**Genome-Wide Association Study Identifies QTL and Candidate Genes Governing Seed Mucilage Content and Hull Content in Flax (*Linum usitatissimum* L.)**

Braulio J. Soto-Cerda1\*, Sylvie Cloutier2, Rocío Quian1, Humberto A. Gajardo1, Marcos Olivos1,   
Frank M. You2,3

1Agriaquaculture Nutritional Genomic Center (CGNA), Las Heras 350, 4781158, Temuco, Chile; [rocio.quian@cgna.cl](mailto:rocio.quian@cgna.cl) (R.Q.); [humberto.gajardo@cgna.cl](mailto:humberto.gajardo@cgna.cl) (H.G.); [marcos.olivos@cgna.cl](mailto:marcos.olivos@cgna.cl) (M.O.)2Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, Ottawa, ON K1A 0C6, Canada; [sylvie.j.cloutier@agr.gc.ca](mailto:sylvie.j.cloutier@agr.gc.ca) (S.C.)

3Morden Research and Development Centre, Agriculture and Agri-Food Canada, Morden, MB R6M 1Y5, Canada; [frank.you@agr.gc.ca](mailto:frank.you@agr.gc.ca) (F.M.Y.)

\*Correspondence: [braulio.soto@cgna.cl](mailto:braulio.soto@cgna.cl) (B.J.SC); Tel 56-45-2740412

**Table S1**. Descriptive statistics and normality test for mucilage content and hull content

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Trait** | **Mean** | **Std. Dev** | **Median** | **Min** | **Max** | **Skew** | **Statistic** | **P** | **Normality** |
| MC\_CAR2014 | 58.67 | 13.33 | 58.46 | 23.52 | 103.57 | -0.013 | 0.9951 | 0.854 | Yes |
| MC\_HU2015 | 55.04 | 12.56 | 54.89 | 18.88 | 91.90 | 0.008 | 0.9972 | 0.989 | Yes |
| HC\_CAR2014 | 42.89 | 2.45 | 42.98 | 35.56 | 48.59 | -0.300 | 0.9920 | 0.462 | Yes |
| HC\_HU2015 | 43.01 | 2.57 | 43.21 | 35.73 | 48.59 | -0.338 | 0.9858 | 0.082 | Yes |

MC\_2014 and MC\_2015 are the mucilage contents observed in Vilcún location 2014 and Huichahue location 2015. HC\_2014 and HC2015 are the hull contents observed in Vilcún location 2014 and Huichahue location 2015.

Figure S1.tiff

**Figure S1.** Normal quantile-quantile (Q-Q) plots of phenotypic data for mucilage content (MC) and hull content (HC) across two environments. CAR2014 = Vilcún location 2014, HU2015= Huichahue location 2015.

**Boxplot MC_HC.tiff**

**Figure S2**. Box plots of phenotypic differences between flax morphotypes (fiber and oil) and seed coat color (yellow and brown). (**a**) mucilage content. (**b**) hull content.

**Figure S3.tiff**

**Figure S3**. Linkage disequilibrium (LD) decay of *r*2 values (red line), against physical distance (bp) across 15 chromosomes of *Linum ussitatissum*. Dashed blue line indicates the cutoff value (*r*2 = 0.1) used to determine LD blocks.

**QQ.tiff**

**Figure S4**. Quantile-quantile (Q-Q) plots of observed P values (y-axis) plotted against expected P values (x-axis) for mucilage content (MC) and hull content (HC) across two environments (CAR2014 = Vilcún location 2014, HU2015 = Huichahue location 2015). (**a**) General linear model (GLM) using the Q matrix as covariate for controlling population structure and cryptic relatedness. (**b**) Mixed linear model (MLM) using the kinship matrix as covariate for controlling population structure and cryptic relatedness.

**Figure S5.tiff**

**Figure S5**. Box plots illustrating the phenotypic differences between flaxseed accessions carrying different alleles of the SNPs associated with mucilage content and hull content across two environments. CAR2014 = Vilcún location 2014, HU2015 = Huichahue location 2015. Different letters indicate significant statistical differences according to the Kruskal-Wallis non-parametric test (*P* < 0.05).

**Table S2**. Peak SNPs and candidate genes for mucilage content and hull content

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| MC | 2 | Lu2-22298066 | Lus10014559 | Oleosin 21.2 kda-related |
|  |  |  | Lus10014558 | Compass component swd2 |
|  |  |  | Lus10014557 | Myb-like dna-binding protein myb |
|  |  |  | Lus10014555 | NADH:ubiquinone reductase |
|  |  |  | Lus10014554 | tRNA (adenine57-n1/adenine58-n1)-methyltransferase |
|  |  |  | Lus10014553 | rna helicase |
|  |  |  | Lus10014552 | DNA cytosine-5- -methyltransferase 3-related |
|  |  |  | Lus10014551 | ATP-dependent rna helicase ddx1 |
|  |  |  | Lus10014550 | Acid phosphatase/vanadium-dependent haloperoxidase-related protein |
|  |  |  | Lus10014549 | Protein of unknown function (duf1421) |
|  |  |  | Lus10014548 | RNA-binding protein 26 (rbm26) |
|  |  |  | Lus10014547 | RNA-binding protein 26 (rbm26) |
|  |  |  | Lus10014546 | PWWP domain-containing protein |
|  |  |  | Lus10014545 | Adenine nucleotide alpha hydrolases-like superfamily protein-related |
|  |  |  | Lus10014543 | proteasome assembly chaperone 3 |
|  |  |  | Lus10014542 | Serine/threonine-protein kinase osr1/stk39 |
|  |  |  | Lus10014541 | Protein of unknown function (duf1645) |
|  |  |  | Lus10014560 | Denticleless (dtl, cdt2, dcaf2) |
|  |  |  | Lus10014561 | Gglycosylphosphatidylinositol transamidase |
|  |  |  | Lus10014562 | RNA-binding protein-related |
|  |  |  | Lus10014563 | Phenylalanine--trna ligase alpha subunit |
|  |  |  | Lus10014564 | GPI inositol-deacylase |
|  |  |  | Lus10014565 | Peptidyl-prolyl isomerase e |
|  |  |  | Lus10014567 | Mitochondrial transcription termination factor family protein |
|  |  |  | Lus10014568 | C3H4 type zinc finger protein-related |
|  |  |  | Lus10014569 | MYB transcription factor |
|  |  |  | Lus10014570 | Zinc finger protein-related |
|  |  |  | Lus10014571 | TPX2 (targeting protein for xklp2) protein family |
|  |  |  | Lus10014572 | Cystinosin |
|  |  |  | Lus10014573 | Succinate dehydrogenase (ubiquinone) iron-sulfur subunit |
|  |  |  | Lus10014574 | Cleavage site for pathogenic type iii effector avirulence factor avr |
|  |  |  | Lus10014575 | Plastocyanin-like domain |
|  |  |  | Lus10014576 | 15-cis-phytoene synthase |
|  |  |  | Lus10014577 | Pentatricopeptide repeat repeat-containing protein |
|  |  |  | Lus10014578 | AGAMOUS-like mads-box protein agl80-related |
|  |  |  | Lus10014579 | Mitochondrial inner membrane protease atp23 |
|  |  |  | Lus10014580 | Sieve element occlusion n-terminus |
|  |  |  | Lus10014581 | 20s proteasome subunit beta 2 |
|  |  |  | Lus10014582 | Leucine-rich repeat-containing protein |
|  |  |  | Lus10014583 | Disease resistance protein-related |
|  | 3 | Lu3-25559600 | Lus10009300 | Brefeldin A-inhibited guanine nucleotide-exchange protein |
|  |  |  | Lus10009301 | AT-HOOK motif nuclear localized protein 18-related |
|  |  |  | Lus10009302 | 4-hydroxy-tetrahydrodipicolinate synthase |
|  |  |  | Lus10009303 | Actin filament-coating protein tropomyosin |
|  |  |  | Lus10009305 | Kinase A-anchor protein Neurobeachin and related BEACH and WD40 repeat proteins |
|  |  |  | Lus10009307 | Protein T01H10.8 |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| MC | 3 | Lu3-25559600 | Lus10009308 | Carboxylesterase 8-related |
|  |  |  | Lus10009309 | Poly A polymerase CID PAP -related |
|  |  |  | Lus10009310 | Poly A polymerase CID PAP -related |
|  |  |  | Lus10009311 | POLYGALACTURONATE 4-ALPHA-GALACTURONOSYLTRANSFERASE-related |
|  |  |  | Lus10009312 | Acyltransferase |
|  |  |  | Lus10009313 | Subtilase family protein-related |
|  |  |  | Lus10009314 | Predicted transporter |
|  |  |  | Lus10009315 | Solute carrier family 35 |
|  |  |  | Lus10009316 | Uncharacterized conserved protein, contains SPRY domain |
|  |  |  | Lus10009299 | PPR repeat (PPR) |
|  |  |  | Lus10009298 | LOB domain-containing protein 19-related |
|  |  |  | Lus10009296 | F13O11.17 PROTEIN |
|  |  |  | Lus10009295 | Protein cornichon homolog 3-related |
|  |  |  | Lus10009294 | ATP-dependent DNA helicase 2 subunit 2 |
|  |  |  | Lus10009293 | Syntaxin-binding protein 1 |
|  |  |  | Lus10009292 | BTB/POZ domain |
|  |  |  | Lus10009291 | Protein S-acyltransferase 13-related |
|  |  |  | Lus10009290 | PPR repeat |
|  |  |  | Lus10009289 | 2'-phosphotransferase [EC:2.7.1.160] |
|  |  |  | Lus10009288 | UDP-glucuronate 4-epimerase 4 |
|  |  |  | Lus10009287 | Pectinesterase/pectinesterase inhibitor 36-related |
|  |  |  | Lus10009286 | Auxin-regulated protein-related |
|  |  |  | Lus10009285 | Ggolgi SNAP receptor complex member 1 |
|  |  |  | Lus10009284 | Plant protein of unknown function (DUF641) |
|  |  |  | Lus10009283 | PLATZ transcription factor |
|  |  |  | Lus10009282 | Hydrophobic seed protein |
|  | 3 | Lu3-26033342 | Lus10007093 | Phosphoglycerate mutase-like protein |
|  |  |  | Lus10007094 | N-(long-chain-acyl)ethanolamine deacylase |
|  |  |  | Lus10007095 | N-(long-chain-acyl)ethanolamine deacylase |
|  |  |  | Lus10007096 | FALZ-related bromodomain-containing proteins |
|  |  |  | Lus10007098 | ZINC transport protein ZNTB |
|  |  |  | Lus10007099 | tRNA-nucleotidyltransferase/poly a polymerase family member |
|  |  |  | Lus10007100 | MADS Box protein |
|  |  |  | Lus10007101 | Basic helix-loop-helix (BHLH) DNA  binding superfamily protein-related |
|  |  |  | Lus10007102 | Pathogenesis-related protein 1 |
|  |  |  | Lus10007104 | K(+) efflux antiporter 3, chloroplastic |
|  |  |  | Lus10007105 | Peptide-methionine (R)-S-oxide reductase |
|  |  |  | Lus10007106 | Macrophage erythroblast attacher-related |
|  |  |  | Lus10007108 | Protein trichome birefringence-like 12 |
|  |  |  | Lus10007109 | Arabidopsis protein of unknown function (DUF241) |
|  |  |  | Lus10007110 | Cysteine-rich secretory protein-related |
|  |  |  | Lus10007092 | Solute carrier family 31 copper transporters |
|  |  |  | Lus10007091 | Domain of unknown function (DUF4598) |
|  |  |  | Lus10007089 | Transcription initiation factor iih-related |
|  |  |  | Lus10007088 | DNA damage-inducible protein 1 |
|  |  |  | Lus10007087 | Striated muscle activator of Rho-dependent signaling-related |
|  |  |  | Lus10007086 | Coiled-coil-helix-coiled-coil-helix domain containing 2/nur77 |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| MC | 3 | Lu3-26033342 | Lus10007085 | Tryptophan aminotransferase-related |
|  |  |  | Lus10007084 | Methylmalonate-semialdehyde dehydrogenase |
|  |  |  | Lus10007083 | SUBTILISIN-LIKE SERINE ENDOPEPTIDASE FAMILY PROTEIN-Related |
|  |  |  | Lus10007081 | Protein of unknown function (DUF295) |
|  |  |  | Lus10007079 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007077 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007076 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007075 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007074 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007073 | L-type lectin-domain containing receptor kinase ix.1-related |
|  |  |  | Lus10007071 | Magnesium-dependent phosphatase 1 |
|  | 3 | Lu3-7398487 | Lus10040675 | Delta(4)-3-oxosteroid 5-beta-reductase |
|  |  |  | Lus10040676 | Pleiotropic drug resistance proteins (PDR1-15) |
|  |  |  | Lus10040677 | Ammonium transporter |
|  |  |  | Lus10040678 | Phospholipase C (plcC) |
|  |  |  | Lus10040679 | D-isomer specific 2-hydroxyacid dehydrogenase, catalytic domain (2-Hacid\_dh) |
|  |  |  | Lus10040680 | Pentatricopeptide repeat domain (PPR\_3) |
|  |  |  | Lus10040681 | Plekhh protein |
|  |  |  | Lus10040682 | Soul heme-binding protein |
|  |  |  | Lus10040684 | MYB domain protein 119 |
|  |  |  | Lus10040686 | Sodium-dependent phosphate transporters |
|  |  |  | Lus10040687 | Fatty acid omega-hydroxylase (CYP86A1) |
|  |  |  | Lus10040689 | Thylakoid soluble phosphoprotein TSP9 |
|  |  |  | Lus10040691 | Josephin 1, 2 |
|  |  |  | Lus10040692 | Calcium-dependent lipid-binding domain protein |
|  |  |  | Lus10040693 | Large subunit ribosomal protein L4 |
|  |  |  | Lus10040694 | Phosphomethylpyrimidine synthase |
|  |  |  | Lus10040695 | ATP-dependent zinc metalloprotease FTSH 7, chloroplastic-related |
|  |  |  | Lus10040696 | Duplicated sant dna-binding domain-containing protein |
|  |  |  | Lus10040697 | LACCASE-16 |
|  |  |  | Lus10040698 | Oligopeptide transporter-related |
|  |  |  | Lus10040674 | Ca2+:H+ antiporter |
|  |  |  | Lus10040670 | Nudc domain-containing protein 2 |
|  |  |  | Lus10040669 | Sugar kinase |
|  |  |  | Lus10040668 | Predicted MutS-related |
|  |  |  | Lus10040667 | Protein ELF4-like 1 |
|  |  |  | Lus10040666 | Peptidyl-prolyl cis-trans isomerase |
|  |  |  | Lus10040665 | Glycosyl transferase |
|  |  |  | Lus10040664 | Phosphatidylinositol phospholipase C, delta |
|  |  |  | Lus10040663 | serine/threonine-protein kinase-like protein CCR3-related |
|  |  |  | Lus10040662 | Zinc finger ccch domain-containing protein 66 |
|  |  |  | Lus10040660 | Omega-3 fatty acid desaturase (delta-15 desaturase) |
|  |  |  | Lus10040659 | WDSAM1 protein |
|  |  |  | Lus10040658 | Selenoprotein T |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| MC | 3 | Lu3-7398487 | Lus10040657 | NADH:ubiquinone reductase (ndh1) |
|  |  |  | Lus10040656 | Nuclear movement protein NUDC |
|  |  |  | Lus10040654 | PHD finger-like domain-containing protein 5A |
|  |  |  | Lus10040653 | Non-specific serine/threonine protein kinase |
|  | 5 | Lu5-3808878 | Lus10008303 | Male germ cell-associated kinase |
|  |  |  | Lus10008304 | Thaumatin family |
|  |  |  | Lus10008305 | U3 small nucleolar rna-associated protein 15 homolog |
|  |  |  | Lus10008306 | Stromal antigen |
|  |  |  | Lus10008307 | Inositol hexakisphosphate |
|  |  |  | Lus10008308 | GST-containing FLYWCH ZINC-FINGER protein |
|  |  |  | Lus10008309 | Cu+-exporting ATPase |
|  |  |  | Lus10008310 | Protein tyrosine kinase |
|  |  |  | Lus10008299 | HEAT and armadillo repeat-containing protein |
|  |  |  | Lus10008298 | Methyltransferase pmt18-related |
|  |  |  | Lus10008297 | IP01149P-related |
|  |  |  | Lus10008295 | F-box domain |
|  |  |  | Lus10008294 | Transmembrane protein induced by tumor necrosis factor alpha |
|  |  |  | Lus10008293 | Beta-1,3-glucosyltransferase |
|  |  |  | Lus10008291 | AP2 domain |
|  |  |  | Lus10008288 | Nuclear pore complex protein Nup98-Nup96 |
|  |  |  | Lus10008286 | Membrane associated ring finger |
|  |  |  | Lus10008285 | NAC transcription factor-like 9 |
|  | 7 | Lu7-13225294 | Lus10007180 | partner of Y14 and mago |
|  |  |  | Lus10007175 | Myb/SANT-like DNA-binding domain |
|  |  |  | Lus10007174 | HSA (HSA) |
|  |  |  | Lus10007173 | PROTEIN PHOTOPERIOD-INDEPENDENT EARLY FLOWERING 1 |
|  |  |  | Lus10007172 | DNA helicase |
|  | 11 | Lu11-2498303 | Lus10041945 | Stress-induced protein Di19, C-terminal |
|  |  |  | Lus10041946 | Elongation factor Tu |
|  |  |  | Lus10041947 | LWNK lysine deficient protein kinase |
|  |  |  | Lus10041948 | Mitochondrial/chloroplast ribosomal protein L19 |
|  |  |  | Lus10041950 | High-affinity nitrate transporter 3.1-related |
|  |  |  | Lus10041951 | CYTOCHROME P450 71A12-related |
|  |  |  | Lus10041952 | Nnucleolin |
|  |  |  | Lus10041953 | Leucine-rich repeat receptor-like serine/threonine/tyrosine-protein kinase SOBIR1 |
|  |  |  | Lus10041954 | Mitochondrial domain of unknown function (DUF1713) |
|  |  |  | Lus10041955 | Enhanced disease susceptibility 5-related |
|  |  |  | Lus10041956 | Glycerol kinase |
|  |  |  | Lus10041957 | snRNA-activating protein complex subunit 3 |
|  |  |  | Lus10041958 | Kinesin motor family protein |
|  |  |  | Lus10041959 | Purple acid phosphatase 10 |
|  |  |  | Lus10041960 | Finger and BAH motif containing putative transcription factor-related |
|  |  |  | Lus10041961 | B3 DNA binding domain |
|  |  |  | Lus10041962 | Major facilitator superfamily protein |
|  |  |  | Lus10041963 | Chromatin remodeling protein-related |
|  |  |  | Lus10041964 | 26S proteasome regulatory subunit T4 |
|  |  |  | Lus10041965 | Nudix hydrolase |
|  |  |  | Lus10041966 | Photosystem I subunit V |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| MC | 11 | Lu11-2498303 | Lus10041967 | Phospholipase A1-IIDELTA |
|  |  |  | Lus10041968 | Histidinol-phosphatase |
|  |  |  | Lus10041969 | Dehydrin |
|  |  |  | Lus10041970 | Zinc finger, C3HC4 type (RING finger) |
|  |  |  | Lus10041940 | 50S ribosomal protein l13, chloroplastic |
|  |  |  | Lus10041939 | transmembrane EMP24 domain-containing protein |
|  |  |  | Lus10041937 | Leucine Rich Repeat 1 |
|  |  |  | Lus10041936 | serine/threonine-protein kinase WNK with no lysine -related |
|  |  |  | Lus10041935 | SBP domain |
|  |  |  | Lus10041934 | Eukaryotic translation initiation factor SUI1 |
|  |  |  | Lus10041933 | Eukaryotic translation initiation factor SUI1 |
|  |  |  | Lus10041932 | PROTON PUMP-INTERACTOR 1-RELATED |
|  |  |  | Lus10041931 | Uncharacterized conserved protein |
|  |  |  | Lus10041929 | VQ motif |
|  |  |  | Lus10041928 | Methylthioribulose 1-phosphate dehydratase |
|  |  |  | Lus10041927 | PPR repeat |
|  |  |  | Lus10041926 | Pollen ole E 1 allergen and extensin family protein |
|  |  |  | Lus10041925 | Small subunit ribosomal protein S20 |
|  |  |  | Lus10041924 | PROTEIN CUP-SHAPED COTYLEDON 1-related |
| HC | 7 | Lu7-6577527 | Lus10035457 | No annotated protein |
|  |  |  | Lus10035458 | Probable glycosyltransferase STELLO1 |
|  |  |  | Lus10035459 | Amidophosphoribosyltransferase |
|  |  |  | Lus10035460 | tRNA-dihydrouridine(47) synthase (NAD(P)(+)) |
|  |  |  | Lus10035461 | No annotated protein |
|  |  |  | Lus10035462 | Protein basic pentacysteine4-related |
|  |  |  | Lus10035456 | AGAMOUS-LIKE MADS-BOX PROTEIN AGL62 |
|  |  |  | Lus10035455 | No annotated protein |
|  |  |  | Lus10035454 | No annotated protein |
|  |  |  | Lus10035453 | Phosphate-transporting ATPase |
|  |  |  | Lus10035452 | UDP-GLYCOSYLTRANSFERASE 82A1 |
|  |  |  | Lus10035451 | Galactose-binding domain-like |
|  |  |  | Lus10035450 | Villin 1 |
|  | 10 | Lu10-21552161 | Lus10020237 | Leucine-rich repeat-containing protein |
|  |  |  | Lus10020238 | Disease resistance protein-related |
|  |  |  | Lus10020239 | Deoxyhypusine synthase |
|  |  |  | Lus10020240 | Plant protein of unknown function (DUF868) |
|  |  |  | Lus10020241 | N-MYC downstream regulated |
|  |  |  | Lus10020242 | Tetratricopeptide repeat protein |
|  |  |  | Lus10020243 | Pentatricopeptide repeat-containing protein |
|  |  |  | Lus10020244 | Serine/threonine-protein kinase NEK1 |
|  |  |  | Lus10020245 | PUR-transcriptional activator |
|  |  |  | Lus10020246 | AD039 HT014 thioredoxin family TRP26 |
|  |  |  | Lus10020247 | GDP-mannose 3,5-epimerase |
|  |  |  | Lus10020248 | Ammonium transporter |
|  |  |  | Lus10020249 | Agglutinin domain |
|  |  |  | Lus10020250 | Chitinase-related |
|  |  |  | Lus10020261 | Glucan endo-1,3-beta-glucosidase 8-related |
|  |  |  | Lus10020236 | Serine/threonine-protein kinase wnk1-related |
|  | 12 | Lu12-5267706 | Lus10018295 | CPG binding protein |
|  |  |  | Lus10018296 | SNARE proteins |
|  |  |  | Lus10018297 | Exocyst complex component EXO84C |
|  |  |  | Lus10018298 | MEF2B protein |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| HC | 12 | Lu12-5267706 | Lus10018300 | Ribonuclease H2 subunit C |
|  |  |  | Lus10018301 | Phloem protein 2 |
|  |  |  | Lus10018302 | Polygalacturonase |
|  |  |  | Lus10018303 | Phloem protein 2 |
|  |  |  | Lus10018304 | Phloem protein 2 |
|  |  |  | Lus10018305 | Myo-inositol-1(or 4)-monophosphatase |
|  |  |  | Lus10018306 | O-GLYCOSYL HYDROLASES FAMILY 17 protein |
|  |  |  | Lus10018307 | Kelch motif |
|  |  |  | Lus10018308 | Disease resistance protein-related |
|  |  |  | Lus10018309 | Disease resistance protein-related |
|  |  |  | Lus10018310 | Lecithin-cholesterol acyltransferase-like 4 |
|  |  |  | Lus10018311 | GDP-mannose transporter |
|  |  |  | Lus10018314 | Exordium like 7 |
|  |  |  | Lus10018315 | LACTOSYLCERAMIDE 4-ALPHA-GALACTOSYLTRANSFERASE |
|  |  |  | Lus10018316 | DCD (development and cell death) domain protein |
|  |  |  | Lus10018317 | Domain of unknown function (DUF3475) |
|  |  |  | Lus10018318 | Proteasome subunit |
|  |  |  | Lus10018319 | glycine cleavage system H protein |
|  |  |  | Lus10018320 | Plant protein of unknown function (DUF247) |
|  |  |  | Lus10018321 | Coatomer subunit delta |
|  |  |  | Lus10018294 | Inhibitor of apoptosis |
|  |  |  | Lus10018293 | RBR family ring finger and ibr domain-containing |
|  |  |  | Lus10018292 | Ring finger domain-containing |
|  |  |  | Lus10018291 | Peptide-O-fucosyltransferase |
|  |  |  | Lus10018290 | eukaryotic translation initiation factor 2C |
|  |  |  | Lus10018289 | regulatory protein NPR1 |
|  |  |  | Lus10018288 | mitotic-spindle organizing protein 1 (MZT1, GIP1, GIP2) |
|  |  |  | Lus10018287 | CT120 protein |
|  |  |  | Lus10018286 | Aspartyl protease family protein |
|  |  |  | Lus10018285 | RAS-related protein Rab-5C |
|  |  |  | Lus10018284 | Small subunit ribosomal protein SAe |
|  |  |  | Lus10018283 | Homeodomain-like superfamily protein-related |
|  |  |  | Lus10018282 | Protein SEY1 homolog |
|  |  |  | Lus10018281 | PROTEIN ROOT HAIR DEFECTIVE 3 HOMOLOG 2 |
|  |  |  | Lus10018280 | S-linalool synthase |
|  |  |  | Lus10018279 | F21B23.6 protein |
|  |  |  | Lus10018278 | PPR repeat |
|  |  |  | Lus10018277 | Multiple RNA-binding domain-containing protein 1 |
|  |  |  | Lus10018276 | Gamma-glutamylcyclotransferase |
|  | 13 | Lu13-2803224 | Lus10026881 | Superoxide dismutase [FE] 2, chloroplastic |
|  |  |  | Lus10026882 | Exosome complex protein LRP1 |
|  |  |  | Lus10026883 | No annotated protein |
|  |  |  | Lus10026884 | PPR repeat |
|  |  |  | Lus10026885 | Protein phosphatase 1G |
|  |  |  | Lus10026886 | Protein phosphatase 2C |
|  |  |  | Lus10026887 | Phospholipid hydroperoxide glutathione peroxidase 1, chloroplastic-related |
|  |  |  | Lus10026888 | PPR repeat family |
|  |  |  | Lus10026889 | No annotated protein |
|  |  |  | Lus10026890 | Folate-biopterin transporter 6-related |
|  |  |  | Lus10026891 | AIG1 domain-containing protein-related |

**Table S2**. continued

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trait** | **Chr.** | **SNP** | **Gene ID** | **Encoded protein** |
| HC | 13 | Lu13-2803224 | Lus10026892 | U2-associated protein SR140 |
|  |  |  | Lus10026893 | Folate-biopterin transporter 2-related |
|  |  |  | Lus10026894 | Mitogen-activated protein kinase kinase kinase 19-related |
|  |  |  | Lus10026895 | Monogalactosyldiacylglycerol synthase |
|  |  |  | Lus10026896 | Potential DNA-binding domain (zf-C3Hc3H) |
|  |  |  | Lus10026897 | VQ motif-containing protein 4-like |
|  |  |  | Lus10026898 | Polyketide cyclase |
|  |  |  | Lus10026899 | Protein disulfide-isomerase |
|  |  |  | Lus10026900 | Spindle and kinetochore-associated protein 2 |
|  |  |  | Lus10026901 | Zinc finger ccch-type with g patch domain-containing protein |
|  |  |  | Lus10026902 | Lariat debranching enzyme [EC:3.1.-.-] |
|  |  |  | Lus10026903 | Peroxidase 18-related |
|  |  |  | Lus10026904 | Translation initiation factor 3 subunit B |
|  |  |  | Lus10026905 | Aspartyl protease family protein |
|  |  |  | Lus10026906 | Aspartyl protease family protein |
|  |  |  | Lus10026923 | Xyloglucan 4-glucosyltransferase |
|  |  |  | Lus10026926 | Flavonol 3-O-glucosyltransferase |
|  |  |  | Lus10026927 | Glucosyl/glucuronosyl transferases |
|  |  |  | Lus10026880 | Early nodulin-like protein 1-related |
|  |  |  | Lus10026879 | NAC domain containing protein 87 |
|  |  |  | Lus10026878 | Thioredoxin-like 1-1, chloroplastic-related |
|  |  |  | Lus10026877 | Glutamate receptor 2.5-related |
|  |  |  | Lus10026876 | Glutamate receptor 2.1-related |
|  |  |  | Lus10026875 | Pyruvate kinase-related |
|  |  |  | Lus10026874 | Protein kinase C substrate 80K-H |
|  |  |  | Lus10026873 | Cupin 1 |
|  |  |  | Lus10026872 | Benzyl alcohol O-benzoyltransferase |
|  |  |  | Lus10026867 | Ribokinase |
|  |  |  | Lus10026865 | Fructokinase |
|  |  |  | Lus10026863 | Endoglucanase 7 |
|  |  |  | Lus10026862 | SCC1 / RAD21 family member |
|  |  |  | Lus10026861 | Beta-glucosidase |
|  |  |  | Lus10026860 | Small nuclear ribonucleoprotein F |
|  |  |  | Lus10026859 | Type 2A phosphatase activator TIP41 |
|  |  |  | Lus10026849 | CALRETICULIN-3 |

MC: mucilage content; HC: Hull content.

**Table S3**. Flaxseed accessions used for GWA analysis

|  |  |  |
| --- | --- | --- |
| **N°** | **Accession** | **Seed color** |
| 1 | F\_AFG\_U\_CN100952 | Brown |
| 2 | F\_BLR\_C\_CN101038 | Brown |
| 3 | F\_EGY\_C\_CN98826 | Brown |
| 4 | F\_FRA\_C\_CN101392 | Brown |
| 5 | F\_FRA\_C\_CN97351 | Brown |
| 6 | F\_FRA\_L\_CN98710 | Brown |
| 7 | F\_JPN\_C\_CN98072 | Brown |
| 8 | F\_NLD\_C\_CN18987 | Brown |
| 9 | F\_NLD\_C\_CN18997 | Brown |
| 10 | F\_NLD\_C\_CN97424 | Yellow |
| 11 | F\_NLD\_U\_CN101407 | Brown |
| 12 | F\_ROM\_U\_CN101405 | Brown |
| 13 | F\_RUS\_B\_CN101039 | Brown |
| 14 | F\_RUS\_B\_CN101055 | Brown |
| 15 | F\_RUS\_B\_CN101114 | Brown |
| 16 | F\_RUS\_B\_CN101115 | Brown |
| 17 | F\_RUS\_B\_CN101116 | Brown |
| 18 | F\_RUS\_B\_CN101127 | Brown |
| 19 | F\_RUS\_C\_CN101099 | Brown |
| 20 | F\_RUS\_C\_CN101136 | Brown |
| 21 | F\_RUS\_C\_CN32542 | Brown |
| 22 | F\_RUS\_C\_CN35791 | Brown |
| 23 | F\_RUS\_L\_CN97531 | Brown |
| 24 | F\_RUS\_U\_CN101348 | Brown |
| 25 | F\_RUS\_U\_CN101394 | Brown |
| 26 | F\_RUS\_U\_CN101395 | Brown |
| 27 | F\_RUS\_U\_CN101402 | Brown |
| 28 | F\_TUR\_U\_CN101382 | Brown |
| 29 | F\_TUR\_U\_CN101385 | Brown |
| 30 | F\_TUR\_U\_CN101386 | Brown |
| 31 | F\_UKR\_U\_CN101378 | Brown |
| 32 | F\_UKR\_U\_CN101379 | Brown |
| 33 | F\_USA\_B\_CN98926 | Brown |
| 34 | O\_AFG\_U\_CN100807 | Brown |
| 35 | O\_AFG\_U\_CN101338 | Brown |
| 36 | O\_ARG\_B\_CN113346 | Brown |
| 37 | O\_ARG\_B\_CN98037 | Brown |
| 38 | O\_ARG\_C\_CN97214 | Yellow |
| 39 | O\_ARG\_C\_CN97953 | Brown |
| 40 | O\_ARG\_C\_CN97961 | Brown |
| 41 | O\_ARG\_C\_CN97967 | Brown |
| 42 | O\_ARG\_C\_CN98007 | Brown |
| 43 | O\_ARG\_C\_CN98027 | Brown |
| 44 | O\_ARG\_C\_CN98039 | Brown |
| 45 | O\_ARG\_C\_CN98279 | Brown |
| 46 | O\_ARG\_C\_CN98634 | Brown |
| 47 | O\_ARM\_U\_CN101373 | Brown |
| 48 | O\_AUS\_C\_CN98984 | Brown |
| 49 | O\_CAN\_B\_CN101463 | Yellow |
| 50 | O\_CAN\_B\_CN101472 | Brown |
| 51 | O\_CAN\_B\_CN101496 | Brown |

**Table S3**. continued

|  |  |  |
| --- | --- | --- |
| **N°** | **Accession** | **Seed color** |
| 52 | O\_CAN\_B\_CN101554 | Yellow |
| 53 | O\_CAN\_B\_CN101560 | Brown |
| 54 | O\_CAN\_B\_CN101565 | Yellow |
| 55 | O\_CAN\_B\_CN101594 | Yellow |
| 56 | O\_CAN\_B\_CN101598 | Yellow |
| 57 | O\_CAN\_C\_CDCBethune | Brown |
| 58 | O\_CAN\_C\_CDCGold | Yellow |
| 59 | O\_CAN\_C\_CDCMons | Brown |
| 60 | O\_IND\_C\_CN98440 | Brown |
| 61 | O\_CAN\_C\_CDCSorrel | Brown |
| 62 | O\_CAN\_C\_CN101413 | Brown |
| 63 | O\_CAN\_C\_CN18981 | Brown |
| 64 | O\_CAN\_C\_CN19004 | Brown |
| 65 | O\_CAN\_C\_CN19005 | Brown |
| 66 | O\_CAN\_C\_CN19159 | Brown |
| 67 | O\_CAN\_C\_CN33385 | Brown |
| 68 | O\_CAN\_C\_CN33386 | Brown |
| 69 | O\_CAN\_C\_CN33388 | Brown |
| 70 | O\_CAN\_C\_CN33389 | Brown |
| 71 | O\_CAN\_C\_CN52732 | Brown |
| 72 | O\_CAN\_C\_CN97571 | Brown |
| 73 | O\_CAN\_C\_CN97633 | Brown |
| 74 | O\_CAN\_C\_CN97671 | Brown |
| 75 | O\_CAN\_C\_Macbeth | Brown |
| 76 | O\_CAN\_C\_PrairieBlue | Brown |
| 77 | O\_CAN\_C\_PrairieThunder | Brown |
| 78 | O\_CAN\_C\_Shape | Brown |
| 79 | O\_CAN\_C\_UGG102-2 | Brown |
| 80 | O\_CSK\_C\_CN100884 | Yellow |
| 81 | O\_CZE\_C\_CN100805 | Yellow |
| 82 | O\_CZE\_C\_CN98683 | Brown |
| 83 | O\_DEU\_B\_CN113306 | Brown |
| 84 | O\_DEU\_B\_CN97430 | Brown |
| 85 | O\_DEU\_C\_CN100881 | Brown |
| 86 | O\_DEU\_C\_CN97886 | Brown |
| 87 | O\_EGY\_U\_CN101329 | Brown |
| 88 | O\_ETH\_B\_CN19007 | Brown |
| 89 | O\_ETH\_C\_CN96988 | Yellow |
| 90 | O\_ETH\_C\_CN96991 | Brown |
| 91 | O\_ETH\_C\_CN96992 | Brown |
| 92 | O\_ETH\_C\_CN97004 | Brown |
| 93 | O\_FRA\_B\_CN100863 | Yellow |
| 94 | O\_FRA\_C\_CN97350 | Brown |
| 95 | O\_FRA\_C\_CN98712 | Brown |
| 96 | O\_FRA\_C\_CN98734 | Brown |
| 97 | O\_GBR\_C\_CN101265 | Brown |
| 98 | O\_GEO\_U\_CN101366 | Brown |
| 99 | O\_HUN\_C\_CN100883 | Brown |
| 100 | O\_HUN\_C\_CN97238 | Brown |
| 101 | O\_HUN\_C\_CN97287 | Brown |
| 102 | O\_HUN\_C\_CN97300 | Brown |

**Table S3**. continued

|  |  |  |
| --- | --- | --- |
| **N°** | **Accession** | **Seed color** |
| 103 | O\_HUN\_C\_CN98263 | Brown |
| 104 | O\_HUN\_C\_CN98263B | Brown |
| 105 | O\_HUN\_C\_CN98275 | Brown |
| 106 | O\_HUN\_C\_CN98276 | Brown |
| 107 | O\_HUN\_C\_CN98278 | Brown |
| 108 | O\_HUN\_C\_CN98854 | Brown |
| 109 | O\_IND\_C\_CN101208 | Yellow |
| 110 | O\_IND\_C\_CN97306 | Brown |
| 111 | O\_IND\_C\_CN98057 | Yellow |
| 112 | O\_IND\_C\_CN98250 | Brown |
| 113 | O\_IND\_C\_CN98364 | Brown |
| 114 | O\_IND\_C\_CN98370 | Brown |
| 115 | O\_IND\_C\_CN98415 | Brown |
| 116 | O\_IND\_C\_CN98961 | Brown |
| 117 | O\_IND\_C\_CN98974 | Brown |
| 118 | O\_IND\_L\_CN98240 | Brown |
| 119 | O\_IND\_U\_CN101308 | Brown |
| 120 | O\_IND\_U\_CN101310 | Brown |
| 121 | O\_IRL\_C\_CN98192 | Brown |
| 122 | O\_IRN\_C\_CN97050 | Brown |
| 123 | O\_IRN\_C\_CN97139 | Brown |
| 124 | O\_IRN\_L\_CN97129 | Brown |
| 125 | O\_IRN\_L\_CN97129B | Brown |
| 126 | O\_JPN\_C\_CN97470 | Brown |
| 127 | O\_LTU\_C\_CN101237 | Brown |
| 128 | O\_MAR\_B\_CN101026 | Brown |
| 129 | O\_NLD\_C\_CN113300 | Brown |
| 130 | O\_NLD\_C\_CN18993 | Brown |
| 131 | O\_NLD\_C\_CN97458 | Brown |
| 132 | O\_NLD\_C\_CN97613 | Brown |
| 133 | O\_NLD\_C\_CN98056 | Brown |
| 134 | O\_PAK\_C\_CN100629 | Brown |
| 135 | O\_PAK\_C\_CN97056 | Brown |
| 136 | O\_PAK\_C\_CN97064 | Brown |
| 137 | O\_PAK\_C\_CN97092 | Yellow |
| 138 | O\_PAK\_C\_CN97096 | Yellow |
| 139 | O\_PAK\_C\_CN97103 | Brown |
| 140 | O\_PAK\_C\_CN98237 | Brown |
| 141 | O\_PAK\_C\_CN98239 | Brown |
| 142 | O\_PAK\_L\_CN97083 | Brown |
| 143 | O\_POL\_B\_CN98733 | Brown |
| 144 | O\_ROM\_C\_CN100674 | Brown |
| 145 | O\_ROM\_C\_CN97321 | Brown |
| 146 | O\_RUS\_B\_CN101241 | Brown |
| 147 | O\_RUS\_B\_CN101289 | Brown |
| 148 | O\_RUS\_B\_CN101296 | Brown |
| 149 | O\_RUS\_B\_CN101301 | Brown |
| 150 | O\_RUS\_C\_CN96845 | Yellow |
| 151 | O\_RUS\_C\_CN96846 | Brown |
| 152 | O\_RUS\_C\_CN97484 | Brown |
| 153 | O\_RUS\_C\_CN97489 | Brown |

**Table S3**. continued

|  |  |  |
| --- | --- | --- |
| **N°** | **Accession** | **Seed color** |
| 154 | O\_RUS\_C\_CN97520 | Brown |
| 155 | O\_TUR\_U\_CN101332 | Brown |
| 156 | O\_UKR\_C\_CN30860 | Brown |
| 157 | O\_UNK\_C\_CN100547 | Brown |
| 158 | O\_UNK\_C\_CN30861 | Brown |
| 159 | O\_URY\_C\_CN98100 | Brown |
| 160 | O\_USA\_B\_CN113314 | Brown |
| 161 | O\_USA\_B\_CN97404 | Brown |
| 162 | O\_USA\_B\_CN97679 | Brown |
| 163 | O\_USA\_B\_CN97679B | Brown |
| 164 | O\_USA\_C\_CN18994 | Brown |
| 165 | O\_USA\_C\_CN19160 | Yellow |
| 166 | O\_USA\_C\_CN33399 | Brown |
| 167 | O\_USA\_C\_CN33400 | Brown |
| 168 | O\_USA\_C\_CN33992 | Brown |
| 169 | O\_USA\_C\_CN97377 | Brown |
| 170 | O\_USA\_C\_CN97396 | Yellow |
| 171 | O\_USA\_C\_CN97403 | Brown |
| 172 | O\_USA\_C\_CN97407 | Brown |
| 173 | O\_USA\_C\_CN97463 | Brown |
| 174 | O\_USA\_C\_CN97586 | Brown |
| 175 | O\_USA\_C\_CN97639 | Brown |
| 176 | O\_USA\_C\_CN97642 | Brown |
| 177 | O\_USA\_C\_CN97649 | Brown |
| 178 | O\_USA\_C\_CN97718 | Brown |
| 179 | O\_USA\_C\_CN97881 | Brown |
| 180 | O\_USA\_C\_CN97890 | Brown |
| 181 | O\_USA\_C\_CN97921 | Brown |
| 182 | O\_USA\_C\_CN98231 | Brown |
| 183 | O\_USA\_C\_CN98541 | Brown |
| 184 | O\_USA\_C\_CN98542 | Brown |
| 185 | O\_USA\_C\_CN98613 | Brown |
| 186 | O\_USA\_C\_CN98821 | Brown |
| 187 | U\_ARG\_C\_CN97341 | Brown |
| 188 | U\_ESP\_U\_CN101327 | Brown |
| 189 | U\_ETH\_L\_CN100895B | Brown |
| 190 | U\_MAR\_C\_CN98193 | Brown |
| 191 | U\_NZL\_B\_CN100797 | Yellow |
| 192 | U\_NZL\_B\_CN100797B | Yellow |
| 193 | U\_PAK\_C\_CN100790 | Brown |
| 194 | U\_ROM\_C\_CN100678 | Brown |
| 195 | U\_RUS\_L\_CN97483 | Brown |
| 196 | U\_TUR\_U\_CN100828 | Brown |
| 197 | U\_USA\_B\_CN97402 | Brown |
| 198 | U\_USA\_B\_CN97406 | Brown |
| 199 | U\_USA\_C\_CN97397 | Brown |
| 200 | U\_USA\_C\_CN97453 | Brown |

F = Fiber morphotype, O = Oil morphotype, U = Unknown morphotype, C = Cultivar, B = Breeding material, L= Landrace, U = Unknown breeding status. CN = Canadian number at Plant Gene Resources of Canada (PGRC)