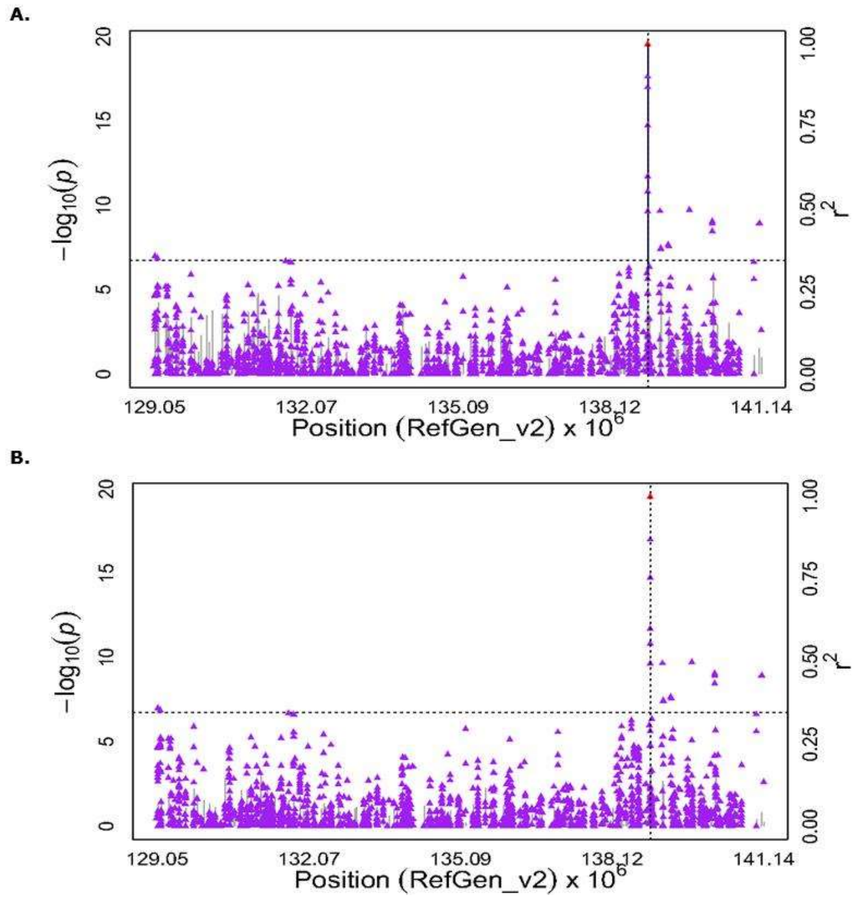



**Figure S11** Genome-wide association study (GWAS) for the ratio of β-carotenoid to α-carotenoid content in maize grain. Scatter plot of association results from a unified mixed model analysis of the ratio of β-carotenoid to α-carotenoid content and linkage disequilibrium (LD) estimates ($r^2$) across the *lcyE* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for the ratio of β-carotenoid to α-carotenoid content and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 12 Mb region on chromosome 8 that encompasses *lcyE*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for the ratio of β-carotenoid to α-carotenoid content at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 138,883,206 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *lcyE* (GRMZM2G12966). (B) Scatter plot of association results from a conditional unified mixed model analysis of the ratio of β-carotenoid to α-carotenoid content and LD estimates ($r^2$) across the *lcyE* chromosome region, as in (A). The two SNPs (*lcyE* SNP216 and S8_138882897) from the optimal multi-locus mixed model (MLMM) model were included as covariates in the unified mixed model to control for the *lcyE* effect.

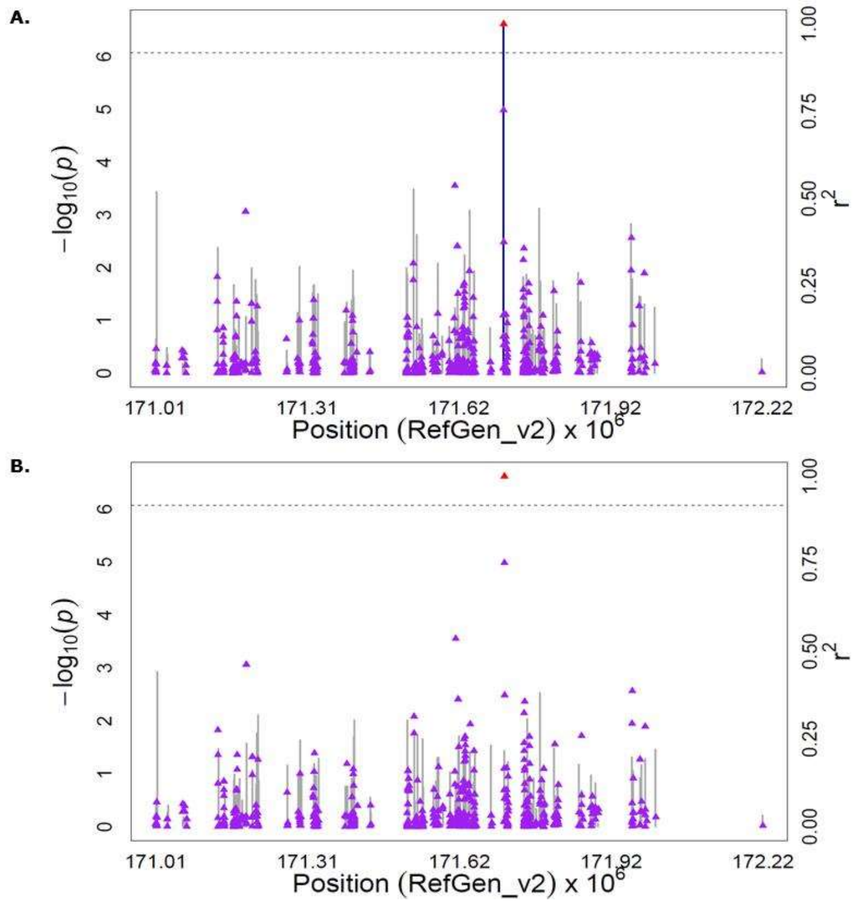



**Figure S12** Genome-wide association study (GWAS) for zeaxanthin content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of zeaxanthin and linkage disequilibrium (LD) estimates ($r^2$) across the surrounding chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS for zeaxanthin and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1.2 Mb region on chromosome 8. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for zeaxanthin at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak SNP (indicated in red) at 171,705,574 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. (B) Scatter plot of association results from a conditional unified mixed model analysis of zeaxanthin and LD estimates ($r^2$) across the 1.2 Mb chromosome region, as in (A). The peak SNP from the unconditional GWAS (S8_171705574; 171,705,574 bp) was included as a covariate in the unified mixed model to control for the novel effect detected on chromosome 8.

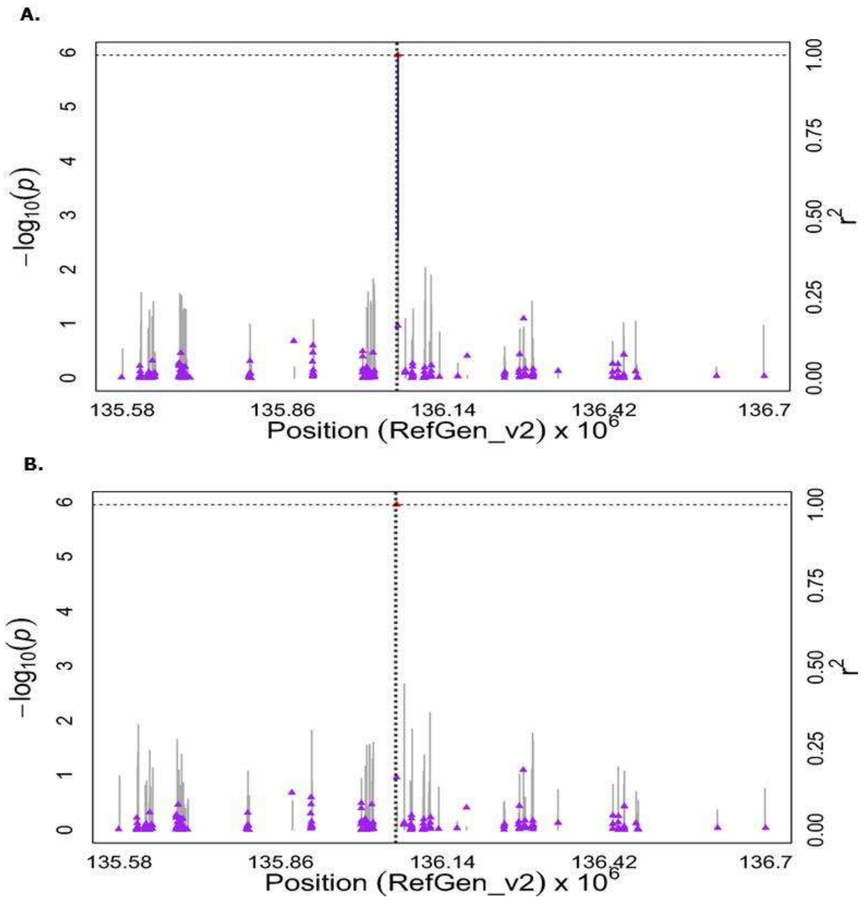



**Figure S13** Genome-wide association study (GWAS) for zeaxanthin content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of zeaxanthin and linkage disequilibrium (LD) estimates ($r^2$) across the *crtRB1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS of zeaxanthin and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1.2 Mb region on chromosome 10 that encompasses *crtRB1*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for zeaxanthin at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak polymorphism (indicated in red) at 136,059,748 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *crtRB1* (GRMZM2G152135). (B) Scatter plot of association results from a conditional unified mixed model analysis of zeaxanthin and LD estimates ($r^2$) across the *crtRB1* chromosome region, as in (A). The peak polymorphism from the unconditional GWAS (*crtRB1* InDel4; 136,059,748 bp) was included as a covariate in the unified mixed model to control for the *crtRB1* effect.

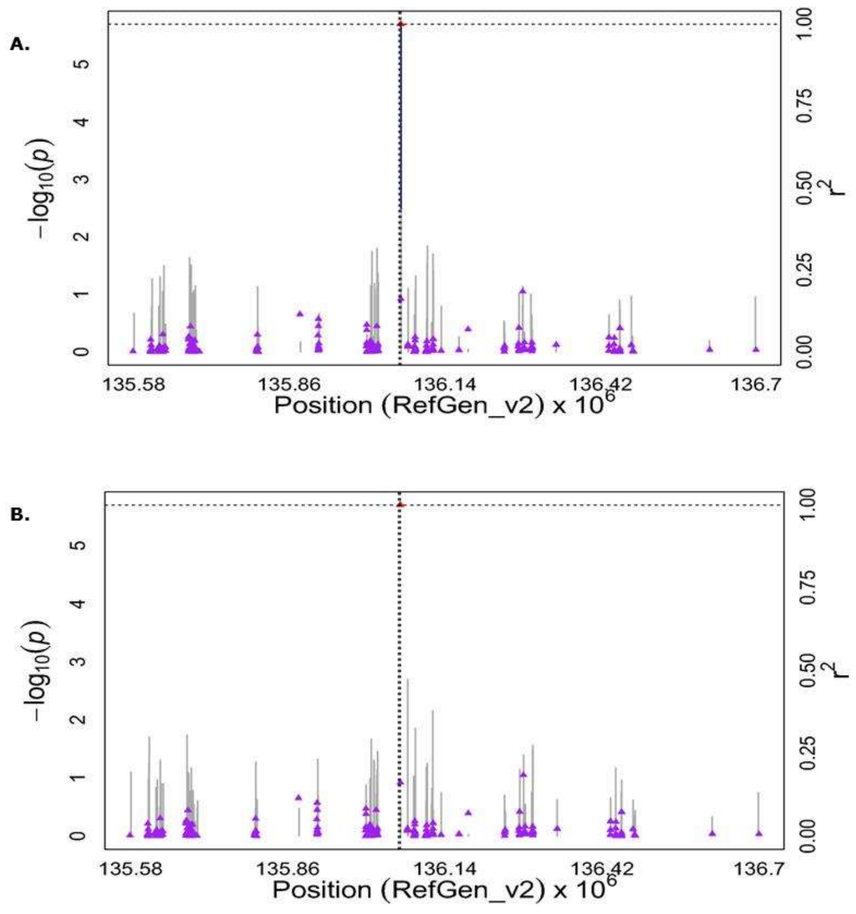



**Figure S14** Genome-wide association study (GWAS) for total β-xanthophyll content in maize grain. (A) Scatter plot of association results from a unified mixed model analysis of total β-xanthophyll content and linkage disequilibrium (LD) estimates ($r^2$) across the *crtRB1* chromosome region. Negative $\log_{10}$-transformed *P*-values (left y-axis) from a GWAS of total β-xanthophyll content and $r^2$ values (right y-axis) are plotted against physical position (B73 RefGen_v2) for a 1.2 Mb region on chromosome 10 that encompasses *crtRB1*. The blue vertical lines are $-\log_{10}$ *P*-values for SNPs that are statistically significant for total β-xanthophyll content at 5% false discovery rate (FDR), while the gray vertical lines are $-\log_{10}$ *P*-values for SNPs that are non-significant at 5% FDR. Triangles are the $r^2$ values of each SNP relative to the peak polymorphism (indicated in red) at 136,059,748 bp. The black horizontal dashed line indicates the $-\log_{10}$ *P*-value of the least statistically significant SNP at 5% FDR. The black vertical dashed lines indicate the start and stop positions of *crtRB1* (GRMZM2G152135). (B) Scatter plot of association results from a conditional unified mixed model analysis of total β-xanthophyll and LD estimates ($r^2$) across the *crtRB1* chromosome region, as in (A). The peak polymorphism from the unconditional GWAS (*crtRB1* InDel4; 136,059,748 bp) was included as a covariate in the unified mixed model to control for the *crtRB1* effect.

**Table S1 Best Linear Unbiased Predictor (BLUP) Values. BLUP values for the 24 carotenoid traits used for the genome-wide association study, pathway-level analysis, and genomic prediction for 201 inbred maize lines.**

Table S1 is available for download as an Excel file at http://www.genetics.org/lookup/suppl/doi:10.1534/genetics.114.169979/-/DC1.

**Table S2 Coordinates for Additional Insertion-Deletion (Indel) and Single-Nucleotide Polymorphism (SNP) Markers**

| Gene-Specific Assay | PCR-Based Marker | Primer Sequence (5′-3'direction) | Specific to PCR Primer | | | Coordinates Spanning Longest Amplicon Length[b] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Chr | Start AGP2 | StopAGP2 | Chr | Start AGP2 | StopAGP2 |
| *y1* Indel388 | PSY-8F | TGAAACAAACAAAGCCAGCA | chr6 | 82,016,321 | 82,016,340 | | | |
| | PSY-9R | GCCTCTCCTCTTCTTGCGTA | chr6 | 82,017,115 | 82,017,134 | | | |
| | PSY-10F | GAAACAAACAAAGCCAGCAG | chr6 | 82,016,322 | 82,016,341 | | | |
| | PSY-11R | CTCCGGCCTCTCCTCTTCT | chr6 | 82,017,121 | 82,017,139 | chr6 | 82,016,321 | 82,017,139 |
| *lcyE* 5′TE | lcyE-TE103PF-F1 | CGCTAGCAAGCCCATTATTTTTA | chr8 | 138,882,291 | 138,882,313 | | | |
| | lcyE-TE103PF-R1 | CGGTATGGTTTTTGGTATACGG | chr8 | [a] | | | | |
| | lcyE-ZGt111R1-F1 | AAGCATCCGACCAAAATAACAG | chr8 | 138,882,423 | 138,882,444 | | | |
| | lcyE-TE105PR-R1 | GAGAGGGAGACGACGAGACAC | chr8 | 138,882,649 | 138,882,670 | chr8 | 138,882,291 | 138,882,670 |
| *lcyE* SNP216 | lcyE-SNP216-F1 | GCGGCAGTGGGCGTGGAT | chr8 | 138,883,009 | 138,883,026 | | | |
| | lcyE-SNP216-R1 | TGAAGTACGGCTGCAGGACAACG | chr8 | 138,883,381 | 138,883,403 | chr8 | 138,883,009 | 138,883,403 |
| *lcyE* 3′ | lcyE-3'indl-F1 | GTACGTCGTTCATCTCCCGTACCC | chr8 | [a] | | | | |
| | lcyE-3'indl-R1 | CTTGGTGAACGCATTTCTGTTGG | chr8 | [a] | | | | |
| | lcyE-3'indl-F2 | GGACCGGAACAGCCAACTG | chr8 | [a] | | | | |
| | lcyE-3'indl-R2 | GGCGAAATGGGTACGGCC | chr8 | [a] | | chr8 | 138,889,812 | 138,892,812 |
| *ccd1* 5′ | CCD1-WC-L1 | CCGTGCTCGGACAGAATAGT | chr8 | [a] | | | | |
| | CCD1-B73-rev-L1 | CTCACACGTGTCAACGCC | chr9 | 152,093,059 | 152,093,042 | | | |
| | CCD1-ALL-R1 | GTGGTTTCGGTGGCTGTC | chr9 | 152,092,686 | 152,092,700 | chr9 | 152,092,686 | 152,093,042 |
| *crtRB1* 5′TE | crtRB1 H1UF | TTAGAGCCTCGACCCTCTGTG | chr10 | 136,061,212 | 136,061,232 | | | |
| | crtRB1 H1UR | AATCCCTTTCCATGTTACGC | chr10 | 136,060,416 | 136,060,435 | chr10 | 136,060,416 | 136,061,232 |
| *crtRB1* InDel4 | crtRB1 D4F | ACCGTCACGTGCTTCGTGCC | chr10 | 136,059,806 | 136,059,787 | | | |
| | crtRB1 D4R | CTTCCGCGCCTCCTTCTC | chr10 | 136,059,690 | 136,059,708 | chr10 | 136,059,690 | 136,059,806 |
| *crtRB1* 3′TE | crtRB1 65F | ACACCACATGGACAAGTTCG | chr10 | [a] | | | | |
| | crtRB1 62R | ACACTCTGGCCCATGAACAC | chr10 | [a] | | | | |
| | crtRB1 66R | ACAGCAATACAGGGGACCAG | chr10 | [a] | | chr10 | 136,060,219 | 136,063,219 |

RefGen_v2 Coordinates and PCR primer sequences for the additional seven indel markers and one SNP marker within and near the coding regions of one carotenoid degradation gene and three carotenoid biosynthetic pathway genes.
Amplification protocols for gene-specific PCR-based marker sets are listed in: Fu et al. 2013b for *y1*; Harjes et al. 2008 for *lcyE*; Kandianis et al. for *ccd1*; Yan et al. 2010 for *crtRB1*.
[a]RefGen_v2 Coordinates are not available
[b]Physical distance encompassing all possible primer combinations

**Table S3 Genomic Information for the 58 *a priori* Candidate Genes (A)**

| ***a priori* candidate gene pathway** | **MaizeGDB Name** | **MaizeGDB Full Name** | **MaizeGDB Synonym(s)** | **RefGen_v2 Gene Model ID** | **Annotated Gene Function** | **RefGen_v2 Chromosome** | **RefGen_v2 ORF Start bp** | **RefGen_v2 ORF Stop bp** |
|---|---|---|---|---|---|---|---|---|
| carotenoid_synthesis_and_degradation | ao1 | aldehyde oxidase1 | ao1, cl1856_2b, aldehyde oxidase1 | GRMZM2G141535 | Aldehyde oxidase and xanthine dehydrogenase | 1 | 286,448,581 | 286,456,365 |
| carotenoid_synthesis_and_degradation | ao2 | aldehyde oxidase2 | ao2 | GRMZM5G899851 | Aldehyde oxidase and xanthine dehydrogenase | 5 | 4,588,532 | 4,592,775 |
| carotenoid_synthesis_and_degradation | ao3 | aldehyde oxidase3 | ao3, TMR51, aldehyde oxidase3, GRMZM2G124260, rs131175362, ss196414838, pzb01403, IDP2436 | GRMZM2G019799 | Aldehyde oxidase and xanthine dehydrogenase | 1 | 286,358,278 | 286,366,211 |
| carotenoid_synthesis_and_degradation | ao4 | aldehyde oxidase4 | ao4 | GRMZM2G141473 | Aldehyde oxidase and xanthine dehydrogenase | 1 | 286,506,118 | 286,513,080 |
| carotenoid_synthesis_and_degradation | ao5 | aldehyde oxidase5 | ao5 | GRMZM2G406830 | Aldehyde oxidase and xanthine dehydrogenase | 7 | 7,446,258 | 7,451,594 |
| carotenoid_synthesis_and_degradation | ccd7 | carotenoid cleavage dioxygenase7 | ccd7 | GRMZM2G158657 | *carotenoid cleavage dioxygenase7 | 2 | 19,458,968 | 19,461,625 |
| carotenoid_synthesis_and_degradation | ccd8 | carotenoid cleavage dioxygenase8 | ccd8, ccd8a, Zmccd8 | GRMZM2G446858 | *carotenoid cleavage dioxygenase8 | 3 | 197,015,856 | 197,019,350 |
| Prenyl_Group_Synthesis | chph1 | chlorophyllase1 | chph1 | GRMZM2G170734 | chlorophyllase, chloroplast | 7 | 62,130,993 | 62,132,323 |
| Prenyl_Group_Synthesis | cmk1 | 4-diphosphocytidyl-2-C-methyl-D-erythritol kinase1 | cmk1, umc2169, 4-diphosphocytidyl-2-C-methyl-D-erythritol kinase1, cdp-me kinase1, cdpmek1 | GRMZM5G859195 | 4-diphosphocytidyl-2-C-methyl-D-erythritol kinase | 3 | 187,922,271 | 187,927,591 |
| carotenoid_synthesis_and_degradation | crti1 | carotene isomerase1 | crti1, carotenoid isomerase1, CRTISO1 | GRMZM2G108457 | carotenoid isomerase | 4 | 200,869,070 | 200,873,710 |
| carotenoid_synthesis_and_degradation | crti2 | carotene isomerase2 | crti2, carotenoid isomerase2, CRTISO2 | GRMZM2G106531 | carotenoid isomerase | 2 | 226,366,352 | 226,371,341 |
| carotenoid_synthesis_and_degradation | crti3 | carotene isomerase3 | crti3, CRTISO3 | GRMZM2G144273 | carotenoid isomerase | 5 | 1,333,304 | 1,341,577 |
| carotenoid_synthesis_and_degradation | cyp13 | cytochrome P450 13 | cyp13, Cytochrome P450, CYP97A16, lutein5, lut5, CYP97A | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | 5 | 215,827,224 | 215,831,730 |
| carotenoid_synthesis_and_degradation | cyp14 | cytochrome P450 14 | cyp14, CYP97C, lutein1, lut1, cytochrome P450-type monooxygenase CYP97C1 | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | 1 | 86,838,334 | 86,848,726 |
| carotenoid_synthesis_and_degradation | cyp15 | cytochrome P450 15 | cyp15, CYP97B, cytochrome P450-type monooxygenase CYP97B3 | GRMZM2G010221 | CYP97B, cytochrome P450 | 4 | 235,724,340 | 235,728,875 |
| Prenyl_Group_Synthesis | dmes1 | 4-Diphosphocytidyl-2C-methyl-D-erythritol synthase1 | dmes1, si618008b02(470), si618008b02f | GRMZM5G856881 | 2-C-methyl-D-erythritol 4-phosphate cytidyltransferase | 3 | 170,115,790 | 170,118,780 |
| Prenyl_Group_Synthesis | dmes2 | 4-Diphosphocytidyl-2C-methyl-D-erythritol synthase2 | dmes2 | GRMZM2G172032 | 2-C-methyl-D-erythritol 4-phosphate cytidyltransferase | 8 | 164,748,939 | 164,752,371 |
| Prenyl_Group_Synthesis | dxr1 | deoxy xylulose reductoisomerase1 | dxr1, IDP154, deoxy xylulose reductoisomerase1, 1-deoxy-D-xylulose 5-phosphate reductoisomerase1, CL389_1(210), CL389_1b | GRMZM2G056975 | 1-deoxy-D-xylulose 5-phosphate reductoisomerase | 3 | 30,226,804 | 30,233,358 |
| Prenyl_Group_Synthesis | dxr2 | deoxy xylulose reductoisomerase2 | dxr2 | GRMZM2G036290 | 1-deoxy-D-xylulose 5-phosphate reductoisomerase | 8 | 8,094,442 | 8,101,055 |
| Prenyl_Group_Synthesis | dxs1 | deoxy xylulose synthase1 | dxs1, PZA02247, CL392_1, AY110050, deoxy xylulose synthase1 | GRMZM2G137151 | 1-deoxy-D-xylulose 5-phosphate synthase | 6 | 146,378,393 | 146,382,661 |
| Prenyl_Group_Synthesis | dxs2 | deoxy xylulose synthase2 | dxs2, CL732_-1, deoxy xylulose synthase2 | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | 7 | 14,077,852 | 14,081,075 |
| Prenyl_Group_Synthesis | dxs3 | deoxy xylulose synthase3 | dxs3, pco071268 | GRMZM2G173641 | 1-deoxy-D-xylulose 5-phosphate synthase | 9 | 20,462,059 | 20,467,072 |
| Prenyl_Group_Synthesis | ggh1 | geranylgeranyl hydrogenase1 | ggh1 | GRMZM2G105644 | geranylgeranyl reductase | 5 | 206,890,298 | 206,892,838 |
| Prenyl_Group_Synthesis | ggh2 | geranylgeranyl hydrogenase2 | ggh2 | GRMZM2G419111 | geranylgeranyl reductase | 3 | 40,062,008 | 40,064,270 |
| Prenyl_Group_Synthesis | ggps1 | geranylgeranyl pyrophosphate synthase1 | ggps1, GGPPS1, ggdps1 | AC194970.5_FG001 | geranylgeranyl pyrophosphate synthase | 2 | 207,236,995 | 207,238,335 |
| Prenyl_Group_Synthesis | ggps2 | geranylgeranyl pyrophosphate synthase2 | ggps2, GGPPS2, ggdps2 | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | 7 | 160,531,537 | 160,533,586 |
| Prenyl_Group_Synthesis | ggps3 | geranylgeranyl pyrophosphate synthase3 | ggps3, GGPPS3, ggdps3 | GRMZM2G058404 | geranylgeranyl pyrophosphate synthase | 8 | 6,358,798 | 6,360,117 |
| Prenyl_Group_Synthesis | hds1 | hydroxymethylbutenyl diphosphate synthase1 | hds1, 4-hydroxy-3-methylbut-2-en-1-yl diphosphate synthase1, Hydroxymethylbutenyl diphosphate synthase1 | GRMZM2G137409 | 4-hydroxy-3-methylbut-2-enyl diphosphate synthase | 5 | 182,124,005 | 182,130,631 |
| carotenoid_synthesis_and_degradation | hyd3 | hydroxylase3 | hyd3, crtRB1, beta-carotene hydroxylase 1, CrtR-B1, bch2 | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 10 | 136,057,100 | 136,060,219 |
| carotenoid_synthesis_and_degradation | hyd4 | hydroxylase4 | hyd4, bch1, crtRB3, HYD1, beta-carotene hydroxylase homolog, BCH1 | GRMZM2G164318 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 2 | 15,865,938 | 15,868,219 |
| carotenoid_synthesis_and_degradation | hyd5 | hydroxylase5 | hyd5, crtRB5 | GRMZM2G382534 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 9 | 153,692,212 | 153,694,576 |
| carotenoid_synthesis_and_degradation | hyd6 | hydroxylase6 | hyd6, crtRB2, beta-carotene hydroxylase homolog | GRMZM2G090051 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 1 | 5,380,152 | 5,382,574 |
| carotenoid_synthesis_and_degradation | hyd7 | hydroxylase7 | hyd7, crtRB4, hydroxylase7 | GRMZM2G163683 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 4 | 236,023,117 | 236,025,051 |
| carotenoid_synthesis_and_degradation | hyd8 | hydroxylase8 | hyd8 | GRMZM5G826824 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 1 | 6,353,416 | 6,354,652 |
| Prenyl_Group_Synthesis | ippi1 | isopentenyl pyrophosphate isomerase1 | ippi1, isopentenyl diphosphate isomerase1, isopentenyl pyrophosphate isomerase1 | GRMZM2G108285 | isopentenyl pyrophosphate isomerase | 7 | 155,559,747 | 155,562,921 |
| Prenyl_Group_Synthesis | ippi2 | isopentenyl pyrophosphate isomerase2 | ippi2, isopentenyl pyrophosphate isomerase2, isopentenyl diphosphate isomerase2 | GRMZM2G145029 | isopentenyl pyrophosphate isomerase | 8 | 104,659,886 | 104,663,941 |
| Prenyl_Group_Synthesis | ippi3 | isopentenyl pyrophosphate isomerase3 | ippi3, isopentenyl pyrophosphate isomerase3, isopentenyl diphosphate isomerase3 | GRMZM2G133082 | isopentenyl pyrophosphate isomerase | 6 | 147,131,116 | 147,136,679 |
| Prenyl_Group_Synthesis | lw1 | lemon white1 | lw1, luteus17, zebra crossbands7, zb7, zb*-N101, zb*-101, ispH, hydroxymethylbutenyl diphosphate reductase1, hmdr1, hdr1, blt1, blotchedN43, 4-hydroxy-3-methylbut-2-enyl diphosphate reductase1, | GRMZM2G027059 | 4-hydroxy-3-methylbut-2-enyl diphosphate reductase | 1 | 272,936,836 | 272,940,502 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | l17, lemon white1 | | | | | |
| carotenoid_synthesis_and_degradation | lyce1 | lycopene epsilon cyclase1 | lyce1, lcye1, lycE, lcyE, LCY-E, lycopene epsilon cyclase1 | GRMZM2G012966 | lycopene epsilon-cyclase | 8 | 138,882,594 | 138,889,812 |
| Prenyl_Group_Synthesis | mecs1 | 2-C-methyl-D-erythritol 2,4-cyclodiphosphate synthase1 | mecs1 | GRMZM5G835542 | 2-C-methyl-D-erythritol 2,4-cyclodiphosphate synthase | 4 | 155,830,779 | 155,832,786 |
| Prenyl_Group_Synthesis | mecs2 | 2-C-methyl-D-erythritol 2,4-cyclodiphosphate synthase2 | mecs2 | AC209374.4_FG002 | 2-C-methyl-D-erythritol 2,4-cyclodiphosphate synthase | 5 | 196,279,295 | 196,281,037 |
| carotenoid_synthesis_and_degradation | nced2 | nine-cis-epoxycarotenoid dioxygenase2 | nced2, NCED2, 9-cis-epoxycarotenoid dioxygenase5a, NCED5a, vp14 homolog | GRMZM2G407181 | *9-cis-epoxycarotenoid dioxygenase5a | 1 | 174,524,887 | 174,527,795 |
| carotenoid_synthesis_and_degradation | nced3 | nine-cis-epoxycarotenoid dioxygenase3 | nced3, vp14 homolog, 9-cis-epoxycarotenoid dioxygenase5b, NCED5b, NCED3 | GRMZM5G858784 | *9-cis-epoxycarotenoid dioxygenase5b | 3 | 87,344,791 | 87,346,554 |
| carotenoid_synthesis_and_degradation | nced4 | nine-cis-epoxycarotenoid dioxygenase4 | nced4, NCED9a, vp14 homolog, 9-cis-epoxycarotenoid dioxygenase9a | GRMZM2G408158 | *9-cis-epoxycarotenoid dioxygenase9a | 2 | 234,574,835 | 234,576,854 |
| carotenoid_synthesis_and_degradation | nced5 | nine-cis-epoxycarotenoid dioxygenase5 | nced5, 9-cis-epoxycarotenoid dioxygenase9b, NCED9b, vp14 homolog | GRMZM2G417954 | *9-cis-epoxycarotenoid dioxygenase9b | 7 | 5,976,197 | 5,978,481 |
| carotenoid_synthesis_and_degradation | nced6 | nine-cis-epoxycarotenoid dioxygenase6 | nced6, NCED6, Carotenoid cleavage dioxygenase4a, CCD4a | GRMZM2G110192 | *carotenoid cleavage dioxygenase4a | 4 | 159,724,032 | 159,726,475 |
| carotenoid_synthesis_and_degradation | nced7 | nine-cis-epoxycarotenoid dioxygenase7 | nced7, NCED9c, vp14 homolog, 9-cis-epoxycarotenoid dioxygenase9c | GRMZM2G330848 | *9-cis-epoxycarotenoid dioxygenase9c | 7 | 175,861,745 | 175,863,458 |
| carotenoid_synthesis_and_degradation | nced8 | nine-cis-epoxycarotenoid dioxygenase8 | nced8, NCED5, Carotenoid cleavage dioxygenase4b, CCD4b | GRMZM2G150363 | *carotenoid cleavage dioxygenase4b | 5 | 200,687,176 | 200,689,579 |
| carotenoid_synthesis_and_degradation | nced9 | nine-cis-epoxycarotenoid dioxygenase9 | nced9, NCED9d, 9-cis-epoxycarotenoid dioxygenase9d | GRMZM5G838285 | *9-cis-epoxycarotenoid dioxygenase9d | 5 | 16,850,172 | 16,851,977 |
| carotenoid_synthesis_and_degradation | ps1 | pink scutellum1 | ps1, ps*-Mu85-3061-21, lycb1, lcyb1, lcyb, lycB, vp7, ps*-8205, pink scutellum1, lyc1, ps*-85-3288-28 | GRMZM5G849107 | lycopene beta-cyclase | 5 | 100,700,176 | 100,702,026 |
| carotenoid_synthesis_and_degradation | psy2 | phytoene synthase2 | psy2, csu572, pco131047(641), PCO131047b, phytoene synthase2 | GRMZM2G149317 | phytoene synthase | 8 | 168,273,042 | 168,276,092 |
| carotenoid_synthesis_and_degradation | vde1 | violaxanthin de-epoxidase1 | vde1, si605018d09, VDE, violaxanthin de-epoxidase1 | GRMZM2G027219 | violaxanthin de-epoxidase | 2 | 74,086,504 | 74,089,290 |
| carotenoid_synthesis_and_degradation | vp14 | viviparous14 | vp14, NCED1, nine-cis-epoxycarotenoid dioxygenase1, NCED1 homolog, siu95953a(82), siu95953a, viviparous14, umc1218, ufg4 | GRMZM2G014392 | *9-cis-epoxycarotenoid dioxygenase1 | 1 | 250,892,567 | 250,895,242 |
| carotenoid_synthesis_and_degradation | vp5 | viviparous5 | vp5, viviparous5, MAGI_109001, PZB00718, MAGI_22938, umc1070, phytoene desaturase, L39266, pds*-L39266, PZB00648, PZA02069, CL1803_1, phytoene desaturase, pds1, vp5-8419, y-vp*-8419, y-vp*-83-3101-36, y-vp*-85-3101-36, vp5-83-3101-36 | GRMZM2G410515 | phytoene desaturase | 1 | 17,660,941 | 17,667,054 |
| carotenoid_synthesis_and_degradation | wc1 | white cap1 | wc1, ccd1, ZmCCD1, PCO084517, AY106323, IDP700, white cap1 | GRMZM2G057243 | *carotenoid cleavage dioxygenase1 | 9 | 152,086,899 | 152,092,882 |
| carotenoid_synthesis_and_degradation | y1 | yellow endosperm1 | y1, y1ssr, rs131175743, rs130328408, y4, yellow endosperm1, white1, pb1, Psy1 | GRMZM2G300348 | phytoene synthase | 6 | 82,017,148 | 82,021,007 |
| carotenoid_synthesis_and_degradation | zds1 | zeta carotene desaturase1 | zds1, zeta carotene desaturase candidate, cl78_1(541), CL78_1 | GRMZM2G454952 | zeta-carotene desaturase | 7 | 17,470,585 | 17,479,020 |
| carotenoid_synthesis_and_degradation | zep1 | zeaxanthin epoxidase1 | zep1, fha5, TMR41 | GRMZM2G127139 | zeaxanthin epoxidase | 2 | 44,440,299 | 44,449,237 |

Genomic information for the 58 *a priori* candidate genes involved in the biosynthesis of isoprenoids and carotenoids, as well as the degradation of carotenoids.

*Carotenoid cleavage enzymes fall into to major phyletic groups, the carotenoid cleavage dioxygenases (which generally have broad substrate specificity) and the NCED clade, which are involved in ABA synthesis and highly specific for 9-cis-epoxycarotenoids. Note that with the exception of ZmCCD1 and ZmNCED1 (vp14) maize carotenoid cleavage family membes have not had their biochemical activities determined. Nomenclature of other maize family members is relative to their most closely related sequencein Arabidopsis but this does not necessarily imply a corresponding biochemical activity for the maize enzyme. Nomenclature is as listed in maizeGDB v3.

Table S3 Genomic Information for the 8 *a priori* Candidate Genes (B)

| ***a priori* candidate gene pathway** | **MaizeGDB Name** | **MaizeGDB Full Name** | **MaizeGDB Synonym(s)** | **RefGen_v2 Gene Model ID** | **Annotated Gene Function** | **RefGen_v2 Chromosome** | **RefGen_v2 ORF Start bp** | **RefGen_v2 ORF Stop bp** |
|---|---|---|---|---|---|---|---|---|
| carotenoid_synthesis_and_degradation | cyp14 | cytochrome P450 14 | cyp14, CYP97C, lutein1, lut1, cytochrome P450-type monooxygenase CYP97C1 | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | 1 | 86838334 | 86848726 |
| carotenoid_synthesis_and_degradation | hyd4 | hydroxylase4 | hyd4, bch1, crtRB3, HYD1, beta-carotene hydroxylase homolog, BCH1 | GRMZM2G164318 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 2 | 15865938 | 15868219 |
| carotenoid_synthesis_and_degradation | zep1 | zeaxanthin epoxidase1 | zep1, fha5, TMR41 | GRMZM2G127139 | zeaxanthin epoxidase | 2 | 44440299 | 44449237 |
| carotenoid_synthesis_and_degradation | y1 | yellow endosperm1 | y1, y1ssr, rs131175743, rs130328408, y4, yellow endosperm1, white1, pb1, Psy1 | GRMZM2G300348 | phytoene synthase | 6 | 82017148 | 82021007 |
| carotenoid_synthesis_and_degradation | zds1 | zeta carotene desaturase1 | zds1, zeta carotene desaturase candidate, cl78_1(541), CL78_1 | GRMZM2G454952 | zeta-carotene desaturase | 7 | 17470585 | 17479020 |
| carotenoid_synthesis_and_degradation | lyce1 | lycopene epsilon cyclase1 | lyce1, lcye1, lycE, lcyE, LCY-E, lycopene epsilon cyclase1 | GRMZM2G012966 | lycopene epsilon-cyclase | 8 | 138882594 | 138889812 |
| carotenoid_synthesis_and_degradation | wc1 | white cap1 | wc1, ccd1, ZmCCD1, PCO084517, AY106323, IDP700, white cap1 | GRMZM2G057243 | *carotenoid cleavage dioxygenase1 | 9 | 152086899 | 152092882 |
| carotenoid_synthesis_and_degradation | hyd3 | hydroxylase3 | hyd3, crtRB1, beta-carotene hydroxylase 1, CrtR-B1, bch2 | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | 10 | 136057100 | 136060219 |

Genomic information for the eight candidate genes that are hypothesized to be critical for marker-assisted selection for orange-colored maize kernels with high total carotenoid and provitamin A levels.

*Carotenoid cleavage enzymes fall into to major phyletic groups, the carotenoid cleavage dioxygenases (which generally have broad substrate specificity) and the NCED clade, which are involved in ABA synthesis and highly specific for 9-cis-epoxycarotenoids. Note that with the exception of ZmCCD1 and ZmNCED1 (vp14) maize carotenoid cleavage family membes have not had their biochemical activities determined. Nomenclature of other maize family members is relative to their most closely related sequencein Arabidopsis but this does not necessarily imply a corresponding biochemical activity for the maize enzyme. Nomenclature is as listed in maizeGDB v3.

**Table S4 Genomic Prediction Model Specifications**

| GP Method | Parameters | Script details |
|---|---|---|
| RR-BLUP[a] | K = "RR" | Kinship.blup function in RR-BLUP R package: Jeff Endelman, 2011 |
| LASSO[b] | α = 1 | cv.glmnet and predict functions in GLMNet R package[c]: Jerome Friedman, Trevor Hastie, Rob Tibshirani, 2009 |
| Elastic net | α = 0.8 | |

[a]RR-BLUP, Ridge regression best linear unbiased prediction
[b]LASSO, Least absolute shrinkage and selection operator
[c]GLMNet, Lasso and elastic net regularized generalized linear models

**Table S5 BLUPs and Heritabilities for 9 Carotenoid Traits**

| Trait | No. Lines | BLUPs | | | Heritabilities | |
|---|---|---|---|---|---|---|
| | | Mean | S.D.[a] | Range | Estimate | S.E.[b] |
| Phytofluene | 199 | 0.90 | 0.42 | 0.20 - 2.22 | 0.65 | 0.058 |
| ζ-Carotene | 200 | 0.62 | 0.25 | 0.28 - 1.61 | 0.45 | 0.067 |
| Tetrahydrolycopene | 197 | 0.24 | 0.07 | -0.06 - 0.52 | 0.60 | 0.067 |
| Total β-Xanthophylls | 195 | 14.10 | 7.62 | 0.89 - 35.95 | 0.96 | 0.006 |
| Total α-Xanthophylls | 200 | 12.07 | 5.40 | 1.50- 28.02 | 0.91 | 0.013 |
| Provitamin A[c]/Total Carotenoids | 199 | 0.07 | 0.03 | 0.02 - 0.20 | 0.86 | 0.023 |
| Acyclic Carotenes/Cyclic Carotenes | 190 | 0.08 | 0.06 | 0 - 0.30 | 0.74 | 0.028 |
| β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 196 | 0.10 | 0.06 | 0.03 - 0.38 | 0.93 | 0.015 |
| Total Carotenes/Total Xanthophylls | 190 | 0.15 | 0.05 | 0 - 0.32 | 0.62 | 0.056 |

Means and ranges (μg/g) for untransformed best linear unbiased predictors (BLUPs) of an additional 9 carotenoid grain traits evaluated on a maize inbred association panel, and estimated heritability on a line mean basis in two summer environments, in West Lafayette, IN, across two years.

[a]S.D., Standard deviation.

[b]S.E., Standard error.

[c]Provitamin A is calculated as the sum of β-carotene, ½ α-carotene and ½ β-cryptoxanthin.

**Table S6 Correlation Matrix for Untransformed BLUPs of the 24 Carotenoid Traits**

| | β-carotene | β-cryptoxanthin | Zeaxanthin | α-carotene | Zeinoxanthin | Lutein | Acyclic and Monocyclic Carotenes | Total Carotenoids | β-Carotenoids / α-Carotenoids | β-Xanthophylls/α-Xanthophylls | β-Carotene/β-Cryptoxanthin | β-Cryptoxanthin /Zeaxanthin | α-Carotene/Zeinoxanthin | Zeinoxanthin/Lutein | Phytofluene | ζ-Carotene | Tetrahydrolycopene | Total β-Xanthophylls | Total α-Xanthophylls | Provitamin A* | Provitamin A*/Total Carotenoids | Acyclic Carotenes/Cyclic Carotenes | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Total Carotenes/Total Xanthophylls |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **β-carotene** | | 0.43 | 0.38 | 0.37 | 0.03 | -0.02 | 0.55 | 0.43 | 0.28 | 0.26 | 0.31 | 0.18 | <0.01 | 0.06 | 0.05 | -0.09 | -0.05 | 0.40 | 0.01 | 0.89 | 0.74 | -0.18 | 0.53 | 0.35 |
| **β-cryptoxanthin** | <0.01 | | 0.63 | <0.01 | 0.25 | -0.17 | 0.16 | 0.58 | 0.54 | 0.60 | -0.38 | 0.51 | -0.34 | 0.38 | -0.08 | -0.02 | -0.12 | 0.73 | -0.09 | 0.71 | 0.42 | -0.23 | -0.07 | -0.17 |
| **Zeaxanthin** | <0.01 | <0.01 | | -0.06 | <0.01 | -0.09 | 0.24 | 0.71 | 0.65 | 0.71 | -0.23 | -0.07 | -0.10 | 0.05 | 0.09 | <0.01 | -0.19 | 0.99 | -0.10 | 0.51 | 0.10 | -0.13 | -0.27 | -0.22 |
| **α-carotene** | <0.01 | 0.95 | 0.38 | | 0.34 | 0.53 | 0.62 | 0.38 | -0.33 | -0.32 | 0.24 | 0.20 | 0.11 | 0.16 | 0.13 | 0.19 | -0.03 | -0.05 | 0.58 | 0.44 | 0.27 | -0.02 | 0.43 | 0.34 |
| **Zeinoxanthin** | 0.67 | <0.01 | 0.99 | <0.01 | | 0.35 | 0.22 | 0.31 | -0.19 | -0.20 | -0.16 | 0.42 | -0.48 | 0.70 | 0.03 | 0.08 | 0.03 | 0.04 | 0.49 | 0.23 | 0.06 | -0.08 | 0.01 | -0.04 |
| **Lutein** | 0.80 | 0.01 | 0.20 | <0.01 | <0.01 | | 0.36 | 0.40 | -0.56 | -0.57 | 0.02 | 0.04 | 0.02 | <0.01 | 0.24 | 0.18 | 0.01 | -0.09 | 0.97 | 0.03 | -0.26 | 0.05 | 0.10 | 0.11 |
| **Acyclic and Monocyclic Carotenes** | <0.01 | 0.02 | <0.01 | <0.01 | <0.01 | <0.01 | | 0.62 | -0.01 | -0.06 | 0.16 | 0.13 | 0.03 | 0.15 | 0.56 | 0.50 | 0.02 | 0.24 | 0.38 | 0.57 | 0.33 | 0.32 | 0.37 | 0.44 |
| **Total Carotenoids** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | | 0.25 | 0.22 | -0.21 | 0.20 | -0.18 | 0.24 | 0.27 | 0.30 | -0.12 | 0.72 | 0.45 | 0.62 | 0.11 | -0.02 | -0.08 | -0.02 |
| **β-Carotenoids/α-Carotenoids** | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | 0.93 | <0.01 | | 0.97 | -0.17 | 0.04 | -0.10 | 0.06 | -0.15 | -0.06 | -0.04 | 0.65 | -0.55 | 0.36 | 0.29 | -0.13 | -0.14 | -0.16 |
| **β-Xanthophylls/α-Xanthophylls** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.40 | <0.01 | <0.01 | | -0.20 | <0.01 | -0.08 | -0.03 | -0.09 | -0.08 | -0.14 | 0.71 | -0.56 | 0.35 | 0.22 | -0.11 | -0.20 | -0.19 |
| **β-Carotene/β-Cryptoxanthin** | <0.01 | <0.01 | <0.01 | <0.01 | 0.03 | 0.74 | 0.02 | <0.01 | 0.01 | <0.01 | | -0.27 | 0.25 | -0.20 | -0.08 | -0.13 | 0.11 | -0.27 | -0.01 | 0.08 | 0.27 | <0.01 | 0.57 | 0.31 |
| **β-Cryptoxanthin/Zeaxanthin** | 0.01 | <0.01 | 0.35 | <0.01 | <0.01 | 0.55 | 0.07 | <0.01 | 0.56 | 0.98 | <0.01 | | -0.35 | 0.48 | -0.04 | 0.03 | -0.01 | 0.03 | 0.16 | 0.36 | 0.41 | -0.06 | 0.15 | 0.13 |
| **α-Carotene/Zeinoxanthin** | 0.97 | <0.01 | 0.17 | 0.10 | <0.01 | 0.80 | 0.62 | 0.01 | 0.16 | 0.25 | <0.01 | <0.01 | | -0.48 | 0.06 | -0.02 | -0.01 | -0.14 | -0.08 | -0.14 | -0.07 | 0.03 | 0.10 | 0.20 |
| **Zeinoxanthin/Lutein** | 0.38 | <0.01 | 0.51 | 0.03 | <0.01 | 0.95 | 0.03 | <0.01 | 0.43 | 0.64 | <0.01 | <0.01 | <0.01 | | -0.03 | 0.08 | 0.02 | 0.08 | 0.14 | 0.24 | 0.24 | -0.09 | -0.01 | -0.07 |
| **Phytofluene** | 0.50 | 0.24 | 0.21 | 0.07 | 0.70 | <0.01 | <0.01 | <0.01 | 0.03 | 0.20 | 0.25 | 0.60 | 0.41 | 0.64 | | 0.42 | -0.10 | 0.07 | 0.25 | -0.02 | -0.14 | 0.48 | 0.05 | 0.29 |
| **ζ-Carotene** | 0.21 | 0.75 | 0.98 | 0.01 | 0.28 | 0.01 | <0.01 | <0.01 | 0.39 | 0.26 | 0.07 | 0.63 | 0.76 | 0.26 | <0.01 | | -0.16 | <0.01 | 0.20 | -0.07 | -0.15 | 0.42 | -0.03 | 0.20 |
| **Tetrahydrolycopene** | 0.45 | 0.08 | 0.01 | 0.67 | 0.67 | 0.90 | 0.79 | 0.08 | 0.59 | 0.05 | 0.14 | 0.87 | 0.93 | 0.73 | 0.16 | 0.02 | | -0.19 | -0.02 | -0.09 | 0.04 | 0.08 | 0.07 | 0.07 |
| **Total β-Xanthophylls** | <0.01 | <0.01 | <0.01 | 0.49 | 0.62 | 0.19 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.66 | 0.05 | 0.23 | 0.34 | 0.96 | 0.01 | | -0.08 | 0.57 | 0.15 | -0.15 | -0.25 | -0.21 |
| **Total α-Xanthophylls** | 0.91 | 0.20 | 0.18 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.90 | 0.03 | 0.25 | 0.04 | <0.01 | <0.01 | 0.73 | 0.25 | | 0.09 | -0.22 | 0.07 | 0.10 | 0.11 |
| **Provitamin A[α]** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.64 | <0.01 | <0.01 | <0.01 | <0.01 | 0.23 | <0.01 | 0.05 | <0.01 | 0.80 | 0.33 | 0.19 | <0.01 | 0.19 | | 0.74 | -0.25 | 0.39 | 0.16 |
| **Provitamin A*/Total Carotenoids** | <0.01 | <0.01 | 0.18 | <0.01 | 0.39 | <0.01 | <0.01 | 0.12 | <0.01 | <0.01 | <0.01 | <0.01 | 0.30 | <0.01 | 0.04 | 0.03 | 0.58 | 0.03 | <0.01 | <0.01 | | -0.34 | 0.63 | 0.31 |
| **Acyclic Carotenes/Cyclic Carotenes** | 0.01 | <0.01 | 0.06 | 0.81 | 0.28 | 0.50 | <0.01 | 0.81 | 0.07 | 0.11 | 0.95 | 0.40 | 0.62 | 0.19 | <0.01 | <0.01 | 0.27 | 0.03 | 0.29 | <0.01 | <0.01 | | -0.10 | 0.39 |
| **β-Carotene/(β-Cryptoxanthin+Zeaxanthin)** | <0.01 | 0.36 | <0.01 | <0.01 | 0.88 | 0.17 | <0.01 | 0.25 | 0.04 | 0.01 | <0.01 | 0.03 | 0.14 | 0.85 | 0.47 | 0.65 | 0.35 | <0.01 | 0.16 | <0.01 | <0.01 | 0.16 | | 0.66 |
| **Total Carotenes/Total Xanthophylls** | <0.01 | 0.02 | <0.01 | <0.01 | 0.61 | 0.12 | <0.01 | 0.80 | 0.02 | 0.01 | <0.01 | 0.07 | <0.01 | 0.31 | <0.01 | <0.01 | 0.32 | <0.01 | 0.11 | 0.02 | <0.01 | <0.01 | <0.01 | |

Pearson correlation coefficients are presented in the upper triangle, and the *P*-values for the significance of associations are in the lower triangle.
[α]Provitamin A is calculated as the sum of β-carotene, ½ α-carotene and ½ β-cryptoxanthin.

**Table S7 Variance Component Estimates from Mixed Linear Models Fitted to 24 Grain Carotenoid Traits**

| | Trait | Genetic Variance Component | Environmental Variance Component | GxE[a] Variance Component |
|---|---|---|---|---|
| **15 priority traits** | Lutein | 24.8787 | 1.5973 | 1.5368 |
| | Zeinoxanthin | 2.0509 | 0.2717 | 0.0286 |
| | α-Carotene | 0.2446 | 0.7396 | 0.0317 |
| | α-Carotene/Zeinoxanthin | 4.0856 | 0.4429 | 1.3267 |
| | Zeinoxanthin/Lutein | 0.0137 | 0.0018 | 0.0142 |
| | Zeaxanthin | 58.1510 | 3.6651 | 0.0000 |
| | β-Cryptoxanthin | 1.4692 | 0.0741 | 0.0691 |
| | β-Carotene | 0.5365 | 0.1189 | 0.1785 |
| | β-Cryptoxanthin/Zeaxanthin | 0.0099 | 0.0011 | 0.0015 |
| | β-Carotene/β-Cryptoxanthin | 0.6497 | 0.0792 | 0.5125 |
| | Total Carotenoids | 129.6260 | 12.7090 | 0.0000 |
| | Acyclic and Monocyclic Carotenes | 2.3351 | 1.7549 | 0.4304 |
| | β-Xanthophylls/α-Xanthophylls | 25.9938 | 5.3756 | 0.0000 |
| | Provitamin A | 1.5758 | 0.3941 | 0.2488 |
| | β-Carotenoids/α-Carotenoids | 1.9802 | 0.0337 | 0.0000 |
| **9 additional traits** | ζ-Carotene | 0.1592 | 0.1985 | 0.0697 |
| | Phytofluene | 0.2827 | 0.1545 | 0.1323 |
| | Tetrahydrolycopene | 0.0157 | 0.0103 | 0.0223 |
| | Total β-Xanthophylls | 74.3102 | 3.3002 | 0.0000 |
| | Total α-Xanthophylls | 35.2877 | 3.3811 | 0.0000 |
| | Provitamin A/Total Carotenoids | 0.0017 | 0.0003 | 0.0001 |
| | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 0.0086 | 0.0007 | 0.0005 |
| | Acyclic Carotenes/Cyclic Carotenes | 0.0047 | 0.0017 | 0.0000 |
| | Total Carotenes/Total Xanthophylls | 0.0053 | 0.0002 | 0.0031 |

Variance component estimates from mixed linear models fitted to each of the 24 maize grain traits. These mixed liner models included random effects accounting for genotype, environment, and their interaction.

[a]GxE, The variance component accounting for the interaction between genotype and environment.

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.

**Table S9 Results from the Pathway-level Analysis with No Covariates (A)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1_5345354 | Carotenoid Synthesis and Degradation | GRMZM2G090051 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Xanthophylls/α-Xanthophylls | GBS | 1 | 5,345,354 | 5,380,152 | 5,382,574 | -34,798 | -37,220 | 1.51E-04 | 4.96E-02 | 0.09 | 0.32 | 0.08 | 196 | 0.15 | 0.21 | 0.1 | -0.4 | -0.2 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 8.95E-08 | 3.41E-04 | 0.3 | 0.4 | 0.28 | 198 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 3.47E-10 | 1.32E-06 | 0.31 | 0.4 | 0.28 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 4.97E-08 | 1.88E-04 | 0.29 | 0.4 | 0.28 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 8.95E-08 | 3.41E-04 | 0.3 | 0.4 | 0.27 | 198 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 3.47E-10 | 1.32E-06 | 0.31 | 0.4 | 0.27 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 4.97E-08 | 1.88E-04 | 0.29 | 0.4 | 0.27 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 3.84E-05 | 2.24E-02 | 0.18 | 0.33 | 0.26 | 196 | 0.05 | 0.13 | -0.19 | 0.35 | -0.45 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 5.13E-05 | 2.05E-02 | 0.18 | 0.33 | 0.26 | 196 | 0.15 | 0.22 | 0.08 | -0.4 | -0.17 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 3.36E-05 | 1.80E-02 | 0.18 | 0.33 | 0.26 | 190 | 0.18 | 0.26 | 0.09 | -0.85 | -0.1 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.22E-09 | 8.42E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.05 | 0.24 | -0.34 | 0.35 | -0.69 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 1.66E-08 | 6.30E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.05 | 0.22 | -0.43 | 0.4 | -0.76 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 4.82E-08 | 7.29E-05 | 0.11 | 0.29 | 0.09 | 196 | 0.15 | 0.29 | 0.13 | -0.4 | -0.26 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.20E-06 | 3.31E-03 | 0.12 | 0.29 | 0.09 | 190 | 0.18 | 0.28 | 0.12 | -0.85 | -0.13 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.22E-09 | 8.42E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.05 | 0.24 | 0.34 | 0.35 | 1.31 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 1.66E-08 | 6.30E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.05 | 0.22 | 0.43 | 0.4 | 1.46 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 4.82E-08 | 7.29E-05 | 0.11 | 0.29 | 0.09 | 196 | 0.15 | 0.29 | -0.13 | -0.4 | 0.42 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.20E-06 | 3.31E-03 | 0.12 | 0.29 | 0.09 | 190 | 0.18 | 0.28 | -0.12 | -0.85 | 0.17 |
| S2_44472618 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,472,618 | 44,440,299 | 44,449,237 | 32,319 | 23,381 | 1.26E-04 | 4.16E-02 | 0.13 | 0.38 | 0.15 | 196 | 0.05 | 0.12 | -0.2 | 0.35 | -0.47 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.47E-06 | 1.59E-03 | 0.14 | 0.25 | 0.12 | 196 | 0.05 | 0.17 | 0.24 | 0.35 | 0.86 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 5.02E-06 | 4.74E-03 | 0.14 | 0.25 | 0.12 | 195 | 0.05 | 0.16 | 0.31 | 0.4 | 0.97 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 5.21E-06 | 2.79E-03 | 0.14 | 0.25 | 0.12 | 196 | 0.15 | 0.24 | -0.09 | -0.4 | 0.28 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 4.89E-05 | 2.16E-02 | 0.14 | 0.25 | 0.12 | 190 | 0.18 | 0.25 | -0.09 | -0.85 | 0.12 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.47E-06 | 1.59E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.05 | 0.17 | -0.24 | 0.35 | -0.55 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 5.02E-06 | 4.74E-03 | 0.14 | 0.24 | 0.12 | 195 | 0.05 | 0.16 | -0.31 | 0.4 | -0.6 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 5.21E-06 | 2.79E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.15 | 0.24 | 0.09 | -0.4 | -0.2 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 4.89E-05 | 2.16E-02 | 0.14 | 0.24 | 0.12 | 190 | 0.18 | 0.25 | 0.09 | -0.85 | -0.1 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.47E-06 | 1.59E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.05 | 0.17 | 0.24 | 0.35 | 0.86 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 5.02E-06 | 4.74E-03 | 0.14 | 0.24 | 0.12 | 195 | 0.05 | 0.16 | 0.31 | 0.4 | 0.97 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 5.21E-06 | 2.79E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.15 | 0.24 | -0.09 | -0.4 | 0.28 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 4.89E-05 | 2.16E-02 | 0.14 | 0.24 | 0.12 | 190 | 0.18 | 0.25 | -0.09 | -0.85 | 0.12 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 9.40E-05 | 3.56E-02 | 0.17 | 0.35 | 0.16 | 196 | 0.15 | 0.22 | -0.07 | -0.4 | 0.21 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 9.75E-05 | 3.86E-02 | 0.18 | 0.35 | 0.16 | 190 | 0.18 | 0.25 | -0.08 | -0.85 | 0.11 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 5.10E-06 | 4.29E-03 | 0.14 | 0.29 | 0.13 | 196 | 0.05 | 0.16 | -0.23 | 0.35 | -0.52 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 1.80E-05 | 1.24E-02 | 0.14 | 0.29 | 0.13 | 195 | 0.05 | 0.15 | -0.29 | 0.4 | -0.57 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 7.57E-06 | 3.18E-03 | 0.14 | 0.29 | 0.13 | 196 | 0.15 | 0.24 | 0.09 | -0.4 | -0.2 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 5.81E-05 | 2.43E-02 | 0.15 | 0.29 | 0.13 | 190 | 0.18 | 0.25 | 0.09 | -0.85 | -0.1 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.19E-06 | 1.59E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.05 | 0.17 | 0.21 | 0.35 | 0.73 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 7.04E-06 | 5.92E-03 | 0.22 | 0.38 | 0.28 | 195 | 0.05 | 0.16 | 0.26 | 0.4 | 0.79 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 7.03E-06 | 3.13E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.15 | 0.24 | -0.08 | -0.4 | 0.24 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.55E-05 | 8.96E-03 | 0.22 | 0.38 | 0.28 | 190 | 0.18 | 0.26 | -0.09 | -0.85 | 0.11 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 7.43E-05 | 2.96E-02 | 0.29 | 0.17 | 0.36 | 196 | 0.05 | 0.13 | 0.17 | 0.35 | 0.56 |
| S5_1315682 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,682 | 1,333,304 | 1,341,577 | -17,622 | -25,895 | 9.26E-05 | 3.29E-02 | 0.28 | 0.06 | 0.35 | 196 | 0.05 | 0.13 | 0.17 | 0.35 | 0.56 |
| S5_215994270 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 215,994,270 | 215,827,224 | 215,831,730 | 167,046 | 162,540 | 8.03E-05 | 3.04E-02 | 0.07 | 0.05 | 0.07 | 196 | 0.05 | 0.13 | -0.28 | 0.35 | -0.62 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 1.95E-05 | 1.23E-02 | 0.13 | 0.17 | 0.17 | 196 | 0.05 | 0.14 | -0.22 | 0.35 | -0.5 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 3.36E-05 | 1.91E-02 | 0.13 | 0.17 | 0.17 | 195 | 0.05 | 0.14 | -0.28 | 0.4 | -0.57 |
| S6_146970803 | Prenyl Group Synthesis | GRMZM2G133082 | isopentenyl pyrophosphate isomerase | β-Carotenoids/α-Carotenoids | GBS | 6 | 146,970,803 | 147,131,116 | 147,136,679 | -160,313 | -165,876 | 1.34E-04 | 4.87E-02 | 0.25 | 0.07 | 0.33 | 190 | 0.18 | 0.24 | 0.07 | -0.85 | -0.07 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeaxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.38E-04 | 4.35E-02 | 0.15 | 0.1 | 0.16 | 196 | 0.05 | 0.12 | -0.18 | 0.35 | -0.43 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.66E-07 | 1.27E-03 | 0.15 | 0.1 | 0.16 | 199 | 0.11 | 0.24 | -0.04 | 0.1 | -0.33 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 7.52E-05 | 2.99E-02 | 0.15 | 0.1 | 0.16 | 195 | 0.05 | 0.13 | -0.25 | 0.4 | -0.52 |
| S7_13980028 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeinoxanthin | GBS | 7 | 13,980,028 | 14,077,852 | 14,081,075 | -97,824 | -101,047 | 1.58E-05 | 4.01E-02 | 0.41 | 0.4 | 0.5 | 198 | 0.1 | 0.19 | -0.08 | -0.25 | 0.38 |
| ss196475750 | Carotenoid Synthesis and Degradation | GRMZM2G454952 | zeta-carotene desaturase | Total α-Xanthophylls | 55K | 7 | 17,254,696 | 17,470,585 | 17,479,020 | -215,889 | -224,324 | 3.14E-05 | 4.01E-02 | 0.11 | 0.19 | 0.1 | 200 | 0.1 | 0.19 | 0.7 | 0.7 | 1.13 |
| S7_160777986 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,777,986 | 160,531,537 | 160,533,586 | 246,449 | 244,400 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778001 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,001 | 160,531,537 | 160,533,586 | 246,464 | 244,415 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778016 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,016 | 160,531,537 | 160,533,586 | 246,479 | 244,430 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | -0.14 | -0.25 | 0.83 |
| S7_160779488 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/β-Cryptoxanthin | GBS | 7 | 160,779,488 | 160,531,537 | 160,533,586 | 247,951 | 245,902 | 7.90E-06 | 2.01E-02 | 0.12 | 0.26 | 0.12 | 198 | 0.1 | 0.19 | 0.12 | -0.7 | -0.15 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 9.56E-05 | 3.29E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.05 | 0.13 | 0.16 | 0.35 | 0.52 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 3.92E-05 | 1.91E-02 | 0.32 | 0.29 | 0.33 | 195 | 0.05 | 0.14 | 0.23 | 0.4 | 0.67 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 1.25E-04 | 4.52E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.15 | 0.22 | -0.07 | -0.4 | 0.19 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 1.36E-04 | 4.87E-02 | 0.32 | 0.29 | 0.33 | 190 | 0.18 | 0.24 | -0.07 | -0.85 | 0.09 |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.75E-08 | 6.69E-05 | NA | NA | NA | 200 | 0.11 | 0.49 | NA | 0.8 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 9.09E-06 | 6.88E-03 | NA | NA | NA | 196 | 0.05 | 0.25 | NA | 0.35 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.16E-05 | 8.76E-03 | NA | NA | NA | 195 | 0.06 | 0.3 | NA | 0.4 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 4.37E-09 | 1.67E-05 | NA | NA | NA | 200 | 0.11 | 0.49 | NA | 0.7 | NA |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 5.31E-05 | 2.51E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.05 | 0.13 | 0.16 | 0.35 | 0.55 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 4.54E-05 | 1.91E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.14 | 0.23 | 0.4 | 0.66 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 8.85E-07 | 6.80E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.15 | 0.26 | -0.09 | -0.4 | 0.25 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 4.27E-06 | 3.57E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.28 | -0.09 | -0.85 | 0.12 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.30E-06 | 2.17E-03 | 0.35 | 0.48 | 0.34 | 196 | 0.05 | 0.16 | -0.19 | 0.35 | -0.45 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.36E-06 | 2.57E-03 | 0.35 | 0.48 | 0.34 | 195 | 0.05 | 0.18 | -0.26 | 0.4 | -0.53 |
| ss196504160 | Carotenoid Synthesis | GRMZM2G012966 | lycopene epsilon-cyclase | Total α- | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.50E-05 | 2.30E-02 | 0.36 | 0.48 | 0.34 | 200 | 0.1 | 0.19 | 0.55 | 0.7 | 0.87 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | and Degradation | | | Xanthophylls | | | | | | | | | | | | | | | | | |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.11E-09 | 4.19E-06 | 0.35 | 0.48 | 0.34 | 196 | 0.15 | 0.33 | 0.11 | -0.4 | -0.22 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.08E-09 | 1.56E-05 | 0.36 | 0.48 | 0.34 | 190 | 0.18 | 0.35 | 0.12 | -0.85 | -0.12 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 5.31E-05 | 2.51E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.05 | 0.13 | 0.16 | 0.35 | 0.55 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 4.54E-05 | 1.91E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.14 | 0.23 | 0.4 | 0.66 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 8.85E-07 | 6.80E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.15 | 0.26 | -0.09 | -0.4 | 0.25 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 4.27E-06 | 3.57E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.28 | -0.09 | -0.85 | 0.12 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 5.31E-05 | 2.51E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.05 | 0.13 | 0.16 | 0.35 | 0.55 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 4.54E-05 | 1.91E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.14 | 0.23 | 0.4 | 0.66 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 8.85E-07 | 6.80E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.15 | 0.26 | -0.09 | -0.4 | 0.25 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 4.27E-06 | 3.57E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.28 | -0.09 | -0.85 | 0.12 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 8.99E-07 | 6.80E-04 | 0.31 | 0.21 | 0.36 | 196 | 0.15 | 0.26 | -0.08 | -0.4 | 0.25 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 2.87E-06 | 3.57E-03 | 0.31 | 0.21 | 0.36 | 190 | 0.18 | 0.28 | -0.09 | -0.85 | 0.12 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 6.07E-05 | 2.71E-02 | 0.44 | 0.12 | 0.44 | 196 | 0.05 | 0.13 | 0.15 | 0.35 | 0.48 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.15E-04 | 4.34E-02 | 0.44 | 0.12 | 0.44 | 195 | 0.05 | 0.13 | 0.19 | 0.4 | 0.55 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 7.60E-06 | 1.45E-02 | 0.43 | 0.12 | 0.44 | 200 | 0.1 | 0.2 | -0.52 | 0.7 | -0.65 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 9.76E-08 | 1.23E-04 | 0.43 | 0.12 | 0.44 | 196 | 0.15 | 0.28 | -0.08 | -0.4 | 0.25 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 6.03E-08 | 2.27E-04 | 0.44 | 0.12 | 0.44 | 190 | 0.18 | 0.32 | -0.1 | -0.85 | 0.13 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 5.90E-06 | 2.79E-03 | 0.4 | 0.18 | 0.48 | 196 | 0.15 | 0.24 | 0.07 | -0.4 | -0.16 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 6.51E-06 | 4.45E-03 | 0.4 | 0.18 | 0.48 | 190 | 0.18 | 0.27 | 0.08 | -0.85 | -0.09 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 5.90E-06 | 2.79E-03 | 0.4 | 0.18 | 0.48 | 196 | 0.15 | 0.24 | -0.07 | -0.4 | 0.21 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 6.51E-06 | 4.45E-03 | 0.4 | 0.18 | 0.48 | 190 | 0.18 | 0.27 | -0.08 | -0.85 | 0.11 |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 6.28E-09 | 4.80E-05 | NA | NA | NA | 200 | 0.11 | 0.45 | NA | 0.8 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.65E-07 | 4.17E-04 | NA | NA | NA | 195 | 0.06 | 0.3 | NA | 0.4 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 4.62E-10 | 3.53E-06 | NA | NA | NA | 200 | 0.11 | 0.45 | NA | 0.7 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 5.05E-16 | 3.82E-12 | NA | NA | NA | 196 | 0.1 | 0.24 | NA | -0.4 | NA |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 3.82E-06 | 2.63E-03 | 0.35 | 0.05 | 0.38 | 196 | 0.15 | 0.25 | 0.08 | -0.4 | -0.17 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 1.51E-05 | 8.96E-03 | 0.35 | 0.05 | 0.38 | 190 | 0.18 | 0.26 | 0.08 | -0.85 | -0.09 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 6.99E-05 | 2.94E-02 | 0.46 | 0.19 | 0.42 | 196 | 0.05 | 0.13 | 0.15 | 0.35 | 0.49 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 4.20E-05 | 1.91E-02 | 0.47 | 0.19 | 0.42 | 195 | 0.05 | 0.14 | 0.21 | 0.4 | 0.62 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 6.09E-06 | 1.45E-02 | 0.47 | 0.19 | 0.42 | 200 | 0.1 | 0.2 | -0.55 | 0.7 | -0.68 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 2.52E-08 | 6.36E-05 | 0.47 | 0.19 | 0.42 | 196 | 0.15 | 0.3 | -0.09 | -0.4 | 0.28 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.82E-07 | 4.56E-04 | 0.47 | 0.19 | 0.42 | 190 | 0.18 | 0.31 | -0.1 | -0.85 | 0.13 |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 1.14E-05 | 7.88E-03 | NA | NA | NA | 196 | 0.05 | 0.13 | NA | 0.35 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.06E-05 | 1.30E-02 | NA | NA | NA | 195 | 0.06 | 0.13 | NA | 0.4 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 1.90E-06 | 1.45E-02 | NA | NA | NA | 198 | 0.09 | 0.08 | NA | -0.7 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.23E-07 | 1.33E-03 | NA | NA | NA | 196 | 0.06 | 0.11 | NA | -0.25 | NA |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 3.15E-06 | 2.36E-02 | NA | NA | NA | 188 | 0.04 | 0.11 | NA | -0.55 | NA |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 7.72E-06 | 2.01E-02 | 0.18 | 0 | 0.22 | 198 | 0.1 | 0.19 | 0.11 | -0.7 | -0.14 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 3.51E-07 | 1.33E-03 | 0.19 | 0 | 0.22 | 196 | 0.04 | 0.18 | 0.12 | -0.25 | -0.36 |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.11E-06 | 1.59E-03 | NA | NA | NA | 196 | 0.05 | 0.17 | NA | 0.35 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.97E-06 | 2.98E-03 | NA | NA | NA | 195 | 0.06 | 0.18 | NA | 0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.51E-04 | 4.96E-02 | NA | NA | NA | 196 | 0.1 | 0.03 | NA | -0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.86E-05 | 3.55E-02 | NA | NA | NA | 198 | 0.09 | 0.07 | NA | -0.7 | NA |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits without any markers tagging the peak GWAS signals included as covariates. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

Table S9 Results from the Pathway-Level Analysis with S2_44448432 as Covariate Tagging *zep1* (B)

| SNP ID | *a priori* candidate gene pathway | | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 8.95E-08 | 3.41E-04 | 0.3 | 0.4 | 0.28 | 198 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 3.47E-10 | 1.32E-06 | 0.31 | 0.4 | 0.28 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 4.97E-08 | 1.88E-04 | 0.29 | 0.4 | 0.28 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 8.95E-08 | 3.41E-04 | 0.3 | 0.4 | 0.27 | 198 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 3.47E-10 | 1.32E-06 | 0.31 | 0.4 | 0.27 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 4.97E-08 | 1.88E-04 | 0.29 | 0.4 | 0.27 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 9.61E-06 | 7.11E-03 | 0.29 | 0.17 | 0.36 | 196 | 0.24 | 0.32 | 0.17 | 0.35 | 0.57 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Total β-Xanthophylls | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 3.44E-05 | 1.73E-02 | 0.29 | 0.17 | 0.36 | 195 | 0.22 | 0.3 | 0.22 | 0.4 | 0.65 |
| S5_1315682 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,682 | 1,333,304 | 1,341,577 | -17,622 | -25,895 | 1.74E-05 | 1.10E-02 | 0.28 | 0.06 | 0.35 | 196 | 0.24 | 0.32 | 0.17 | 0.35 | 0.56 |
| S5_1315682 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Total β-Xanthophylls | GBS | 5 | 1,315,682 | 1,333,304 | 1,341,577 | -17,622 | -25,895 | 6.11E-05 | 2.89E-02 | 0.28 | 0.06 | 0.35 | 195 | 0.22 | 0.29 | 0.22 | 0.4 | 0.63 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 8.60E-05 | 3.43E-02 | 0.13 | 0.17 | 0.17 | 196 | 0.24 | 0.3 | -0.18 | 0.35 | -0.43 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeaxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 4.69E-05 | 2.15E-02 | 0.15 | 0.1 | 0.16 | 196 | 0.24 | 0.31 | -0.17 | 0.35 | -0.42 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.66E-07 | 1.27E-03 | 0.15 | 0.1 | 0.16 | 199 | 0.11 | 0.24 | -0.04 | 0.1 | -0.33 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 2.74E-05 | 1.68E-02 | 0.15 | 0.1 | 0.16 | 195 | 0.22 | 0.3 | -0.25 | 0.4 | -0.51 |
| S7_13980028 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeinoxanthin | GBS | 7 | 13,980,028 | 14,077,852 | 14,081,075 | -97,824 | -101,047 | 1.58E-05 | 4.01E-02 | 0.41 | 0.4 | 0.5 | 198 | 0.1 | 0.19 | -0.08 | -0.25 | 0.38 |
| ss196475750 | Carotenoid Synthesis and Degradation | GRMZM2G454952 | zeta-carotene desaturase | Total α-Xanthophylls | 55K | 7 | 17,254,696 | 17,470,585 | 17,479,020 | -215,889 | -224,324 | 3.14E-05 | 4.00E-02 | 0.11 | 0.19 | 0.1 | 200 | 0.1 | 0.19 | 0.7 | 0.7 | 1.13 |
| S7_160777986 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,777,986 | 160,531,537 | 160,533,586 | 246,449 | 244,400 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778001 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,001 | 160,531,537 | 160,533,586 | 246,464 | 244,415 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778016 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,016 | 160,531,537 | 160,533,586 | 246,479 | 244,430 | 3.04E-05 | 4.61E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | -0.14 | -0.25 | 0.83 |
| S7_160779488 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/β-Cryptoxanthin | GBS | 7 | 160,779,488 | 160,531,537 | 160,533,586 | 247,951 | 245,902 | 7.90E-06 | 2.01E-02 | 0.12 | 0.26 | 0.12 | 198 | 0.1 | 0.19 | 0.12 | -0.7 | -0.15 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 4.82E-05 | 2.15E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.24 | 0.31 | 0.15 | 0.35 | 0.49 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 2.35E-05 | 1.62E-02 | 0.32 | 0.29 | 0.33 | 195 | 0.22 | 0.3 | 0.22 | 0.4 | 0.63 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 6.92E-05 | 4.36E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.29 | 0.35 | -0.06 | -0.4 | 0.18 |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.92E-08 | 7.34E-05 | NA | NA | NA | 200 | 0.11 | 0.49 | NA | 0.8 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.19E-07 | 3.39E-04 | NA | NA | NA | 196 | 0.24 | 0.38 | NA | 0.35 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 3.22E-07 | 8.11E-04 | NA | NA | NA | 195 | 0.22 | 0.4 | NA | 0.4 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 4.85E-09 | 1.85E-05 | NA | NA | NA | 200 | 0.09 | 0.43 | NA | 0.7 | NA |
| *lcyE* 5'TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 7.24E-14 | 5.48E-10 | NA | NA | NA | 196 | 0.21 | 0.3 | NA | -0.4 | NA |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 7.95E-06 | 6.69E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.24 | 0.32 | 0.16 | 0.35 | 0.55 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 9.61E-06 | 9.09E-03 | 0.28 | 0.41 | 0.3 | 195 | 0.22 | 0.31 | 0.22 | 0.4 | 0.66 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.59E-07 | 1.96E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.29 | 0.4 | -0.08 | -0.4 | 0.24 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.85E-06 | 1.54E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.29 | 0.38 | -0.09 | -0.85 | 0.11 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.37E-07 | 3.39E-04 | 0.35 | 0.48 | 0.34 | 196 | 0.24 | 0.36 | -0.19 | 0.35 | -0.45 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.19E-07 | 4.52E-04 | 0.35 | 0.48 | 0.34 | 195 | 0.22 | 0.35 | -0.27 | 0.4 | -0.54 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.50E-05 | 2.30E-02 | 0.36 | 0.48 | 0.34 | 200 | 0.1 | 0.19 | 0.55 | 0.7 | 0.87 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.32E-10 | 4.98E-07 | 0.35 | 0.48 | 0.34 | 196 | 0.29 | 0.46 | 0.1 | -0.4 | -0.22 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 4.23E-10 | 3.17E-06 | 0.37 | 0.48 | 0.34 | 189 | 0.29 | 0.45 | 0.11 | -0.85 | -0.12 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 7.95E-06 | 6.69E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.24 | 0.32 | 0.16 | 0.35 | 0.55 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 9.61E-06 | 9.09E-03 | 0.28 | 0.41 | 0.3 | 195 | 0.22 | 0.31 | 0.22 | 0.4 | 0.66 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 2.59E-07 | 1.96E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.29 | 0.4 | -0.08 | -0.4 | 0.24 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.85E-06 | 1.54E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.29 | 0.38 | -0.09 | -0.85 | 0.11 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 7.95E-06 | 6.69E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.24 | 0.32 | 0.16 | 0.35 | 0.55 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 9.61E-06 | 9.09E-03 | 0.28 | 0.41 | 0.3 | 195 | 0.22 | 0.31 | 0.22 | 0.4 | 0.66 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 2.59E-07 | 1.96E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.29 | 0.4 | -0.08 | -0.4 | 0.24 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.85E-06 | 1.54E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.29 | 0.38 | -0.09 | -0.85 | 0.11 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 1.03E-05 | 7.11E-03 | 0.31 | 0.21 | 0.36 | 196 | 0.24 | 0.32 | 0.16 | 0.35 | 0.53 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 1.81E-05 | 1.37E-02 | 0.31 | 0.21 | 0.36 | 195 | 0.22 | 0.3 | 0.21 | 0.4 | 0.62 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 8.75E-08 | 1.22E-04 | 0.31 | 0.21 | 0.36 | 196 | 0.29 | 0.4 | -0.08 | -0.4 | 0.25 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 4.77E-07 | 5.96E-04 | 0.31 | 0.21 | 0.36 | 189 | 0.29 | 0.39 | -0.09 | -0.85 | 0.12 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.81E-05 | 3.46E-02 | 0.43 | 0.12 | 0.44 | 200 | 0.12 | 0.21 | -0.78 | 0.8 | -0.85 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 5.03E-06 | 6.35E-03 | 0.44 | 0.12 | 0.44 | 196 | 0.24 | 0.33 | 0.15 | 0.35 | 0.49 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.65E-05 | 1.37E-02 | 0.44 | 0.12 | 0.44 | 195 | 0.22 | 0.3 | 0.2 | 0.4 | 0.56 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 7.60E-06 | 1.45E-02 | 0.43 | 0.12 | 0.44 | 200 | 0.1 | 0.2 | -0.52 | 0.7 | -0.65 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.52E-08 | 2.88E-05 | 0.43 | 0.12 | 0.44 | 196 | 0.29 | 0.42 | -0.08 | -0.4 | 0.24 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.27E-08 | 4.78E-05 | 0.43 | 0.12 | 0.44 | 189 | 0.29 | 0.42 | -0.1 | -0.85 | 0.13 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 2.20E-05 | 1.19E-02 | 0.4 | 0.18 | 0.48 | 196 | 0.24 | 0.31 | -0.14 | 0.35 | -0.36 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 3.10E-05 | 1.68E-02 | 0.4 | 0.18 | 0.48 | 195 | 0.22 | 0.3 | -0.19 | 0.4 | -0.42 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 1.13E-07 | 1.22E-04 | 0.4 | 0.18 | 0.48 | 196 | 0.29 | 0.4 | 0.08 | -0.4 | -0.17 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 2.13E-07 | 3.19E-04 | 0.4 | 0.18 | 0.48 | 189 | 0.29 | 0.4 | 0.09 | -0.85 | -0.1 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 2.20E-05 | 1.19E-02 | 0.4 | 0.18 | 0.48 | 196 | 0.24 | 0.31 | 0.14 | 0.35 | 0.47 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 3.10E-05 | 1.68E-02 | 0.4 | 0.18 | 0.48 | 195 | 0.22 | 0.3 | 0.19 | 0.4 | 0.56 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 1.13E-07 | 1.22E-04 | 0.4 | 0.18 | 0.48 | 196 | 0.29 | 0.4 | -0.08 | -0.4 | 0.23 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 2.13E-07 | 3.19E-04 | 0.4 | 0.18 | 0.48 | 189 | 0.29 | 0.4 | -0.09 | -0.85 | 0.12 |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 6.78E-09 | 5.18E-05 | NA | NA | NA | 200 | 0.11 | 0.45 | NA | 0.8 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.57E-09 | 1.19E-05 | NA | NA | NA | 196 | 0.24 | 0.39 | NA | 0.35 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 5.83E-09 | 4.41E-05 | NA | NA | NA | 195 | 0.22 | 0.4 | NA | 0.4 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 4.71E-10 | 3.60E-06 | NA | NA | NA | 200 | 0.09 | 0.4 | NA | 0.7 | NA |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 1.03E-05 | 7.09E-03 | 0.35 | 0.05 | 0.38 | 196 | 0.29 | 0.37 | 0.07 | -0.4 | -0.15 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 2.05E-05 | 1.54E-02 | 0.35 | 0.05 | 0.38 | 189 | 0.29 | 0.36 | 0.08 | -0.85 | -0.08 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 8.74E-06 | 2.23E-02 | 0.47 | 0.19 | 0.42 | 200 | 0.12 | 0.21 | -0.85 | 0.8 | -0.91 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.36E-06 | 5.09E-03 | 0.46 | 0.19 | 0.42 | 196 | 0.24 | 0.33 | 0.16 | 0.35 | 0.53 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.28E-06 | 4.97E-03 | 0.47 | 0.19 | 0.42 | 195 | 0.22 | 0.32 | 0.22 | 0.4 | 0.65 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 6.09E-06 | 1.45E-02 | 0.47 | 0.19 | 0.42 | 200 | 0.1 | 0.2 | -0.55 | 0.7 | -0.68 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 2.25E-09 | 5.67E-06 | 0.47 | 0.19 | 0.42 | 196 | 0.29 | 0.44 | -0.09 | -0.4 | 0.28 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.13E-08 | 7.83E-05 | 0.47 | 0.19 | 0.42 | 189 | 0.29 | 0.41 | -0.1 | -0.85 | 0.13 |
| *lcyE*_3TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | Additonal Markers | 8 | 138,891,312 | 138,882,594 | 138,889,812 | 8,718 | 1,500 | 3.31E-05 | 2.26E-02 | NA | NA | NA | 189 | 0.2 | 0.16 | NA | -0.85 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 3.73E-05 | 1.88E-02 | NA | NA | NA | 196 | 0.24 | 0.26 | NA | 0.35 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 7.75E-05 | 3.45E-02 | NA | NA | NA | 195 | 0.22 | 0.24 | NA | 0.4 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 5.29E-07 | 4.03E-03 | NA | NA | NA | 198 | 0.07 | 0.07 | NA | -0.7 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.14E-07 | 1.33E-03 | NA | NA | NA | 196 | 0.04 | 0.09 | NA | -0.25 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 7.68E-06 | 1.91E-02 | NA | NA | NA | 188 | 0.05 | 0.11 | NA | -0.55 | NA |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 5.50E-05 | 2.31E-02 | 0.2 | 0 | 0.22 | 196 | 0.24 | 0.31 | 0.16 | 0.35 | 0.54 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 9.04E-05 | 3.80E-02 | 0.2 | 0 | 0.22 | 195 | 0.22 | 0.29 | 0.22 | 0.4 | 0.64 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 7.72E-06 | 2.01E-02 | 0.18 | 0 | 0.22 | 198 | 0.1 | 0.19 | 0.11 | -0.7 | -0.14 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 3.51E-07 | 1.33E-03 | 0.19 | 0 | 0.22 | 196 | 0.04 | 0.18 | 0.12 | -0.25 | -0.36 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 6.15E-06 | 1.91E-02 | 0.19 | 0 | 0.22 | 188 | 0.07 | 0.17 | 0.19 | -0.55 | -0.27 |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.79E-07 | 3.39E-04 | NA | NA | NA | 196 | 0.24 | 0.31 | NA | 0.35 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 7.09E-07 | 1.34E-03 | NA | NA | NA | 195 | 0.22 | 0.3 | NA | 0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.52E-05 | 2.90E-02 | NA | NA | NA | 198 | 0.07 | 0.05 | NA | -0.7 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.89E-07 | 1.41E-03 | NA | NA | NA | 188 | 0.05 | 0.15 | NA | -0.55 | NA |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits with a SNP tagging the peak GWAS signals from *zep1* included as a covariate. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S9 Results from the Pathway-Level Analysis with ss196425306 as Covariate Tagging *lut1* (C)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 3.62E-05 | 2.11E-02 | 0.18 | 0.33 | 0.26 | 196 | 0.04 | 0.13 | -0.19 | 0.35 | -0.45 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 1.39E-04 | 4.76E-02 | 0.18 | 0.33 | 0.26 | 195 | 0.05 | 0.12 | -0.24 | 0.4 | -0.49 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 2.27E-05 | 1.21E-02 | 0.18 | 0.33 | 0.26 | 189 | 0.2 | 0.28 | 0.09 | -0.35 | -0.22 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 2.27E-05 | 1.21E-02 | 0.18 | 0.33 | 0.26 | 189 | 0.2 | 0.28 | 0.09 | -0.85 | -0.1 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.06E-09 | 7.79E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.04 | 0.24 | -0.34 | 0.35 | -0.69 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 1.57E-08 | 5.95E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.05 | 0.22 | -0.43 | 0.4 | -0.76 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 5.29E-07 | 3.64E-04 | 0.11 | 0.29 | 0.09 | 196 | 0.11 | 0.24 | 0.12 | -0.4 | -0.24 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 9.29E-07 | 1.39E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.2 | 0.31 | 0.13 | -0.35 | -0.29 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 9.29E-07 | 1.39E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.2 | 0.31 | 0.13 | -0.85 | -0.13 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.06E-09 | 7.79E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.04 | 0.24 | 0.34 | 0.35 | 1.31 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 1.57E-08 | 5.95E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.05 | 0.22 | 0.43 | 0.4 | 1.46 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 5.29E-07 | 3.64E-04 | 0.11 | 0.29 | 0.09 | 196 | 0.11 | 0.24 | -0.12 | -0.4 | 0.37 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 9.29E-07 | 1.39E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.2 | 0.31 | -0.13 | -0.35 | 0.47 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 9.29E-07 | 1.39E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.2 | 0.31 | -0.13 | -0.85 | 0.17 |
| S2_44472618 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,472,618 | 44,440,299 | 44,449,237 | 32,319 | 23,381 | 1.13E-04 | 3.72E-02 | 0.13 | 0.38 | 0.15 | 196 | 0.04 | 0.12 | -0.2 | 0.35 | -0.47 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.32E-06 | 1.43E-03 | 0.14 | 0.25 | 0.12 | 196 | 0.04 | 0.17 | 0.24 | 0.35 | 0.86 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 4.49E-06 | 4.24E-03 | 0.14 | 0.25 | 0.12 | 195 | 0.05 | 0.16 | 0.31 | 0.4 | 0.97 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.65E-05 | 7.34E-03 | 0.14 | 0.25 | 0.12 | 196 | 0.11 | 0.2 | -0.09 | -0.4 | 0.27 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 4.35E-05 | 1.92E-02 | 0.14 | 0.25 | 0.12 | 189 | 0.2 | 0.27 | -0.09 | -0.35 | 0.33 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 4.35E-05 | 1.92E-02 | 0.14 | 0.25 | 0.12 | 189 | 0.2 | 0.27 | -0.09 | -0.85 | 0.12 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.32E-06 | 1.43E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.04 | 0.17 | -0.24 | 0.35 | -0.55 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 4.49E-06 | 4.24E-03 | 0.14 | 0.24 | 0.12 | 195 | 0.05 | 0.16 | -0.31 | 0.4 | -0.61 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.65E-05 | 7.34E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.11 | 0.2 | 0.09 | -0.4 | -0.19 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 4.35E-05 | 1.92E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.2 | 0.27 | 0.09 | -0.35 | -0.23 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 4.35E-05 | 1.92E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.2 | 0.27 | 0.09 | -0.85 | -0.1 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.32E-06 | 1.43E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.04 | 0.17 | 0.24 | 0.35 | 0.86 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 4.49E-06 | 4.24E-03 | 0.14 | 0.24 | 0.12 | 195 | 0.05 | 0.16 | 0.31 | 0.4 | 0.97 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.65E-05 | 7.34E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.11 | 0.2 | -0.09 | -0.4 | 0.27 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 4.35E-05 | 1.92E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.2 | 0.27 | -0.09 | -0.35 | 0.33 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 4.35E-05 | 1.92E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.2 | 0.27 | -0.09 | -0.85 | 0.12 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 9.15E-05 | 3.61E-02 | 0.18 | 0.35 | 0.16 | 189 | 0.2 | 0.26 | -0.08 | -0.35 | 0.28 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 9.15E-05 | 3.61E-02 | 0.18 | 0.35 | 0.16 | 189 | 0.2 | 0.26 | -0.08 | -0.85 | 0.11 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 4.65E-06 | 3.91E-03 | 0.14 | 0.29 | 0.13 | 196 | 0.04 | 0.15 | -0.23 | 0.35 | -0.52 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 1.65E-05 | 1.13E-02 | 0.14 | 0.29 | 0.13 | 195 | 0.05 | 0.14 | -0.29 | 0.4 | -0.57 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 2.87E-05 | 1.14E-02 | 0.14 | 0.29 | 0.13 | 196 | 0.11 | 0.2 | 0.09 | -0.4 | -0.19 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 4.62E-05 | 1.93E-02 | 0.15 | 0.29 | 0.13 | 189 | 0.2 | 0.27 | 0.09 | -0.35 | -0.22 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 4.62E-05 | 1.93E-02 | 0.15 | 0.29 | 0.13 | 189 | 0.2 | 0.27 | 0.09 | -0.85 | -0.1 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.09E-06 | 1.43E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.04 | 0.17 | 0.21 | 0.35 | 0.73 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 6.51E-06 | 5.47E-03 | 0.22 | 0.38 | 0.28 | 195 | 0.05 | 0.15 | 0.26 | 0.4 | 0.8 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.55E-05 | 7.34E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.11 | 0.2 | -0.08 | -0.4 | 0.23 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeinoxanthin/Lutein | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.55E-05 | 8.94E-03 | 0.22 | 0.38 | 0.28 | 189 | 0.2 | 0.28 | -0.09 | -0.35 | 0.29 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.55E-05 | 8.94E-03 | 0.22 | 0.38 | 0.28 | 189 | 0.2 | 0.28 | -0.09 | -0.85 | 0.11 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 6.46E-05 | 2.58E-02 | 0.29 | 0.17 | 0.36 | 196 | 0.04 | 0.13 | 0.17 | 0.35 | 0.57 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Total β-Xanthophylls | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 1.38E-04 | 4.76E-02 | 0.29 | 0.17 | 0.36 | 195 | 0.05 | 0.12 | 0.22 | 0.4 | 0.64 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | β-Xanthophylls/α-Xanthophylls | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 6.93E-05 | 2.42E-02 | 0.29 | 0.17 | 0.36 | 196 | 0.11 | 0.19 | -0.07 | -0.4 | 0.21 |
| S5_1315682 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,682 | 1,333,304 | 1,341,577 | -17,622 | -25,895 | 8.09E-05 | 2.92E-02 | 0.28 | 0.06 | 0.35 | 196 | 0.04 | 0.12 | 0.17 | 0.35 | 0.56 |
| S5_1315682 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | β-Xanthophylls/α-Xanthophylls | GBS | 5 | 1,315,682 | 1,333,304 | 1,341,577 | -17,622 | -25,895 | 7.05E-05 | 2.42E-02 | 0.28 | 0.06 | 0.35 | 196 | 0.11 | 0.19 | -0.07 | -0.4 | 0.21 |
| S5_215994270 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 215,994,270 | 215,827,224 | 215,831,730 | 167,046 | 162,540 | 7.84E-05 | 2.92E-02 | 0.07 | 0.05 | 0.07 | 196 | 0.04 | 0.12 | -0.29 | 0.35 | -0.62 |
| S5_215994270 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 215,994,270 | 215,827,224 | 215,831,730 | 167,046 | 162,540 | 1.47E-04 | 4.84E-02 | 0.07 | 0.05 | 0.07 | 195 | 0.05 | 0.12 | -0.37 | 0.4 | -0.69 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 1.39E-05 | 8.76E-03 | 0.13 | 0.17 | 0.17 | 196 | 0.04 | 0.14 | -0.22 | 0.35 | -0.51 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 2.20E-05 | 1.38E-02 | 0.13 | 0.17 | 0.17 | 195 | 0.05 | 0.14 | -0.29 | 0.4 | -0.58 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeaxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.39E-04 | 4.40E-02 | 0.15 | 0.1 | 0.16 | 196 | 0.04 | 0.12 | -0.18 | 0.35 | -0.43 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 3.40E-08 | 2.60E-04 | 0.15 | 0.1 | 0.16 | 199 | 0.15 | 0.29 | -0.04 | 0.1 | -0.34 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 7.59E-05 | 3.02E-02 | 0.15 | 0.1 | 0.16 | 195 | 0.05 | 0.13 | -0.26 | 0.4 | -0.52 |
| S7_160777986 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zea | GBS | 7 | 160,777,986 | 160,531,537 | 160,533,586 | 246,449 | 244,400 | 2.90E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | xanthin) | | | | | | | | | | | | | | | | | |
| S7_160778001 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,001 | 160,531,537 | 160,533,586 | 246,464 | 244,415 | 2.90E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778016 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,016 | 160,531,537 | 160,533,586 | 246,479 | 244,430 | 2.90E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | -0.14 | -0.25 | 0.83 |
| S7_160779488 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/β-Cryptoxanthin | GBS | 7 | 160,779,488 | 160,531,537 | 160,533,586 | 247,951 | 245,902 | 1.28E-05 | 2.45E-02 | 0.12 | 0.26 | 0.12 | 198 | 0.1 | 0.19 | 0.11 | -0.7 | -0.14 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 8.50E-05 | 2.93E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.04 | 0.12 | 0.16 | 0.35 | 0.53 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 3.39E-05 | 1.80E-02 | 0.32 | 0.29 | 0.33 | 195 | 0.05 | 0.14 | 0.23 | 0.4 | 0.68 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 6.53E-05 | 2.42E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.11 | 0.19 | -0.07 | -0.4 | 0.2 |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 2.24E-08 | 8.56E-05 | NA | NA | NA | 200 | 0.12 | 0.49 | NA | 0.8 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 9.13E-06 | 6.92E-03 | NA | NA | NA | 196 | 0.04 | 0.24 | NA | 0.35 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.04E-05 | 7.87E-03 | NA | NA | NA | 195 | 0.05 | 0.29 | NA | 0.4 | NA |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 6.12E-05 | 2.58E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.04 | 0.13 | 0.16 | 0.35 | 0.54 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 5.47E-05 | 2.30E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.13 | 0.22 | 0.4 | 0.65 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 3.23E-07 | 3.06E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.11 | 0.24 | -0.09 | -0.4 | 0.26 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.35 | 0.32 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.85 | 0.12 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.80E-06 | 2.65E-03 | 0.35 | 0.48 | 0.34 | 196 | 0.04 | 0.16 | -0.19 | 0.35 | -0.44 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.77E-06 | 2.68E-03 | 0.35 | 0.48 | 0.34 | 195 | 0.05 | 0.17 | -0.26 | 0.4 | -0.53 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 4.03E-10 | 1.52E-06 | 0.35 | 0.48 | 0.34 | 196 | 0.11 | 0.31 | 0.11 | -0.4 | -0.23 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.75E-09 | 2.06E-05 | 0.37 | 0.48 | 0.34 | 189 | 0.2 | 0.36 | 0.12 | -0.35 | -0.27 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.75E-09 | 2.06E-05 | 0.37 | 0.48 | 0.34 | 189 | 0.2 | 0.36 | 0.12 | -0.85 | -0.12 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 6.12E-05 | 2.58E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.04 | 0.13 | 0.16 | 0.35 | 0.54 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 5.47E-05 | 2.30E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.13 | 0.22 | 0.4 | 0.65 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 3.23E-07 | 3.06E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.11 | 0.24 | -0.09 | -0.4 | 0.26 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.35 | 0.32 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.85 | 0.12 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 6.12E-05 | 2.58E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.04 | 0.13 | 0.16 | 0.35 | 0.54 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 5.47E-05 | 2.30E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.05 | 0.13 | 0.22 | 0.4 | 0.65 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 3.23E-07 | 3.06E-04 | 0.28 | 0.41 | 0.3 | 196 | 0.11 | 0.24 | -0.09 | -0.4 | 0.26 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.35 | 0.32 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.71E-06 | 1.60E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.2 | 0.3 | -0.09 | -0.85 | 0.12 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 2.65E-07 | 3.06E-04 | 0.31 | 0.21 | 0.36 | 196 | 0.11 | 0.24 | -0.09 | -0.4 | 0.26 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 2.59E-06 | 2.16E-03 | 0.31 | 0.21 | 0.36 | 189 | 0.2 | 0.3 | -0.09 | -0.35 | 0.31 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 2.59E-06 | 2.16E-03 | 0.31 | 0.21 | 0.36 | 189 | 0.2 | 0.3 | -0.09 | -0.85 | 0.12 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.84E-05 | 3.52E-02 | 0.43 | 0.12 | 0.44 | 200 | 0.12 | 0.21 | -0.78 | 0.8 | -0.85 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 5.90E-05 | 2.58E-02 | 0.44 | 0.12 | 0.44 | 196 | 0.04 | 0.13 | 0.15 | 0.35 | 0.48 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.10E-04 | 4.17E-02 | 0.44 | 0.12 | 0.44 | 195 | 0.05 | 0.13 | 0.19 | 0.4 | 0.55 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.55E-08 | 2.92E-05 | 0.43 | 0.12 | 0.44 | 196 | 0.11 | 0.27 | -0.09 | -0.4 | 0.26 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 6.73E-08 | 2.52E-04 | 0.43 | 0.12 | 0.44 | 189 | 0.2 | 0.33 | -0.1 | -0.35 | 0.34 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 6.73E-08 | 2.52E-04 | 0.43 | 0.12 | 0.44 | 189 | 0.2 | 0.33 | -0.1 | -0.85 | 0.13 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 1.04E-06 | 6.08E-04 | 0.4 | 0.18 | 0.48 | 196 | 0.11 | 0.23 | 0.08 | -0.4 | -0.17 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 6.84E-06 | 4.41E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.2 | 0.29 | 0.08 | -0.35 | -0.2 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 6.84E-06 | 4.41E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.2 | 0.29 | 0.08 | -0.85 | -0.09 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 1.04E-06 | 6.08E-04 | 0.4 | 0.18 | 0.48 | 196 | 0.11 | 0.23 | -0.08 | -0.4 | 0.22 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 6.84E-06 | 4.41E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.2 | 0.29 | -0.08 | -0.35 | 0.28 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 6.84E-06 | 4.41E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.2 | 0.29 | -0.08 | -0.85 | 0.11 |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 6.44E-09 | 4.92E-05 | NA | NA | NA | 200 | 0.12 | 0.45 | NA | 0.8 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.64E-07 | 4.13E-04 | NA | NA | NA | 195 | 0.05 | 0.29 | NA | 0.4 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 7.15E-16 | 5.41E-12 | NA | NA | NA | 196 | 0.08 | 0.22 | NA | -0.4 | NA |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 5.28E-07 | 3.64E-04 | 0.35 | 0.05 | 0.38 | 196 | 0.11 | 0.24 | 0.08 | -0.4 | -0.18 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 7.05E-06 | 4.41E-03 | 0.35 | 0.05 | 0.38 | 189 | 0.2 | 0.29 | 0.09 | -0.35 | -0.21 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 7.05E-06 | 4.41E-03 | 0.35 | 0.05 | 0.38 | 189 | 0.2 | 0.29 | 0.09 | -0.85 | -0.09 |
| ss196504158 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,886,334 | 138,882,594 | 138,889,812 | 3,740 | -3,478 | 7.38E-05 | 2.43E-02 | 0.31 | 0.29 | 0.25 | 196 | 0.11 | 0.19 | 0.07 | -0.4 | -0.16 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 8.85E-06 | 2.25E-02 | 0.47 | 0.19 | 0.42 | 200 | 0.12 | 0.21 | -0.85 | 0.8 | -0.91 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 6.16E-05 | 2.58E-02 | 0.46 | 0.19 | 0.42 | 196 | 0.04 | 0.13 | 0.15 | 0.35 | 0.5 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.58E-05 | 1.80E-02 | 0.47 | 0.19 | 0.42 | 195 | 0.05 | 0.14 | 0.21 | 0.4 | 0.62 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 2.98E-09 | 7.52E-06 | 0.47 | 0.19 | 0.42 | 196 | 0.11 | 0.29 | -0.1 | -0.4 | 0.3 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeinoxanthin/Lutein | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.80E-07 | 4.50E-04 | 0.47 | 0.19 | 0.42 | 189 | 0.2 | 0.32 | -0.1 | -0.35 | 0.35 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.80E-07 | 4.50E-04 | 0.47 | 0.19 | 0.42 | 189 | 0.2 | 0.32 | -0.1 | -0.85 | 0.13 |
| S8_138911758 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,911,758 | 138,882,594 | 138,889,812 | 29,164 | 21,946 | 8.16E-05 | 2.57E-02 | 0.06 | 0.16 | 0.05 | 196 | 0.11 | 0.19 | -0.14 | -0.4 | 0.46 |
| S8_139136162 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 139,136,162 | 138,882,594 | 138,889,812 | 253,568 | 246,350 | 2.76E-05 | 1.14E-02 | 0.45 | 0 | 0.47 | 196 | 0.11 | 0.2 | -0.07 | -0.4 | 0.2 |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 1.23E-05 | 8.47E-03 | NA | NA | NA | 196 | 0.04 | 0.11 | NA | 0.35 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.44E-05 | 1.42E-02 | NA | NA | NA | 195 | 0.05 | 0.11 | NA | 0.4 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.20E-06 | 1.67E-02 | NA | NA | NA | 198 | 0.08 | 0.09 | NA | -0.7 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 1.72E-07 | 1.31E-03 | NA | NA | NA | 196 | 0.03 | 0.08 | NA | -0.25 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 5.91E-06 | 2.21E-02 | NA | NA | NA | 188 | 0.02 | 0.09 | NA | -0.55 | NA |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 7.95E-06 | 2.02E-02 | 0.18 | 0 | 0.22 | 198 | 0.1 | 0.2 | 0.11 | -0.7 | -0.14 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 3.67E-07 | 1.39E-03 | 0.19 | 0 | 0.22 | 196 | 0.04 | 0.18 | 0.12 | -0.25 | -0.36 |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.12E-06 | 1.43E-03 | NA | NA | NA | 196 | 0.04 | 0.15 | NA | 0.35 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.77E-06 | 2.68E-03 | NA | NA | NA | 195 | 0.05 | 0.17 | NA | 0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.00E-04 | 3.03E-02 | NA | NA | NA | 196 | 0.08 | 0.03 | NA | -0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 6.68E-06 | 2.02E-02 | NA | NA | NA | 198 | 0.08 | 0.09 | NA | -0.7 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.33E-07 | 9.94E-04 | NA | NA | NA | 188 | 0.02 | 0.14 | NA | -0.55 | NA |

Covariate Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits with a SNP tagging the peak GWAS signals from *lut1* included as a covariate. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S9 Results from the Pathway-Level Analysis with S8_138882897 and *lcyE* SNP216 as Covariates Tagging *lcyE* (D)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ss196425293 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,597,575 | 86,838,334 | 86,848,726 | -240,759 | -251,151 | 1.62E-05 | 3.05E-02 | 0.31 | 0.24 | 0.33 | 175 | 0.08 | 0.18 | -0.16 | -0.35 | 0.65 |
| ss196501639 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,597,631 | 86,838,334 | 86,848,726 | -240,703 | -251,095 | 7.61E-06 | 1.92E-02 | 0.31 | 0.24 | 0.33 | 175 | 0.08 | 0.19 | -0.17 | -0.35 | 0.7 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 4.28E-08 | 1.63E-04 | 0.32 | 0.4 | 0.28 | 178 | 0.1 | 0.27 | -0.12 | -0.25 | 0.67 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 7.23E-10 | 2.76E-06 | 0.33 | 0.4 | 0.28 | 178 | 0.16 | 0.37 | 0.07 | -0.25 | -0.22 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 4.98E-08 | 1.88E-04 | 0.31 | 0.4 | 0.28 | 175 | 0.08 | 0.25 | -0.21 | -0.35 | 0.93 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 4.28E-08 | 1.63E-04 | 0.32 | 0.4 | 0.27 | 178 | 0.1 | 0.27 | -0.12 | -0.25 | 0.67 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 7.23E-10 | 2.76E-06 | 0.33 | 0.4 | 0.27 | 178 | 0.16 | 0.37 | 0.07 | -0.25 | -0.22 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 4.98E-08 | 1.88E-04 | 0.31 | 0.4 | 0.27 | 175 | 0.08 | 0.25 | -0.21 | -0.35 | 0.93 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 7.43E-09 | 2.81E-05 | 0.11 | 0.29 | 0.09 | 176 | 0.18 | 0.36 | -0.32 | 0.35 | -0.67 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 8.43E-08 | 3.18E-04 | 0.11 | 0.29 | 0.09 | 175 | 0.2 | 0.34 | -0.4 | 0.4 | -0.73 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 5.10E-07 | 1.93E-03 | 0.11 | 0.29 | 0.09 | 176 | 0.45 | 0.54 | 0.1 | -0.4 | -0.22 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 7.43E-09 | 2.81E-05 | 0.11 | 0.29 | 0.09 | 176 | 0.18 | 0.36 | 0.32 | 0.35 | 1.22 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 8.43E-08 | 3.18E-04 | 0.11 | 0.29 | 0.09 | 175 | 0.2 | 0.34 | 0.4 | 0.4 | 1.34 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 5.10E-07 | 1.93E-03 | 0.11 | 0.29 | 0.09 | 176 | 0.45 | 0.54 | -0.1 | -0.4 | 0.32 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.91E-05 | 1.80E-02 | 0.14 | 0.25 | 0.12 | 176 | 0.18 | 0.27 | 0.21 | 0.35 | 0.7 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.91E-05 | 1.80E-02 | 0.14 | 0.24 | 0.12 | 176 | 0.18 | 0.27 | -0.21 | 0.35 | -0.48 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.91E-05 | 1.80E-02 | 0.14 | 0.24 | 0.12 | 176 | 0.18 | 0.27 | 0.21 | 0.35 | 0.7 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 4.98E-05 | 4.19E-02 | 0.15 | 0.29 | 0.13 | 176 | 0.18 | 0.26 | -0.19 | 0.35 | -0.46 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 5.83E-05 | 4.41E-02 | 0.21 | 0.38 | 0.28 | 176 | 0.18 | 0.26 | 0.17 | 0.35 | 0.57 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 2.89E-06 | 5.11E-03 | 0.14 | 0.17 | 0.17 | 176 | 0.18 | 0.29 | -0.23 | 0.35 | -0.52 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 5.35E-06 | 8.08E-03 | 0.14 | 0.17 | 0.17 | 175 | 0.2 | 0.3 | -0.29 | 0.4 | -0.58 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.40E-07 | 1.07E-03 | 0.16 | 0.1 | 0.16 | 179 | 0.19 | 0.33 | -0.04 | 0.1 | -0.33 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 2.96E-05 | 3.72E-02 | 0.17 | 0.1 | 0.16 | 175 | 0.2 | 0.28 | -0.25 | 0.4 | -0.51 |
| S7_160777986 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,777,986 | 160,531,537 | 160,533,586 | 246,449 | 244,400 | 3.46E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 178 | 0.04 | 0.14 | 0.15 | -0.25 | -0.43 |
| S7_160778001 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,001 | 160,531,537 | 160,533,586 | 246,464 | 244,415 | 3.46E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 178 | 0.04 | 0.14 | 0.15 | -0.25 | -0.43 |
| S7_160778016 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,016 | 160,531,537 | 160,533,586 | 246,479 | 244,430 | 3.46E-05 | 4.40E-02 | 0.07 | 0.08 | 0.1 | 178 | 0.04 | 0.14 | -0.15 | -0.25 | 0.93 |
| S8_168167679 | Carotenoid Synthesis and Degradation | GRMZM2G149317 | phytoene synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 8 | 168,167,679 | 168,273,042 | 168,276,092 | -105,363 | -108,413 | 1.27E-05 | 3.22E-02 | 0.11 | 0.05 | 0.12 | 178 | 0.04 | 0.15 | -0.14 | -0.25 | 0.81 |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 3.38E-06 | 5.11E-03 | NA | NA | NA | 196 | 0.24 | 0.32 | NA | 0.35 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 4.93E-06 | 8.08E-03 | NA | NA | NA | 195 | 0.29 | 0.36 | NA | 0.4 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 6.88E-07 | 5.25E-03 | NA | NA | NA | 198 | -0.06 | 0.03 | NA | -0.7 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 3.98E-08 | 1.49E-04 | NA | NA | NA | 188 | 0.06 | 0.19 | NA | -0.55 | NA |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 8.21E-06 | 2.41E-02 | 0.18 | 0 | 0.22 | 179 | 0.1 | 0.21 | 0.11 | -0.7 | -0.14 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 8.35E-07 | 3.18E-03 | 0.19 | 0 | 0.22 | 178 | 0.04 | 0.19 | 0.12 | -0.25 | -0.37 |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.61E-06 | 4.06E-03 | NA | NA | NA | 196 | 0.24 | 0.33 | NA | 0.35 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.76E-06 | 4.44E-03 | NA | NA | NA | 195 | 0.29 | 0.38 | NA | 0.4 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 9.48E-06 | 2.41E-02 | NA | NA | NA | 198 | -0.06 | 0.02 | NA | -0.7 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 2.13E-10 | 1.62E-06 | NA | NA | NA | 196 | 0.04 | 0.1 | NA | -0.25 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 3.30E-09 | 2.47E-05 | NA | NA | NA | 188 | 0.06 | 0.22 | NA | -0.55 | NA |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits with the markers tagging *lcyE* identified in the multi-locus mixed model included as covariates. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S9 Results from the Pathway-Level Analysis with S8_171705574 Covariate (E)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 7.31E-08 | 2.78E-04 | 0.3 | 0.4 | 0.28 | 198 | 0.1 | 0.25 | -0.11 | -0.25 | 0.62 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 5.23E-10 | 1.99E-06 | 0.31 | 0.4 | 0.28 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 4.34E-08 | 1.64E-04 | 0.29 | 0.4 | 0.28 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 7.31E-08 | 2.78E-04 | 0.3 | 0.4 | 0.27 | 198 | 0.1 | 0.25 | -0.11 | -0.25 | 0.62 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 5.23E-10 | 1.99E-06 | 0.31 | 0.4 | 0.27 | 196 | 0.17 | 0.35 | 0.06 | -0.25 | -0.22 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 4.34E-08 | 1.64E-04 | 0.29 | 0.4 | 0.27 | 195 | 0.09 | 0.24 | -0.19 | -0.35 | 0.84 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 9.02E-05 | 4.24E-02 | 0.18 | 0.33 | 0.26 | 196 | 0.19 | 0.25 | -0.17 | 0.35 | -0.41 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 1.38E-04 | 4.75E-02 | 0.18 | 0.33 | 0.26 | 196 | 0.19 | 0.25 | 0.07 | -0.4 | -0.16 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 8.85E-05 | 3.49E-02 | 0.18 | 0.33 | 0.26 | 189 | 0.22 | 0.29 | 0.08 | -0.85 | -0.09 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.15E-09 | 8.14E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.19 | 0.35 | -0.32 | 0.35 | -0.66 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 1.75E-08 | 6.64E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.2 | 0.34 | -0.4 | 0.4 | -0.72 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 1.31E-07 | 1.98E-04 | 0.11 | 0.29 | 0.09 | 196 | 0.19 | 0.31 | 0.12 | -0.4 | -0.25 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 6.74E-06 | 7.02E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.22 | 0.31 | 0.11 | -0.85 | -0.12 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.15E-09 | 8.14E-06 | 0.11 | 0.29 | 0.09 | 196 | 0.19 | 0.35 | 0.32 | 0.35 | 1.19 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 1.75E-08 | 6.64E-05 | 0.11 | 0.29 | 0.09 | 195 | 0.2 | 0.34 | 0.4 | 0.4 | 1.32 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 1.31E-07 | 1.98E-04 | 0.11 | 0.29 | 0.09 | 196 | 0.19 | 0.31 | -0.12 | -0.4 | 0.39 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 6.74E-06 | 7.02E-03 | 0.12 | 0.29 | 0.09 | 189 | 0.22 | 0.31 | -0.11 | -0.85 | 0.15 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.72E-07 | 2.61E-04 | 0.14 | 0.25 | 0.12 | 196 | 0.19 | 0.31 | 0.24 | 0.35 | 0.87 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 5.64E-07 | 8.53E-04 | 0.14 | 0.25 | 0.12 | 195 | 0.2 | 0.31 | 0.32 | 0.4 | 0.99 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 2.75E-06 | 1.49E-03 | 0.14 | 0.25 | 0.12 | 196 | 0.19 | 0.28 | -0.1 | -0.4 | 0.28 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 5.19E-05 | 2.43E-02 | 0.14 | 0.25 | 0.12 | 189 | 0.22 | 0.29 | -0.09 | -0.85 | 0.12 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.72E-07 | 2.61E-04 | 0.14 | 0.24 | 0.12 | 196 | 0.19 | 0.31 | -0.24 | 0.35 | -0.55 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 5.64E-07 | 8.53E-04 | 0.14 | 0.24 | 0.12 | 195 | 0.2 | 0.31 | -0.32 | 0.4 | -0.61 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 2.75E-06 | 1.49E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.19 | 0.28 | 0.1 | -0.4 | -0.2 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 5.19E-05 | 2.43E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.22 | 0.29 | 0.09 | -0.85 | -0.1 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.72E-07 | 2.61E-04 | 0.14 | 0.24 | 0.12 | 196 | 0.19 | 0.31 | 0.24 | 0.35 | 0.87 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 5.64E-07 | 8.53E-04 | 0.14 | 0.24 | 0.12 | 195 | 0.2 | 0.31 | 0.32 | 0.4 | 0.99 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 2.75E-06 | 1.49E-03 | 0.14 | 0.24 | 0.12 | 196 | 0.19 | 0.28 | -0.1 | -0.4 | 0.28 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 5.19E-05 | 2.43E-02 | 0.14 | 0.24 | 0.12 | 189 | 0.22 | 0.29 | -0.09 | -0.85 | 0.12 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 5.18E-05 | 3.02E-02 | 0.17 | 0.35 | 0.16 | 196 | 0.19 | 0.26 | 0.17 | 0.35 | 0.57 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 9.35E-05 | 3.54E-02 | 0.17 | 0.35 | 0.16 | 196 | 0.19 | 0.25 | -0.07 | -0.4 | 0.21 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 8.38E-05 | 3.49E-02 | 0.18 | 0.35 | 0.16 | 189 | 0.22 | 0.29 | -0.08 | -0.85 | 0.11 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 9.65E-07 | 1.14E-03 | 0.14 | 0.29 | 0.13 | 196 | 0.19 | 0.29 | -0.23 | 0.35 | -0.52 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 3.38E-06 | 4.26E-03 | 0.14 | 0.29 | 0.13 | 195 | 0.2 | 0.29 | -0.29 | 0.4 | -0.57 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 4.99E-06 | 2.52E-03 | 0.14 | 0.29 | 0.13 | 196 | 0.19 | 0.28 | 0.09 | -0.4 | -0.2 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 7.20E-05 | 3.18E-02 | 0.15 | 0.29 | 0.13 | 189 | 0.22 | 0.29 | 0.09 | -0.85 | -0.1 |
| S2_44474308 | Carotenoid Synthesis and | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.09E-06 | 1.14E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.19 | 0.29 | 0.2 | 0.35 | 0.67 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Degradation | | | | | | | | | | | | | | | | | | | | | |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 6.38E-06 | 5.36E-03 | 0.22 | 0.38 | 0.28 | 195 | 0.2 | 0.29 | 0.24 | 0.4 | 0.73 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.04E-05 | 4.58E-03 | 0.21 | 0.38 | 0.28 | 196 | 0.19 | 0.27 | -0.08 | -0.4 | 0.22 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 3.06E-05 | 1.77E-02 | 0.22 | 0.38 | 0.28 | 189 | 0.22 | 0.3 | -0.08 | -0.85 | 0.11 |
| S5_1315672 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeaxanthin | GBS | 5 | 1,315,672 | 1,333,304 | 1,341,577 | -17,632 | -25,905 | 7.31E-05 | 3.95E-02 | 0.29 | 0.17 | 0.36 | 196 | 0.19 | 0.26 | 0.16 | 0.35 | 0.52 |
| ss196471946 | Carotenoid Synthesis and Degradation | GRMZM2G300348 | phytoene synthase | Acyclic and Monocyclic Carotenes | 55K | 6 | 82,019,955 | 82,017,148 | 82,021,007 | 2,807 | -1,052 | 4.82E-06 | 3.68E-02 | 0.18 | 0.1 | 0.19 | 200 | 0.05 | 0.16 | 0.01 | -0.15 | -0.07 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 2.78E-07 | 2.12E-03 | 0.15 | 0.1 | 0.16 | 199 | 0.17 | 0.29 | -0.04 | 0.1 | -0.32 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.12E-04 | 4.97E-02 | 0.15 | 0.1 | 0.16 | 195 | 0.2 | 0.26 | -0.23 | 0.4 | -0.48 |
| S7_13980028 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeinoxanthin | GBS | 7 | 13,980,028 | 14,077,852 | 14,081,075 | -97,824 | -101,047 | 1.08E-05 | 2.75E-02 | 0.41 | 0.4 | 0.5 | 198 | 0.1 | 0.2 | -0.08 | -0.25 | 0.39 |
| S7_160777986 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,777,986 | 160,531,537 | 160,533,586 | 246,449 | 244,400 | 3.16E-05 | 4.80E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778001 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,001 | 160,531,537 | 160,533,586 | 246,464 | 244,415 | 3.16E-05 | 4.80E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | 0.14 | -0.25 | -0.41 |
| S7_160778016 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | GBS | 7 | 160,778,016 | 160,531,537 | 160,533,586 | 246,479 | 244,430 | 3.16E-05 | 4.80E-02 | 0.07 | 0.08 | 0.1 | 196 | 0.04 | 0.13 | -0.14 | -0.25 | 0.83 |
| S7_160779488 | Prenyl Group Synthesis | GRMZM2G102550 | geranylgeranyl pyrophosphate synthase | β-Carotene/β-Cryptoxanthin | GBS | 7 | 160,779,488 | 160,531,537 | 160,533,586 | 247,951 | 245,902 | 1.08E-05 | 2.74E-02 | 0.12 | 0.26 | 0.12 | 198 | 0.1 | 0.19 | 0.12 | -0.7 | -0.15 |
| S8_138648940 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,648,940 | 138,882,594 | 138,889,812 | -233,654 | -240,872 | 1.31E-04 | 4.67E-02 | 0.19 | 0.28 | 0.25 | 189 | 0.22 | 0.28 | -0.08 | -0.85 | 0.1 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 3.89E-05 | 2.46E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.19 | 0.26 | 0.16 | 0.35 | 0.51 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 1.53E-05 | 1.16E-02 | 0.32 | 0.29 | 0.33 | 195 | 0.2 | 0.28 | 0.22 | 0.4 | 0.65 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 8.49E-05 | 3.38E-02 | 0.32 | 0.29 | 0.33 | 196 | 0.19 | 0.25 | -0.07 | -0.4 | 0.19 |
| ss196487098 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,861,176 | 138,882,594 | 138,889,812 | -21,418 | -28,636 | 9.59E-05 | 3.60E-02 | 0.32 | 0.29 | 0.33 | 189 | 0.22 | 0.29 | -0.07 | -0.85 | 0.1 |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.52E-08 | 5.81E-05 | NA | NA | NA | 200 | 0.11 | 0.49 | NA | 0.8 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 3.99E-09 | 1.52E-05 | NA | NA | NA | 200 | 0.1 | 0.43 | NA | 0.7 | NA |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.01E-04 | 4.24E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.25 | 0.15 | 0.35 | 0.48 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 9.91E-05 | 4.69E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.2 | 0.26 | 0.2 | 0.4 | 0.57 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.58E-06 | 1.19E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.29 | -0.08 | -0.4 | 0.24 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.03E-05 | 7.02E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.22 | 0.3 | -0.08 | -0.85 | 0.11 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 2.40E-05 | 3.67E-02 | 0.36 | 0.48 | 0.34 | 200 | 0.13 | 0.22 | 0.84 | 0.8 | 1.15 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 8.11E-06 | 6.15E-03 | 0.35 | 0.48 | 0.34 | 196 | 0.19 | 0.28 | -0.17 | 0.35 | -0.4 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 6.36E-06 | 5.36E-03 | 0.35 | 0.48 | 0.34 | 195 | 0.2 | 0.29 | -0.23 | 0.4 | -0.47 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 9.40E-06 | 1.44E-02 | 0.36 | 0.48 | 0.34 | 200 | 0.11 | 0.21 | 0.56 | 0.7 | 0.9 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 3.69E-09 | 1.40E-05 | 0.35 | 0.48 | 0.34 | 196 | 0.19 | 0.35 | 0.1 | -0.4 | -0.21 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 4.67E-09 | 3.50E-05 | 0.37 | 0.48 | 0.34 | 189 | 0.22 | 0.38 | 0.11 | -0.85 | -0.12 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.01E-04 | 4.24E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.25 | 0.15 | 0.35 | 0.48 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 9.91E-05 | 4.69E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.2 | 0.26 | 0.2 | 0.4 | 0.57 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.58E-06 | 1.19E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.29 | -0.08 | -0.4 | 0.24 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.03E-05 | 7.02E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.22 | 0.3 | -0.08 | -0.85 | 0.11 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.01E-04 | 4.24E-02 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.25 | 0.15 | 0.35 | 0.48 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 9.91E-05 | 4.69E-02 | 0.28 | 0.41 | 0.3 | 195 | 0.2 | 0.26 | 0.2 | 0.4 | 0.57 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.58E-06 | 1.19E-03 | 0.28 | 0.41 | 0.3 | 196 | 0.19 | 0.29 | -0.08 | -0.4 | 0.24 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.03E-05 | 7.02E-03 | 0.29 | 0.41 | 0.3 | 189 | 0.22 | 0.3 | -0.08 | -0.85 | 0.11 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 2.66E-06 | 1.49E-03 | 0.31 | 0.21 | 0.36 | 196 | 0.19 | 0.28 | -0.08 | -0.4 | 0.23 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 1.16E-05 | 7.22E-03 | 0.31 | 0.21 | 0.36 | 189 | 0.22 | 0.3 | -0.08 | -0.85 | 0.11 |
| S8_13888289 | Carotenoid | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 7.94E-06 | 1.52E-02 | 0.43 | 0.12 | 0.44 | 200 | 0.13 | 0.23 | -0.82 | 0.8 | -0.88 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Synthesis and Degradation | | | | | | | | | | | | | | | | | | | | | |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 3.85E-06 | 8.95E-03 | 0.43 | 0.12 | 0.44 | 200 | 0.11 | 0.21 | -0.54 | 0.7 | -0.67 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 2.15E-07 | 2.72E-04 | 0.43 | 0.12 | 0.44 | 196 | 0.19 | 0.31 | -0.08 | -0.4 | 0.23 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.14E-07 | 4.28E-04 | 0.43 | 0.12 | 0.44 | 189 | 0.22 | 0.35 | -0.09 | -0.85 | 0.12 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 1.09E-05 | 4.58E-03 | 0.4 | 0.18 | 0.48 | 196 | 0.19 | 0.27 | 0.07 | -0.4 | -0.15 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 1.01E-05 | 7.02E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.22 | 0.31 | 0.08 | -0.85 | -0.09 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 1.09E-05 | 4.58E-03 | 0.4 | 0.18 | 0.48 | 196 | 0.19 | 0.27 | -0.07 | -0.4 | 0.2 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 1.01E-05 | 7.02E-03 | 0.4 | 0.18 | 0.48 | 189 | 0.22 | 0.31 | -0.08 | -0.85 | 0.1 |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 4.75E-09 | 3.63E-05 | NA | NA | NA | 200 | 0.11 | 0.45 | NA | 0.8 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 7.05E-06 | 5.93E-03 | NA | NA | NA | 196 | 0.17 | 0.35 | NA | 0.35 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.88E-05 | 1.29E-02 | NA | NA | NA | 195 | 0.18 | 0.39 | NA | 0.4 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 3.24E-10 | 2.48E-06 | NA | NA | NA | 200 | 0.1 | 0.4 | NA | 0.7 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 2.78E-15 | 2.10E-11 | NA | NA | NA | 196 | 0.13 | 0.26 | NA | -0.4 | NA |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 1.47E-06 | 1.19E-03 | 0.35 | 0.05 | 0.38 | 196 | 0.19 | 0.29 | 0.08 | -0.4 | -0.18 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 3.05E-06 | 5.72E-03 | 0.35 | 0.05 | 0.38 | 189 | 0.22 | 0.32 | 0.09 | -0.85 | -0.1 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 6.03E-06 | 1.52E-02 | 0.47 | 0.19 | 0.42 | 200 | 0.13 | 0.23 | -0.87 | 0.8 | -0.92 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.22E-04 | 4.86E-02 | 0.46 | 0.19 | 0.42 | 196 | 0.19 | 0.25 | 0.14 | 0.35 | 0.44 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 9.58E-05 | 4.69E-02 | 0.47 | 0.19 | 0.42 | 195 | 0.2 | 0.26 | 0.19 | 0.4 | 0.54 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 4.68E-06 | 8.95E-03 | 0.47 | 0.19 | 0.42 | 200 | 0.11 | 0.21 | -0.56 | 0.7 | -0.69 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.58E-08 | 4.00E-05 | 0.47 | 0.19 | 0.42 | 196 | 0.19 | 0.33 | -0.09 | -0.4 | 0.28 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 2.43E-07 | 6.08E-04 | 0.47 | 0.19 | 0.42 | 189 | 0.22 | 0.34 | -0.1 | -0.85 | 0.13 |
| S8_139136162 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 139,136,162 | 138,882,594 | 138,889,812 | 253,568 | 246,350 | 1.24E-04 | 4.47E-02 | 0.45 | 0 | 0.47 | 196 | 0.19 | 0.25 | -0.06 | -0.4 | 0.18 |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.43E-05 | 1.67E-02 | NA | NA | NA | 196 | 0.17 | 0.24 | NA | 0.35 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 4.22E-05 | 2.66E-02 | NA | NA | NA | 195 | 0.18 | 0.25 | NA | 0.4 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 3.17E-06 | 2.42E-02 | NA | NA | NA | 198 | 0.07 | 0.06 | NA | -0.7 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 2.87E-07 | 1.51E-03 | NA | NA | NA | 196 | 0.04 | 0.08 | NA | -0.25 | NA |
| *crtRB1* InDel4 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total Carotenes/Total Xanthophylls | Additonal Markers | 10 | 136,059,748 | 136,057,100 | 136,060,219 | 2,648 | -471 | 4.43E-06 | 3.31E-02 | NA | NA | NA | 188 | 0.03 | 0.09 | NA | -0.55 | NA |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/β-Cryptoxanthin | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 8.30E-06 | 2.74E-02 | 0.18 | 0 | 0.22 | 198 | 0.1 | 0.2 | 0.11 | -0.7 | -0.14 |
| ss196501627 | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 55K | 10 | 136,060,033 | 136,057,100 | 136,060,219 | 2,933 | -186 | 3.99E-07 | 1.51E-03 | 0.19 | 0 | 0.22 | 196 | 0.04 | 0.18 | 0.12 | -0.25 | -0.36 |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Zeaxanthin | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 1.20E-06 | 1.14E-03 | NA | NA | NA | 196 | 0.17 | 0.27 | NA | 0.35 | NA |
| *crtRB1* 3'TE | Carotenoid Synthesis and Degradation | GRMZM2G152135 | Beta-carotene hydroxylase (non-heme dioxygenase type) | Total β-Xanthophylls | Additonal Markers | 10 | 136,061,719 | 136,057,100 | 136,060,219 | 4,619 | 1,500 | 4.42E-06 | 4.77E-03 | NA | NA | NA | 195 | 0.18 | 0.29 | NA | 0.4 | NA |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits with SNP S8 171705574 included as a covariate. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S9 Results from the Pathway-Level Analysis with crtRB1_3'TE as Covariate Tagging *crtRB1* (F)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1_5345354 | Carotenoid Synthesis and Degradation | GRMZM2G090051 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Xanthophylls/α-Xanthophylls | GBS | 1 | 5,345,354 | 5,380,152 | 5,382,574 | -34,798 | -37,220 | 6.42E-05 | 2.25E-02 | 0.09 | 0.32 | 0.08 | 190 | 0.18 | 0.25 | 0.1 | -0.4 | -0.22 |
| S1_5345457 | Carotenoid Synthesis and Degradation | GRMZM2G090051 | Beta-carotene hydroxylase (non-heme dioxygenase type) | β-Carotenoids/α-Carotenoids | GBS | 1 | 5,345,457 | 5,380,152 | 5,382,574 | -34,695 | -37,117 | 1.46E-04 | 4.72E-02 | 0.06 | 0.21 | 0.07 | 184 | 0.2 | 0.27 | 0.14 | -0.85 | -0.14 |
| S1_17695167 | Carotenoid Synthesis and Degradation | GRMZM2G410515 | phytoene desaturase | β-Carotenoids/α-Carotenoids | GBS | 1 | 17,695,167 | 17,660,941 | 17,667,054 | 34,226 | 28,113 | 1.42E-04 | 4.72E-02 | 0.41 | 0.42 | 0.46 | 184 | 0.2 | 0.27 | -0.07 | -0.85 | 0.08 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 1.21E-07 | 4.55E-04 | 0.31 | 0.4 | 0.28 | 192 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 8.94E-10 | 3.37E-06 | 0.32 | 0.4 | 0.28 | 190 | 0.17 | 0.36 | 0.06 | -0.25 | -0.21 |
| ss196425306 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,844,203 | 86,838,334 | 86,848,726 | 5,869 | -4,523 | 5.87E-08 | 2.20E-04 | 0.3 | 0.4 | 0.28 | 189 | 0.09 | 0.25 | -0.19 | -0.35 | 0.85 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 1.21E-07 | 4.55E-04 | 0.31 | 0.4 | 0.27 | 192 | 0.1 | 0.24 | -0.11 | -0.25 | 0.62 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | α-Carotene/Zeinoxanthin | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 8.94E-10 | 3.37E-06 | 0.32 | 0.4 | 0.27 | 190 | 0.17 | 0.36 | 0.06 | -0.25 | -0.21 |
| ss196425308 | Carotenoid Synthesis and Degradation | GRMZM2G143202 | CYP97A3, Cytochrome P450 epsilon-ring hydroxylase | Zeinoxanthin/Lutein | 55K | 1 | 86,945,134 | 86,838,334 | 86,848,726 | 106,800 | 96,408 | 5.87E-08 | 2.20E-04 | 0.3 | 0.4 | 0.27 | 189 | 0.09 | 0.25 | -0.19 | -0.35 | 0.85 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 8.13E-06 | 6.11E-03 | 0.17 | 0.33 | 0.26 | 190 | 0.12 | 0.22 | -0.2 | 0.35 | -0.47 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 4.20E-05 | 2.71E-02 | 0.17 | 0.33 | 0.26 | 189 | 0.12 | 0.21 | -0.25 | 0.4 | -0.51 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 2.43E-05 | 1.01E-02 | 0.17 | 0.33 | 0.26 | 190 | 0.18 | 0.26 | 0.08 | -0.4 | -0.18 |
| S2_44445965 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,445,965 | 44,440,299 | 44,449,237 | 5,666 | -3,272 | 4.62E-05 | 2.11E-02 | 0.17 | 0.33 | 0.26 | 184 | 0.2 | 0.28 | 0.09 | -0.85 | -0.1 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.71E-09 | 1.02E-05 | 0.11 | 0.29 | 0.09 | 190 | 0.12 | 0.3 | -0.32 | 0.35 | -0.67 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 2.34E-08 | 8.77E-05 | 0.11 | 0.29 | 0.09 | 189 | 0.12 | 0.28 | -0.41 | 0.4 | -0.74 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 8.21E-08 | 1.23E-04 | 0.11 | 0.29 | 0.09 | 190 | 0.18 | 0.31 | 0.13 | -0.4 | -0.26 |
| S2_44448432 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,432 | 44,440,299 | 44,449,237 | 8,133 | -805 | 6.76E-06 | 8.38E-03 | 0.11 | 0.29 | 0.09 | 184 | 0.2 | 0.3 | 0.12 | -0.85 | -0.12 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.71E-09 | 1.02E-05 | 0.11 | 0.29 | 0.09 | 190 | 0.12 | 0.3 | 0.32 | 0.35 | 1.22 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 2.34E-08 | 8.77E-05 | 0.11 | 0.29 | 0.09 | 189 | 0.12 | 0.28 | 0.41 | 0.4 | 1.37 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 8.21E-08 | 1.23E-04 | 0.11 | 0.29 | 0.09 | 190 | 0.18 | 0.31 | -0.13 | -0.4 | 0.41 |
| S2_44448438 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,448,438 | 44,440,299 | 44,449,237 | 8,139 | -799 | 6.76E-06 | 8.38E-03 | 0.11 | 0.29 | 0.09 | 184 | 0.2 | 0.3 | -0.12 | -0.85 | 0.16 |
| S2_44472618 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,472,618 | 44,440,299 | 44,449,237 | 32,319 | 23,381 | 3.07E-05 | 1.93E-02 | 0.12 | 0.38 | 0.15 | 190 | 0.12 | 0.21 | -0.21 | 0.35 | -0.49 |
| S2_44472618 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,472,618 | 44,440,299 | 44,449,237 | 32,319 | 23,381 | 8.92E-05 | 2.79E-02 | 0.12 | 0.38 | 0.15 | 190 | 0.18 | 0.25 | 0.08 | -0.4 | -0.18 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 3.89E-07 | 5.85E-04 | 0.13 | 0.25 | 0.12 | 190 | 0.12 | 0.25 | 0.25 | 0.35 | 0.89 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.41E-06 | 1.76E-03 | 0.13 | 0.25 | 0.12 | 189 | 0.12 | 0.24 | 0.32 | 0.4 | 1.01 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 1.76E-06 | 1.32E-03 | 0.13 | 0.25 | 0.12 | 190 | 0.18 | 0.28 | -0.1 | -0.4 | 0.31 |
| S2_44473748 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,748 | 44,440,299 | 44,449,237 | 33,449 | 24,511 | 5.10E-05 | 2.11E-02 | 0.14 | 0.25 | 0.12 | 184 | 0.2 | 0.28 | -0.1 | -0.85 | 0.13 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 3.89E-07 | 5.85E-04 | 0.13 | 0.24 | 0.12 | 190 | 0.12 | 0.25 | -0.25 | 0.35 | -0.56 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.41E-06 | 1.76E-03 | 0.13 | 0.24 | 0.12 | 189 | 0.12 | 0.24 | -0.32 | 0.4 | -0.62 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 1.76E-06 | 1.32E-03 | 0.13 | 0.24 | 0.12 | 190 | 0.18 | 0.28 | 0.1 | -0.4 | -0.21 |
| S2_44473758 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,758 | 44,440,299 | 44,449,237 | 33,459 | 24,521 | 5.10E-05 | 2.11E-02 | 0.14 | 0.24 | 0.12 | 184 | 0.2 | 0.28 | 0.1 | -0.85 | -0.1 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 3.89E-07 | 5.85E-04 | 0.13 | 0.24 | 0.12 | 190 | 0.12 | 0.25 | 0.25 | 0.35 | 0.89 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.41E-06 | 1.76E-03 | 0.13 | 0.24 | 0.12 | 189 | 0.12 | 0.24 | 0.32 | 0.4 | 1.01 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 1.76E-06 | 1.32E-03 | 0.13 | 0.24 | 0.12 | 190 | 0.18 | 0.28 | -0.1 | -0.4 | 0.31 |
| S2_44473801 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,801 | 44,440,299 | 44,449,237 | 33,502 | 24,564 | 5.10E-05 | 2.11E-02 | 0.14 | 0.24 | 0.12 | 184 | 0.2 | 0.28 | -0.1 | -0.85 | 0.13 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 4.68E-05 | 2.51E-02 | 0.17 | 0.35 | 0.16 | 190 | 0.12 | 0.2 | 0.18 | 0.35 | 0.6 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 4.51E-05 | 1.78E-02 | 0.17 | 0.35 | 0.16 | 190 | 0.18 | 0.25 | -0.08 | -0.4 | 0.23 |
| S2_44473994 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,473,994 | 44,440,299 | 44,449,237 | 33,695 | 24,757 | 6.11E-05 | 2.24E-02 | 0.17 | 0.35 | 0.16 | 184 | 0.2 | 0.28 | -0.09 | -0.85 | 0.11 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 1.48E-06 | 1.53E-03 | 0.14 | 0.29 | 0.13 | 190 | 0.12 | 0.24 | -0.23 | 0.35 | -0.53 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 5.63E-06 | 6.03E-03 | 0.14 | 0.29 | 0.13 | 189 | 0.12 | 0.23 | -0.3 | 0.4 | -0.59 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 2.48E-06 | 1.70E-03 | 0.14 | 0.29 | 0.13 | 190 | 0.18 | 0.28 | 0.1 | -0.4 | -0.21 |
| S2_44474139 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,139 | 44,440,299 | 44,449,237 | 33,840 | 24,902 | 5.82E-05 | 2.24E-02 | 0.14 | 0.29 | 0.13 | 184 | 0.2 | 0.28 | 0.09 | -0.85 | -0.1 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Zeaxanthin | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.63E-06 | 1.53E-03 | 0.21 | 0.38 | 0.28 | 190 | 0.12 | 0.24 | 0.2 | 0.35 | 0.68 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | Total β-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 1.14E-05 | 8.78E-03 | 0.21 | 0.38 | 0.28 | 189 | 0.12 | 0.22 | 0.25 | 0.4 | 0.74 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Xanthophylls/α-Xanthophylls | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 6.66E-06 | 4.00E-03 | 0.21 | 0.38 | 0.28 | 190 | 0.18 | 0.27 | -0.08 | -0.4 | 0.24 |
| S2_44474308 | Carotenoid Synthesis and Degradation | GRMZM2G127139 | zeaxanthin epoxidase | β-Carotenoids/α-Carotenoids | GBS | 2 | 44,474,308 | 44,440,299 | 44,449,237 | 34,009 | 25,071 | 2.82E-05 | 1.61E-02 | 0.21 | 0.38 | 0.28 | 184 | 0.2 | 0.28 | -0.09 | -0.85 | 0.11 |
| S5_1321833 | Carotenoid Synthesis and Degradation | GRMZM2G144273 | carotenoid isomerase | Zeinoxanthin/Lutein | GBS | 5 | 1,321,833 | 1,333,304 | 1,341,577 | -11,471 | -19,744 | 1.45E-05 | 3.62E-02 | 0.19 | 0.06 | 0.21 | 189 | 0.09 | 0.19 | 0.21 | -0.35 | -0.42 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 6.49E-06 | 5.42E-03 | 0.13 | 0.17 | 0.17 | 190 | 0.12 | 0.22 | -0.22 | 0.35 | -0.51 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 1.17E-05 | 8.78E-03 | 0.13 | 0.17 | 0.17 | 189 | 0.12 | 0.22 | -0.3 | 0.4 | -0.58 |
| S6_146970803 | Prenyl Group Synthesis | GRMZM2G133082 | isopentenyl pyrophosphate isomerase | Zeaxanthin | GBS | 6 | 146,970,803 | 147,131,116 | 147,136,679 | -160,313 | -165,876 | 5.37E-05 | 2.69E-02 | 0.27 | 0.07 | 0.33 | 190 | 0.12 | 0.2 | -0.15 | 0.35 | -0.37 |
| S6_146970803 | Prenyl Group Synthesis | GRMZM2G133082 | isopentenyl pyrophosphate isomerase | β-Xanthophylls/α-Xanthophylls | GBS | 6 | 146,970,803 | 147,131,116 | 147,136,679 | -160,313 | -165,876 | 8.72E-05 | 2.79E-02 | 0.26 | 0.07 | 0.33 | 190 | 0.18 | 0.25 | 0.06 | -0.4 | -0.14 |
| S6_146970803 | Prenyl Group Synthesis | GRMZM2G133082 | isopentenyl pyrophosphate isomerase | β-Carotenoids/α-Carotenoids | GBS | 6 | 146,970,803 | 147,131,116 | 147,136,679 | -160,313 | -165,876 | 6.33E-05 | 2.24E-02 | 0.25 | 0.07 | 0.33 | 184 | 0.2 | 0.28 | 0.07 | -0.85 | -0.08 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeaxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 8.21E-05 | 3.85E-02 | 0.16 | 0.1 | 0.16 | 190 | 0.12 | 0.2 | -0.18 | 0.35 | -0.43 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 1.77E-07 | 1.34E-03 | 0.16 | 0.1 | 0.16 | 193 | 0.13 | 0.27 | -0.04 | 0.1 | -0.33 |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 5.39E-05 | 3.11E-02 | 0.16 | 0.1 | 0.16 | 189 | 0.12 | 0.2 | -0.25 | 0.4 | -0.51 |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 4.06E-05 | 2.35E-02 | NA | NA | NA | 196 | 0.17 | 0.34 | NA | 0.35 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 4.34E-05 | 2.71E-02 | NA | NA | NA | 195 | 0.18 | 0.38 | NA | 0.4 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 2.43E-13 | 9.12E-10 | NA | NA | NA | 196 | 0.04 | 0.24 | NA | -0.4 | NA |
| *lcyE* 5′TE | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | Additonal Markers | 8 | 138,882,481 | 138,882,594 | 138,889,812 | -114 | -7,332 | 1.35E-13 | 1.01E-09 | NA | NA | NA | 189 | 0.01 | 0.28 | NA | -0.85 | NA |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 8.52E-06 | 4.00E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.27 | -0.08 | -0.4 | 0.22 |
| S8_138882711 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.86E-05 | 1.38E-02 | 0.28 | 0.41 | 0.3 | 184 | 0.2 | 0.29 | -0.08 | -0.85 | 0.11 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.54E-05 | 2.92E-02 | 0.36 | 0.48 | 0.34 | 194 | 0.12 | 0.21 | 0.88 | 0.8 | 1.2 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 1.43E-05 | 9.78E-03 | 0.35 | 0.48 | 0.34 | 190 | 0.12 | 0.21 | -0.16 | 0.35 | -0.4 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 9.27E-06 | 8.69E-03 | 0.35 | 0.48 | 0.34 | 189 | 0.12 | 0.22 | -0.23 | 0.4 | -0.48 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 6.32E-06 | 1.20E-02 | 0.36 | 0.48 | 0.34 | 194 | 0.11 | 0.21 | 0.59 | 0.7 | 0.94 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 6.86E-09 | 1.72E-05 | 0.35 | 0.48 | 0.34 | 190 | 0.18 | 0.34 | 0.1 | -0.4 | -0.21 |
| ss196504160 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 55K | 8 | 138,882,711 | 138,882,594 | 138,889,812 | 117 | -7,101 | 7.10E-09 | 2.64E-05 | 0.36 | 0.48 | 0.34 | 184 | 0.2 | 0.37 | 0.11 | -0.85 | -0.12 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 8.52E-06 | 4.00E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.27 | -0.08 | -0.4 | 0.22 |
| S8_138882747 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,747 | 138,882,594 | 138,889,812 | 153 | -7,065 | 1.86E-05 | 1.38E-02 | 0.28 | 0.41 | 0.3 | 184 | 0.2 | 0.29 | -0.08 | -0.85 | 0.11 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 8.52E-06 | 4.00E-03 | 0.28 | 0.41 | 0.3 | 190 | 0.18 | 0.27 | -0.08 | -0.4 | 0.22 |
| S8_138882751 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,751 | 138,882,594 | 138,889,812 | 157 | -7,061 | 1.86E-05 | 1.38E-02 | 0.28 | 0.41 | 0.3 | 184 | 0.2 | 0.29 | -0.08 | -0.85 | 0.11 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 7.06E-06 | 4.00E-03 | 0.31 | 0.21 | 0.36 | 190 | 0.18 | 0.27 | -0.08 | -0.4 | 0.22 |
| S8_138882798 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,798 | 138,882,594 | 138,889,812 | 204 | -7,014 | 1.13E-05 | 1.20E-02 | 0.31 | 0.21 | 0.36 | 184 | 0.2 | 0.29 | -0.09 | -0.85 | 0.11 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 8.91E-06 | 2.25E-02 | 0.43 | 0.12 | 0.44 | 194 | 0.12 | 0.22 | -0.85 | 0.8 | -0.9 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 4.25E-06 | 1.07E-02 | 0.43 | 0.12 | 0.44 | 194 | 0.11 | 0.21 | -0.56 | 0.7 | -0.69 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 4.03E-07 | 4.33E-04 | 0.43 | 0.12 | 0.44 | 190 | 0.18 | 0.3 | -0.08 | -0.4 | 0.24 |
| S8_138882897 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,882,897 | 138,882,594 | 138,889,812 | 303 | -6,915 | 1.28E-07 | 3.18E-04 | 0.43 | 0.12 | 0.44 | 184 | 0.2 | 0.34 | -0.1 | -0.85 | 0.13 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 6.58E-05 | 2.25E-02 | 0.39 | 0.18 | 0.48 | 190 | 0.18 | 0.25 | 0.07 | -0.4 | -0.15 |
| S8_138883026 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,026 | 138,882,594 | 138,889,812 | 432 | -6,786 | 2.77E-05 | 1.61E-02 | 0.4 | 0.18 | 0.48 | 184 | 0.2 | 0.28 | 0.08 | -0.85 | -0.09 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 6.58E-05 | 2.25E-02 | 0.39 | 0.18 | 0.48 | 190 | 0.18 | 0.25 | -0.07 | -0.4 | 0.18 |
| S8_138883056 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,883,056 | 138,882,594 | 138,889,812 | 462 | -6,756 | 2.77E-05 | 1.61E-02 | 0.4 | 0.18 | 0.48 | 184 | 0.2 | 0.28 | -0.08 | -0.85 | 0.1 |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.08E-09 | 8.17E-06 | NA | NA | NA | 200 | 0.12 | 0.49 | NA | 0.8 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Zeaxanthin | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.02E-06 | 1.28E-03 | NA | NA | NA | 196 | 0.17 | 0.34 | NA | 0.35 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total β-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 8.01E-07 | 1.76E-03 | NA | NA | NA | 195 | 0.18 | 0.39 | NA | 0.4 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.39E-10 | 1.05E-06 | NA | NA | NA | 200 | 0.09 | 0.42 | NA | 0.7 | NA |
| *lcyE* SNP216 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | Additonal Markers | 8 | 138,883,206 | 138,882,594 | 138,889,812 | 612 | -6,606 | 1.86E-14 | 1.40E-10 | NA | NA | NA | 196 | 0.04 | 0.25 | NA | -0.4 | NA |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 2.40E-05 | 1.01E-02 | 0.34 | 0.05 | 0.38 | 190 | 0.18 | 0.26 | 0.07 | -0.4 | -0.16 |
| PZB00665.1 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | 4K | 8 | 138,886,137 | 138,882,594 | 138,889,812 | 3,543 | -3,675 | 5.06E-05 | 2.11E-02 | 0.35 | 0.05 | 0.38 | 184 | 0.2 | 0.28 | 0.08 | -0.85 | -0.09 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Lutein | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.70E-06 | 1.40E-02 | 0.47 | 0.19 | 0.42 | 194 | 0.12 | 0.23 | -0.91 | 0.8 | -0.95 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | Total α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.32E-06 | 1.07E-02 | 0.47 | 0.19 | 0.42 | 194 | 0.11 | 0.21 | -0.59 | 0.7 | -0.72 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Xanthophylls/α-Xanthophylls | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 1.06E-07 | 1.33E-04 | 0.47 | 0.19 | 0.42 | 190 | 0.18 | 0.31 | -0.09 | -0.4 | 0.27 |
| S8_138888278 | Carotenoid Synthesis and Degradation | GRMZM2G012966 | lycopene epsilon-cyclase | β-Carotenoids/α-Carotenoids | GBS | 8 | 138,888,278 | 138,882,594 | 138,889,812 | 5,684 | -1,534 | 3.97E-07 | 7.38E-04 | 0.47 | 0.19 | 0.42 | 184 | 0.2 | 0.32 | -0.1 | -0.85 | 0.13 |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits the peak marker tagging the GWAS signal from *crtRB1* included as a covariate. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S9 Results from the Pathway-Level Analysis with Covariates Tagging *lut1*, *zep1*, *lcyE*, and *crtRB1* (G)**

| SNP ID | *a priori* candidate gene pathway | RefGen_v2 Gene ID | Annotated Gene Function | Trait | SNP Source | Chromosome | Position | Gene ORF start | Gene ORF End | Distance from Gene ORF Start | Distance from Gene ORF Finish | *P*-value | FDR Adjusted *P*-value | Minor Allele Frequency (MAF) | MAF Tropical (8% of 201 Lines) | MAF Temperate (92% of 201 Lines) | Sample Size | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Zeaxanthin | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 4.72E-06 | 2.93E-02 | 0.13 | 0.17 | 0.17 | 174 | 0.42 | 0.5 | -0.19 | 0.35 | -0.45 |
| S5_216074707 | Carotenoid Synthesis and Degradation | GRMZM5G837869 | CYP97A3, Cytochrome P450 beta-ring hydroxylase | Total β-Xanthophylls | GBS | 5 | 216,074,707 | 215,827,224 | 215,831,730 | 247,483 | 242,977 | 9.94E-06 | 3.74E-02 | 0.13 | 0.17 | 0.17 | 173 | 0.41 | 0.49 | -0.25 | 0.4 | -0.51 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Zeaxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 7.77E-06 | 2.93E-02 | 0.17 | 0.1 | 0.16 | 174 | 0.42 | 0.5 | -0.17 | 0.35 | -0.41 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | β-Cryptoxanthin | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 4.86E-08 | 3.70E-04 | 0.16 | 0.1 | 0.16 | 177 | 0.24 | 0.39 | -0.04 | 0.1 | -0.33 |
| S7_13843351 | Prenyl Group Synthesis | GRMZM2G493395 | 1-deoxy-D-xylulose 5-phosphate synthase | Total β-Xanthophylls | GBS | 7 | 13,843,351 | 14,077,852 | 14,081,075 | -234,501 | -237,724 | 2.44E-06 | 1.83E-02 | 0.17 | 0.1 | 0.16 | 173 | 0.41 | 0.5 | -0.25 | 0.4 | -0.51 |

Statistically significant results from a pathway-level analysis of 58 *a priori* candidate genes from the carotenoid biosynthesis, carotenoid degradation, and isoprenoid biosynthetic pathways on 24 grain carotenoid traits with markers tagging the signals at *lut1*, *zep1*, *lcyE*, and *crtRB1* included as covariates. All markers (Column A) proximal to *a priori* candidate genes (Column B) found to be significantly associated with the indicated trait (Column E) at 5% FDR are shown.

**Table S10 Comparison of Genomic Prediction Methods for 24 Grain Carotenoid Traits using Three Marker Sets as Predictors**

| | | | Carotenoid QTL-Targeted Prediction | | | Pathway-Level Prediction | | | Genome-Wide Prediction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Trait** | **Heritability** | **RR-BLUP[a]** | **LASSO[b]** | **eNet[c]** | **RR-BLUP** | **LASSO** | **eNet** | **RR-BLUP** | **LASSO** | **eNet** |
| **15 priority traits** | Lutein | 0.94 | 0.582 (0.039) | 0.534 (0.091) | 0.516 (0.117) | 0.461 (0.185) | 0.514 (0.163) | 0.521 (0.160) | 0.509 (0.204) | 0.476 (0.157) | 0.471 (0.156) |
| | Zeinoxanthin | 0.88 | 0.443 (0.166) | 0.451 (0.099) | 0.488 (0.051) | 0.427 (0.136) | 0.512 (0.070) | 0.520 (0.075) | 0.442 (0.172) | 0.549 (0.085) | 0.560 (0.082) |
| | α-Carotene | 0.25 | 0.65 (0.338) | 0.212 (0.206)[d] | 0.187 (0.198) | 0.676 (0.238) | 0.111 (0.582)[d] | 0.030 (0.025)[d] | 0.769 (0.282) | 0.500 (0.289) | 0.374 (0.200) |
| | α-Carotene/Zeinoxanthin | 0.9 | 0.443 (0.155) | 0.576 (0.153) | 0.561 (0.13) | 0.462 (0.118) | 0.470 (0.199) | 0.451 (0.199) | 0.411 (0.110) | 0.589 (0.200) | 0.590 (0.193) |
| | Zeinoxanthin/Lutein | 0.89 | 0.467 (0.11) | 0.483 (0.121) | 0.487 (0.121) | 0.393 (0.233) | 0.457 (0.183) | 0.502 (0.187) | 0.387 (0.243) | 0.363 (0.266) | 0.350 (0.241) |
| | Zeaxanthin | 0.94 | 0.566 (0.076) | 0.619 (0.078) | 0.611 (0.079) | 0.433 (0.223) | 0.516 (0.127) | 0.544 (0.134) | 0.346 (0.278) | 0.519 (0.132) | 0.512 (0.170) |
| | β-Cryptoxanthin | 0.95 | 0.49 (0.137) | 0.3 (0.107) | 0.316 (0.132) | 0.501 (0.190) | 0.441 (0.194) | 0.434 (0.190) | 0.464 (0.144) | 0.530 (0.104) | 0.478 (0.111) |
| | β-Carotene | 0.82 | 0.282 (0.205) | 0.168 (0.191) | 0.169 (0.167) | 0.336 (0.127) | 0.159 (0.180) | 0.166 (0.167) | 0.254 (0.123) | 0.152 (0.101) | 0.185 (0.062)[d] |
| | β-Cryptoxanthin/Zeaxanthin | 0.9 | 0.372 (0.188) | 0.358 (0.134) | 0.377 (0.119) | 0.388 (0.184) | 0.339 (0.074) | 0.314 (0.155) | 0.384 (0.185) | 0.215 (0.193) | 0.243 (0.127)[d] |
| | β-Carotene/β-Cryptoxanthin | 0.89 | 0.351 (0.098) | 0.312 (0.101) | 0.317 (0.126) | 0.399 (0.110) | 0.434 (0.095) | 0.444 (0.100) | 0.402 (0.065) | 0.455 (0.116) | 0.444 (0.064) |
| | Total Carotenoids | 0.91 | 0.367 (0.151) | 0.228 (0.015)[d] | 0.19 (0.072)[d] | 0.267 (0.208) | 0.336 (0.186) | 0.358 (0.152) | 0.191 (0.228) | 0.065 (0.170)[d] | 0.084 (0.160)[d] |
| | Acyclic and Monocyclic Carotenes | 0.57 | 0.342 (0.199) | 0.242 (0.247) | 0.224 (0.254) | 0.456 (0.153) | 0.328 (0.395) | 0.331 (0.397) | 0.407 (0.126) | 0.384 (0.173) | 0.389 (0.175) |
| | β-Xanthophylls/α-Xanthophylls | 0.83 | 0.716 (0.073) | 0.717 (0.056) | 0.719 (0.042) | 0.663 (0.166) | 0.774 (0.101) | 0.779 (0.108) | 0.587 (0.237) | 0.732 (0.187) | 0.736 (0.195) |
| | Provitamin A | 0.8 | 0.325 (0.158) | 0.352 (0.182) | 0.335 (0.062)[d] | 0.434 (0.142) | 0.293 (0.161) | 0.292 (0.093) | 0.390 (0.147) | 0.328 (0.116)[d] | 0.330 (0.115)[d] |
| | β-Carotenoids/α-Carotenoids | 0.98 | 0.566 (0.076) | 0.615 (0.056) | 0.617 (0.058) | 0.535 (0.161) | 0.586 (0.176) | 0.598 (0.152) | 0.555 (0.192) | 0.610 (0.101) | 0.605 (0.107) |
| **9 additional traits** | ζ-Carotene | 0.45 | 0.346 (0.073) | 0.409 (0.2) | 0.385 (0.241) | 0.457 (0.247) | 0.431 (0.111) | 0.447 (0.123) | 0.465 (0.205) | 0.469 (0.124) | 0.431 (0.111) |
| | Phytofluene | 0.65 | 0.358 (0.273) | 0.283 (0.16) | 0.262 (0.161) | 0.549 (0.150) | 0.499 (0.185) | 0.494 (0.182) | 0.497 (0.149) | 0.397 (0.086) | 0.499 (0.185) |
| | Tetrahydrolycopene | 0.6 | 0.369 (0.122) | 0.197 (0.096) | 0.208 (0.102) | 0.522 (0.148) | 0.451 (0.154) | 0.463 (0.162) | 0.541 (0.151) | 0.682 (0.132) | 0.451 (0.154) |
| | Total β-Xanthophylls | 0.96 | 0.41 (0.135) | 0.446 (0.086) | 0.449 (0.097) | 0.396 (0.251) | 0.554 (0.158) | 0.559 (0.188) | 0.313 (0.287) | 0.428 (0.204) | 0.554 (0.158) |
| | Total α-Xanthophylls | 0.91 | 0.546 (0.09) | 0.51 (0.102) | 0.503 (0.107) | 0.400 (0.210) | 0.540 (0.119) | 0.542 (0.120) | 0.479 (0.226) | 0.455 (0.159) | 0.540 (0.119) |
| | Provitamin A/Total Carotenoids | 0.86 | 0.335 (0.224) | 0.281 (0.272) | 0.275 (0.271) | 0.286 (0.124) | -0.101 (0.17)[d] | -0.031 (0.15)[d] | 0.321 (0.089) | -0.054 (0.119)[d] | 0.065 (0.259)[d] |
| | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 0.93 | 0.308 (0.221) | 0.428 (0.12) | 0.411 (0.146) | 0.251 (0.182) | 0.361 (0.118) | 0.355 (0.111) | 0.290 (0.148) | 0.396 (0.095) | 0.361 (0.118) |
| | Acyclic Carotenes/Cyclic Carotenes | 0.74 | 0.149 (0.106) | 0.142 (0.09)[d] | 0.221 (0.083)[d] | 0.577 (0.155) | 0.729 (0.150) | 0.734 (0.156) | 0.565 (0.219) | 0.743 (0.198) | 0.729 (0.150) |
| | Total Carotenes/Total Xanthophylls | 0.62 | 0.286 (0.367) | 0.378 (0.28) | 0.376 (0.273) | 0.351 (0.088) | 0.327 (0.098)[d] | 0.310 (0.093)[d] | 0.294 (0.059) | 0.291 (0.121) | 0.327 (0.098)[d] |

The three marker sets tested were carotenoid quantitative trait loci (QTL)-targeted prediction (the 944 SNP markers and 7 indels within ± 250 kb of 8 *a priori* candidate genes), pathway-level prediction (the 7,408 SNP markers and 7 indels within ± 250 kb of 58 *a priori* candidate genes,) and genome-wide prediction (all 284,180 SNP markers and 7 indels used in our genome-wide association studies). Standardized average correlations resulting from the 5-fold cross-validation are reported, with standardized standard deviations in parentheses. Standardization was conducted as follows: Raw correlations were divided by the square root of a trait's broad-sense heritability to obtain standardized average correlations, also called prediction accuracy. Raw standard deviations were squared to obtain variance, divided by heritability, and the square root was taken to obtain standardized standard deviation.

[a]RR-BLUP, Ridge Regression Best Linear Unbiased Prediction

[b]LASSO, Least Absolute Shrinkage and Selection Operator

[c]eNet, Elastic net

[d]indicates that no markers were selected in one or two of the five folds, or in three of the five folds in one case (α-Carotene, Pathway-Level Prediction, eNet)

**Table S11 Prediction Accuracies for 24 Grain Carotenoid Traits using the Carotenoid QTL-Targeted Prediction Marker Set Relative to Random Marker Sets**

| | | Mean Prediction Accuracy | | | Fold Difference in Prediction Accuracy | |
|---|---|---|---|---|---|---|
| | **Trait** | Carotenoid QTL-Targeted Prediction **(CQTP)** | Random Candidate Regions **(Candidate)** | Random Genomic Regions **(Genomic)** | **CQTP: Candidate** | **CQTP: Genomic** |
| **15 priority traits** | Lutein | 0.544 | 0.205 | 0.210 | 2.649 | 2.594 |
| | Zeinoxanthin | 0.461 | 0.195 | 0.178 | 2.361 | 2.587 |
| | α-Carotene | 0.350 | 0.176 | 0.174 | 1.985 | 2.006 |
| | α-Carotene/Zeinoxanthin | 0.527 | 0.221 | 0.196 | 2.388 | 2.687 |
| | Zeinoxanthin/Lutein | 0.479 | 0.192 | 0.156 | 2.497 | 3.076 |
| | Zeaxanthin | 0.599 | 0.132 | 0.133 | 4.527 | 4.492 |
| | β-Cryptoxanthin | 0.369 | 0.189 | 0.195 | 1.954 | 1.889 |
| | β-Carotene | 0.206 | 0.108 | 0.131 | 1.918 | 1.569 |
| | β-Cryptoxanthin/Zeaxanthin | 0.369 | 0.155 | 0.166 | 2.375 | 2.221 |
| | β-Carotene/β-Cryptoxanthin | 0.327 | 0.139 | 0.117 | 2.347 | 2.796 |
| | Total Carotenoids | 0.262 | 0.111 | 0.080 | 2.362 | 3.255 |
| | Acyclic and Monocyclic Carotenes | 0.269 | 0.177 | 0.153 | 1.518 | 1.756 |
| | β-Xanthophylls/α-Xanthophylls | 0.717 | 0.189 | 0.209 | 3.796 | 3.437 |
| | Provitamin A | 0.337 | 0.175 | 0.171 | 1.925 | 1.969 |
| | β-Carotenoids/α-Carotenoids | 0.599 | 0.209 | 0.217 | 2.874 | 2.764 |
| **9 additional traits** | ζ-Carotene | 0.380 | 0.124 | 0.107 | 3.071 | 3.558 |
| | Phytofluene | 0.301 | 0.135 | 0.127 | 2.231 | 2.375 |
| | Tetrahydrolycopene | 0.258 | 0.156 | 0.157 | 1.656 | 1.648 |
| | Total β-Xanthophylls | 0.435 | 0.092 | 0.109 | 4.720 | 3.981 |
| | Total α-Xanthophylls | 0.520 | 0.156 | 0.191 | 3.324 | 2.725 |
| | Provitamin A/Total Carotenoids | 0.297 | 0.149 | 0.136 | 1.993 | 2.190 |
| | β-Carotene/(β-Cryptoxanthin+Zeaxanthin) | 0.382 | 0.148 | 0.120 | 2.575 | 3.194 |
| | Acyclic Carotenes/Cyclic Carotenes | 0.171 | 0.046 | 0.066 | 3.716 | 2.586 |
| | Total Carotenes/Total Xanthophylls | 0.347 | 0.081 | 0.069 | 4.256 | 4.997 |

The three marker sets tested were the carotenoid quantitative trait loci (QTL)-targeted prediction set (the 944 SNP markers and 7 indels within ± 250 kb of 8 *a priori* candidate genes), random candidate gene-targeted regions (markers within ± 250 kb of 8 other candidate genes in the pathway-level prediction set), and 8 random 500 kb genomic regions (selected from the markers used in our genome-wide association studies that did not overlap with the carotenoid QTL-targeted prediction set). Average raw correlations resulting from the 5-fold cross-validation were divided by the square root of a trait's broad-sense heritability to obtain prediction accuracies, which are reported as an average across the three genomic prediction methods tested: ridge-regression best linear unbiased prediction (RR-BLUP), least absolute shrinkage and selection operator (LASSO), and elastic net (eNET). For the random candidate region and random genomic region analyses, marker selection was conducted over 100 iterations with replacement, and prediction accuracies were averaged across these iterations. R scripts for these analyses are available upon request.