Discovery, Characterization, and Linkage Mapping of Simple Sequence Repeat Markers In Hazelnut

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ADDITIONAL INDEX WORDS. *Corylus avellana*, dendrogram, filbert, genetic diversity, microsatellite

ABSTRACT. From the genome sequence of hazelnut (*Corylus avellana*), 192 new polymorphic simple sequence repeat (SSR) markers were developed, characterized, and used to investigate genetic diversity in 50 accessions. Next-generation sequencing allows inexpensive sequencing of plant genomes and transcriptomes, and efficient development of polymorphic SSR markers, also known as microsatellite markers, at low cost. A search of the genome sequence of ‘Jefferson’ hazelnut identified 9094 fragments with long repeat motifs of 4, 5, or 6 base pairs (bp), from which polymorphic SSR markers were developed. The repeat regions in the ‘Jefferson’ genome were used as references to which genomic sequence reads of seven additional cultivars were aligned in silico. Visual inspection for variation in repeat number among the aligned reads identified 246 as polymorphic, for which primer pairs were designed. Polymerase chain reaction (PCR) amplification followed by agarose gel separation indicated polymorphism at 195 loci, for which fluorescent forward primers were used to amplify the DNA of 50 hazelnut accessions. Amplicons were post-PCR multiplexed for capillary electrophoresis, and allele sizes were determined for 50 accessions. After eliminating three, 192 were confirmed as polymorphic, and 169 showed only one or two alleles in each of the 50 cultivars, as expected in a diploid. At these 169 SSRs, a total of 843 alleles were found, for an average of 4.99 and a range of 2 to 17 alleles per locus. The mean observed heterozygosity, expected heterozygosity, polymorphism information content, and the frequency of null alleles were 0.51, 0.53, 0.47, and 0.03, respectively. An additional 25 primer pairs produced more than two bands in some accessions with an average of 6.8 alleles. The UPGMA dendrogram revealed a wide genetic diversity and clustered the 50 accessions according to their geographic origin. Of the new SSRs, 132 loci were placed on the linkage map. These new markers will be useful for diversity and parentage studies, cultivar fingerprinting, marker-assisted selection, and aligning the linkage map with scaffolds of the genome sequence.

Hazelnut, one of the world’s major nut crops, is an important crop in the Willamette Valley of Oregon where 99% of the U.S. hazelnut crop is produced. Over a 10-year period (2005–14), Turkey produced 67.2% of the world crop, followed by Italy (12.6%), the United States (4.0%), Azerbaijan (3.4%), and Republic of Georgia (3.1%) (Food and Agriculture Organization of the United Nations, 2017). In Oregon, hazelnuts are planted on 27,000 ha and plantings are expanding at 1200 ha per year (Oregon Hazelnuts, 2018). There are also many new plantings and production is increasing in China, Chile, Republic of Georgia, and other countries.

Hazelnut is diploid ($2n = 2x = 22$) and belongs to the family Betulaceae. Of the 13 commonly recognized species of *Corylus*, only the European species (*C. avellana*) is widely planted for commercial production. Hazelnuts are monoecious, dichogamous, and self-incompatible, and thus cross-pollinated in nature. Cultivars are highly heterozygous and clonally propagated. Most of the world’s cultivars are selections from local wild vegetation. Based on simple sequence repeat markers, most cultivars have been assigned to one of four

major geographical groups: Central European, Black Sea, English or Spanish-Italian (Boccacci et al., 2006; Gökirmak et al., 2009).

Simple sequence repeat markers are DNA segments comprised of tandem repeat motifs that are 1 to 8 nucleotides in length. SSRs are polymerase chain reaction (PCR)-based markers for which primers are designed from conserved sequences that flank the repeat region. At polymorphic loci, PCR amplification results in different product sizes. SSR markers are preferred over several other marker types because of their high level of polymorphism, multiple alleles, codominant inheritance, good genome coverage, interspecific and intergeneric transferability, high reproducibility, amenability to automated high-throughput genotyping, and ease of sharing among laboratories (Parida et al., 2009). SSR markers are widely used in plant genetics and breeding, including studies of genetic diversity and evolution, association, gene flow, genetic mapping, gene tagging, gene cloning, cultivar identification, parentage analysis, identification of duplicates, marker-assisted selection (MAS), and quantitative trait locus (QTL) analysis (Ellegren, 2004; Hearne et al., 1992; Parida et al., 2009). In hazelnut, SSR markers were initially developed from DNA libraries enriched for specific repeats (Bassil et al., 2005a, 2005b; Boccacci et al., 2005; Gürcan et al., 2010). Later, Gürcan and Mehlenbacher (2010a) developed SSRs from the sequences of inter simple sequence repeat (ISSR) markers and flanking regions. Sathuvalli and Mehlenbacher (2013) developed SSR markers from bacterial artificial chromosome (BAC) sequences. SSRs have also been developed from sequences of the hazelnut transcriptome (Colburn et al., 2017) and genome

Received for publication 21 May 2018. Accepted for publication 18 July 2018. This research was supported by the Oregon Hazelnut Commission, USDA-NIFA Specialty Crops Research Initiative Competitive Grants (2009-51181-06028 and 2016-51181-25412), and a USDA Specific Cooperative Agreement for Eastern Filbert Blight Research.

This research partially fulfilled the requirement for G. Bhattarai’s Master of Science degree. The authors thank Erik Rowley and Todd Mockler for providing the hazelnut genome sequences used in this study.

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Table 1. Hazelnut accessions used to identify and characterize tetra-, penta-, and hexa- repeat microsatellite markers mined from genome sequences. Accessions 1 to 24 were used to screen for polymorphism on agarose gels, while all 50 accessions were used for characterization of polymorphic simple sequence repeat loci. Some were imported as scions, and others as seed lots from which individuals were selected.

No.	Accession	Designation	Origin	Source
1	Ala Kieri COR187	PI 557080	Lappa, Finland	Lappa, Finland (seeds)
2	Albania 55	PI 617207	Cajup, Albania	Cajup, Albania (seeds)
3	Aurea	PI 557050	France	Morton Arboretum, Lisle, IL, USA (scions)
4	Barcelona	PI 557037	Spain	Oregon nursery (scions)
5	Bergeri	PI 557114	Liège, Belgium	ISF Rome, Italy (scions)
6	Casina	PI 557033	Asturias, Spain	Q.B. Zielinski from Spain (scions)
7	Cosford	PI 557039	Reading, England, UK	NYAES, Geneva, NY (scions)
8	Cutleaf	PI 557306	England	Arnold Arboretum, Boston, MA, USA (scions)
9	Du Chilly	PI 557099	England	OSU Entomology Farm, OR, USA (scions)
10	Fusco Rubra	PI 557047	Germany	Morton Arboretum, Lisle, IL, USA (scions)
11	Gasaway	PI 557042	Washington, USA	Orchard in Washington, USA (scions)
12	Hall's Giant	PI 557027	Germany/France	Oregon State Univ. Entomology Farm, OR, USA
13	Imperiale de Trebizonde	PI 271105	Turkey	Q.B. Zielinski from France (scions)
14	Negret	PI 270340	Tarragona, Spain	Q.B. Zielinski from Spain (scions)
15	OSU 408.040	PI 617266	Minnesota, USA	Univ. Minnesota Horticulture, MN, USA (seeds)
16	OSU 495.049	PI 557421.2	Russia	VIR, southern Russia (seeds)
17	OSU 681.078	PI 634204	Moscow, Russia	Moscow, Russia (seeds)
18	Palaz	PI 304632	Ordu, Turkey	Q.B. Zielinski from Greece (scions)
19	Pendula	PI 557048	France	Arnold Arboretum, Boston, MA, USA (scions)
20	Ratoli	PI 557167	Tarragona, Spain	IRTA Mas Bove, Reus, Spain (scions)
21	Rote Zellernuss	PI 271280	Netherlands	Q.B. Zielinski from Netherlands (scions)
22	Tombul Ghiaghli	PI 304634	Turkey	Q.B. Zielinski from Greece (scions)
23	Tonda di Giffoni	PI 296207	Campania, Italy	Q.B. Zielinski from Italy (scions)
24	Tonda Gentile delle Langhe	PI 557035	Piemonte, Italy	Univ. di Torino, Italy (scions)
25	Alli	PI 686862	Estonia	Polli, Estonia (scions)
26	Artellet	PI 557108	Tarragona, Spain	IRTA Mas Bove, Reus, Spain (scions)
27	B-3	PI 557122	Macedonia	Skopje, Macedonia (scions)
28	Barcelloner Zeller	PI 557156	Spain	Faversham, England, UK (scions)
29	Buttner's Zeller	PI 557094	Landsberg, Germany	Faversham, England, UK (scions)
30	Contorta	PI 557049	England, UK	Arnold Arboretum, Boston, MA, USA (scions)
31	Des Anglais	PI 557423	Unknown	INRA, Bordeaux, France (scions)
32	Early Long Zeller	PI 557090	Germany	Faversham, England, UK (scions)
33	Gem	PI 557029	Washington, USA	Orchard in Oregon, USA (scions)
34	Gunslebert	PI 557191	Gunsleben, Germany	INRA Bordeaux, France (scions)
35	Gustav's Zeller	PI 557085	Landsberg, Germany	Faversham, England, UK (scions)
36	Iannusa Racinante	PI 557183	Sicily, Italy	Univ. di Torino, Italy (scions)
37	Mortarella	PI 339723	Campania, Italy	Q.B. Zielinski from Italy (scions)
38	OSU 26.072	PI 323961	Russia	North Caucasus, Russia (seeds)
39	OSU 54.039	PI 557060	Giresun/Ordu, Turkey	Giresun, Turkey (seeds)
40	OSU 556.027	PI 617269	Istanbul, Turkey	Istanbul market, Turkey (seeds)
41	OSU 759.010	OSU 759.010	Ozurgeti, Republic of Georgia	Ozurgeti, Republic of Georgia (scions)
42	Pellicule Rouge	PI 271110	France	Q.B. Zielinski from France (scions)
43	Römische Nuss	PI 557171	Unknown	Hermansverk, Norway (scions)
44	Sant Jaume	PI 557103	Tarragona, Spain	IRTA Mas Bove, Reus, Spain (scions)
45	Simon	PI 557166	Tarragona, Spain	IRTA Mas Bove, Reus, Spain (scions)
46	Tapparona di San Colombano Cortemoli	PI 617239	Liguria, Italy	Univ. di Torino, Italy (scions)
47	Tonda Bianca	PI 296206	Campania, Italy	Q.B. Zielinski from Italy (scions)
48	Tonda Romana	PI 557025	Lazio, Italy	ISF Rome, Italy (scions)
49	OSU 252.146	–	Oregon State Univ., USA	Parent of mapping population 93001
50	OSU 414.062	–	Oregon State Univ., USA	Parent of mapping population 93001

(Bhattarai and Mehlenbacher, 2017), and sequences in public databases (Boccacci et al., 2015; Gürçan and Mehlenbacher, 2010b). Although about 525 SSR markers are publicly available in hazelnut, the majority contain di-nucleotide motifs which suffer from PCR artifacts that prevent automated

scoring (Testolin and Cipriani, 2010). In this study, we mined the 'Jefferson' genome sequence to develop new polymorphic SSR markers with repeat motifs of 4, 5, or 6 bp and further saturated the reference hazelnut genetic linkage map.

Materials and Methods

PLANT MATERIAL. A set of 48 diverse hazelnut accessions plus the two parents of a mapping population (Table 1) were used to characterize the new SSR markers. These accessions were a subset of the 198 unique types investigated by Gökirmak et al. (2009), and are phenotypically, genetically, and geographically diverse. The same 50 accessions were used in previous characterization studies (Bhattarai and Mehlenbacher, 2017; Colburn et al., 2017; Gürcan and Mehlenbacher, 2010a; Gürcan et al., 2010). Of these accessions, 24 were used to screen all primer pairs for polymorphism on agarose gels. For SSRs that appeared to be polymorphic on agarose gels, all 50 accessions and capillary electrophoresis were used to characterize them.

DNA EXTRACTION. DNA was extracted from two to four young leaves collected during early spring from trees growing in fields at the USDA-ARS National Clonal Germplasm Repository (NCGR) and Smith Horticultural Research Farm of Oregon State University (OSU) in Corvallis. DNA extraction followed the method of Lunde et al. (2000) without RNAase treatment. The extracted DNA was quantified using ultraviolet spectrophotometry with a Synergy 2 Multi-Mode Reader with a Take 3 microplate reader and the data were analyzed with Gen5 software (all Biotek Instruments, Winooski, VT). The DNA was diluted with TE buffer to a concentration of 20 ng-μL⁻¹.

SSR IDENTIFICATION. The hazelnut genome sequences of Rowley (2016) generated by Illumina (San Diego, CA) technology were used in this study. The ‘Jefferson’ genome sequence (93 × coverage with 333,492 sequences comprising 224.58 Mb) was used as the reference. Seven other cultivars (Barcelona, Ratoli, Tonda Gentile delle Langhe, Tonda di Giffoni, Daviana, Hall’s Giant, and Tombul) were resequenced at lower coverage (≈20×). The ‘Jefferson’ genome sequences were searched for SSRs using the MISA tool (Thiel et al., 2003) with the search criteria for minimum number of repeats set at six for dinucleotide repeats, five for trinucleotide repeats, and four each for tetra-, penta-, hexa-, hepta- and octanucleotide motifs. This study pursued only the tetra-, penta-, and hexanucleotide repeat SSRs. Repeats that contained only As and Ts were removed, as they tend to be very difficult to score. Short fragments (<400 bases) and fragments with repeats near the ends of the contigs were also removed, the latter because they lacked a flanking sequence sufficient for primer design. Paired-end Illumina reads from the seven other cultivars were concatenated into a single file, and aligned with SSR-containing sequences in the ‘Jefferson’ reference using the

MAQ program (Li et al., 2008). The aligned reads were imported into Tablet software (Milne et al., 2013) for visualization and identification of SSRs with variation in the number of repeat units but conserved flanking sequences. Tablet software displayed the reference sequence at the top of the screen, with the aligned reads from the seven cultivars shown in subsequent rows without identification of the originating cultivar. The four nucleotides were displayed with unique colors for ease of visualization. After alignment and visualization, each sequence was classified as “clearly polymorphic,” “slightly polymorphic,” “not polymorphic,” “poor alignment,” or “no reads.” Of these categories, only the “clearly polymorphic” sequences were pursued, and forward and reverse primers were designed using the Websat (Martins et al., 2009) and Primer 3 (Untergasser et al., 2012) programs with lengths of 18 to 27 bp, annealing temperature of 60 °C, and a range of expected product sizes of 90–400 bp to facilitate post-PCR multiplexing. Non-fluorescent forward and reverse primers were ordered from Integrated DNA Technologies (Coralville, IA). The “slightly polymorphic” sequences, for which <2% of the aligned reads showed variation in the number of repeats, were not pursued.

PCR AMPLIFICATION FOR POLYMORPHISM SCREENING. PCR was performed with each primer pair using DNA of 24 accessions in the diversity panel (Table 1). PCRs were in 10-μL volumes containing 0.3 μM each of forward and reverse primers, 1 × Biolase NH₄ reaction buffer, 2 mM MgCl₂, 200 μM each of dATP, dCTP, dGTP, and dTTP, 20 ng template DNA, and 0.25 units of DNA polymerase (Biolase; Bioline USA, Taunton, MA). PCR amplification was performed in thermal cyclers (GeneAmp PCR system 9700; Applied Biosystems, Foster City, CA) in 96-well plates using the following program: denaturation at 95 °C for 5 min followed by 40 cycles of at 94 °C for 40 s, 60 °C for 40 s, 72 °C for 40 s, a final extension at 72 °C for 7 min, and an infinite hold at 4 °C. The PCR products were separated by electrophoresis on 3% agarose gels in TBE buffer at 90V for 3.5 h, stained for 30 min in ethidium bromide and then destained in distilled water for 25 min. The gels were then photographed under ultraviolet light using an imaging system (BioDoc-It®; UVP, Upland, CA), and the images were inspected for size polymorphism among the 24 genotypes.

GENOTYPING AT POLYMORPHIC SSRs. For SSR loci that were polymorphic on the agarose gels, fluorescent forward primers labeled with 6-FAM or 5-HEX were ordered from Integrated DNA Technologies and fluorescent forward primers labeled with NED were ordered from Applied Biosystems. The fluorescent forward and non-fluorescent reverse primers (Supplemental Table 1) were used to amplify DNA from the 48

Table 2. Counts of SSR in the ‘Jefferson’ hazelnut genome by type and number of repeats.

Repeat type	Repeats (no.)												Repeat type (%)
	4	5	6	7	8	9	10	11	12	13	14	Total	
Dinucleotide	—	—	11,131	7,079	4,962	3,453	2,340	2,109	1,832	348	19	33,273	64.90
Trinucleotide	—	4,625	2,181	1,079	616	191	14	2	0	0	0	8,708	16.99
Tetranucleotide	4,937	1,214	214	34	4	0	0	0	0	0	0	6,403	12.49
Pentanucleotide	1,481	266	13	0	0	0	0	0	0	0	0	1,760	3.43
Hexanucleotide	825	98	8	0	0	0	0	0	0	0	0	931	1.82
Heptanucleotide	176	12	3	0	0	0	0	0	0	0	0	191	0.37
Octanucleotide	2	0	0	0	0	0	0	0	0	0	0	2	0.00
Sum												51,268	100.00

Table 3. Characteristics and linkage group assignments of new simple sequence repeat markers developed from the ‘Jefferson’ hazelnut genome sequence.

Marker	GenBank no.	n ^z	H _e ^y	H _o ^x	PIC ^w	F(null) ^v	LG ^u
<i>Loci with one or two bands in all accessions</i>							
GB401	KU131606	4	0.63	0.82	0.56	−0.15	5S, 5R
GB402	KU131607	3	0.34	0.42	0.29	−0.11	9S, 9R
GB403	KU131608	2	0.40	0.44	0.32	−0.04	NA
GB404	KU131609	2	0.08	0.08	0.07	−0.01	7S
GB405	KU131610	3	0.04	0.04	0.04	0.00	NA
GB407	KU131611	7	0.51	0.40	0.49	0.13	NA
GB408	KU131612	4	0.40	0.28	0.38	0.19	5R
GB409	KU131613	4	0.17	0.14	0.16	0.08	NA
GB410	KU131614	6	0.67	0.70	0.61	−0.03	4R
GB413	KU131615	8	0.65	0.74	0.59	−0.07	1S, 1R
GB414	KU131616	4	0.73	0.64	0.68	0.06	8S
GB416	KU131617	5	0.49	0.42	0.45	0.09	NA
GB417	KU131618	2	0.42	0.40	0.33	0.02	9S, 9R
GB418	KU131619	7	0.43	0.40	0.40	0.03	1S
GB420	KU131620	6	0.75	0.74	0.70	0.00	9S, 9R
GB421	KU131621	3	0.17	0.10	0.16	0.25	NA
GB422	KU131622	11	0.85	0.78	0.83	0.04	7S
GB423	KU131623	7	0.60	0.70	0.57	−0.09	6S, 6R
GB424	KU131624	2	0.49	0.46	0.37	0.03	9S, 9R
GB425	KU131625	4	0.27	0.26	0.26	0.00	NA
GB426	KU131626	5	0.27	0.30	0.26	−0.07	NA
GB427	KU131627	3	0.23	0.18	0.21	0.12	NA
GB428	KU131628	3	0.53	0.50	0.42	0.03	8S
GB429	KU131629	9	0.83	0.68	0.81	0.11	NA
GB430	KU131630	5	0.72	0.68	0.68	0.04	9S, 9R
GB431	KU131621	5	0.69	0.78	0.64	−0.07	NA
GB432	KU131622	9	0.78	0.80	0.75	−0.02	4S, 4R
GB433	KU131623	3	0.27	0.26	0.25	0.00	10S, 10R
GB434	KU131624	5	0.63	0.56	0.57	0.05	4S
GB435	KU131625	6	0.65	0.62	0.59	0.03	9S, 9R
GB436	KU131626	2	0.13	0.14	0.12	−0.03	4S
GB437	KU131627	5	0.52	0.48	0.47	0.04	4S, 4R
GB438	KU131628	4	0.39	0.36	0.36	0.06	4S, 4R
GB441	KU131629	2	0.26	0.26	0.22	−0.01	4S
GB444	KU131630	5	0.73	0.80	0.68	−0.05	1S
GB445	KU131641	2	0.26	0.22	0.22	0.07	NA
GB446	KU131642	2	0.06	0.06	0.06	−0.01	NA
GB447	KU159355	5	0.53	0.54	0.49	−0.02	1S, 1R
GB448	KU159356	3	0.56	0.60	0.47	−0.04	NA
GB450	KU131643	4	0.34	0.36	0.30	−0.05	11S, 11R
GB452	KU131644	4	0.57	0.58	0.48	−0.01	NA
GB454	KU131645	7	0.72	0.42	0.67	0.26	NA
GB456	KU131646	2	0.44	0.44	0.34	−0.01	6S
GB457	KU131647	2	0.24	0.24	0.21	0.00	6S, 6R
GB458	KU131648	5	0.74	0.74	0.70	0.00	2S, 2R
GB461	KU131649	5	0.56	0.34	0.49	0.23	4S
GB463	KU131651	8	0.54	0.46	0.50	0.08	NA
GB465	KU131652	8	0.53	0.26	0.47	0.37	NA
GB466	KU131653	2	0.47	0.32	0.36	0.19	8R
GB467	KU131654	3	0.51	0.60	0.41	−0.09	7S, 7R
GB468	KU131655	6	0.58	0.44	0.49	0.15	4S, 4R
GB469	KU131656	8	0.70	0.78	0.65	−0.05	1S, 1R
GB470	KU131657	11	0.69	0.48	0.64	0.17	1R
GB473	KU131658	3	0.35	0.40	0.33	−0.07	1S, 1R
GB475	KU131659	2	0.48	0.42	0.37	0.07	4R (gap)
GB476	KU131660	6	0.51	0.46	0.48	0.06	NA

Continued next page

Table 3. Continued.

Marker	GenBank no.	n ^z	H _e ^y	H _o ^x	PIC ^w	F(null) ^v	LG ^u
GB477	KU131661	3	0.37	0.48	0.31	-0.13	3R
GB478	KU131662	3	0.63	0.48	0.56	0.14	6R
GB480	KU131663	5	0.40	0.34	0.34	0.09	NA
GB482	KU131664	4	0.68	0.66	0.63	0.01	7S, 7R
GB483	KU131665	5	0.52	0.44	0.47	0.10	2R
GB504	KU159292	4	0.60	0.52	0.53	0.07	NA
GB505	KU159293	8	0.72	0.40	0.68	0.31	8S, 8R
GB526	KU159294	9	0.77	0.78	0.75	-0.01	NA
GB527	KU159295	4	0.49	0.42	0.40	0.08	NA
GB532	KU159296	6	0.71	0.30	0.66	0.42	3R
GB533	KU159297	3	0.54	0.56	0.44	-0.02	1S
GB537	KU159299	2	0.32	0.32	0.27	0.00	NA
GB544	KU159300	6	0.61	0.66	0.56	-0.05	5S, 5R
GB545	KU159301	3	0.32	0.34	0.30	-0.04	NA
GB548	KU159302	3	0.34	0.38	0.31	-0.06	1S, 1R
GB551	KU159303	3	0.52	0.56	0.40	-0.04	NA
GB560	KU159304	6	0.69	0.72	0.63	-0.04	NA
GB563	KU159305	4	0.57	0.58	0.50	-0.02	1S
GB565	KU159306	2	0.50	0.54	0.37	-0.04	2R
GB577	KU159308	9	0.75	0.78	0.71	-0.02	NA
GB580	KU159309	2	0.11	0.12	0.11	-0.02	NA
GB581	KU159310	5	0.67	0.80	0.60	-0.10	1R
GB587	KU159311	6	0.54	0.60	0.44	-0.06	4S, 4R
GB601	KU306263	4	0.12	0.12	0.11	-0.02	NA
GB602	KU306264	3	0.50	0.48	0.41	0.02	6R
GB603	KU306265	4	0.36	0.40	0.32	-0.07	NA
GB604	KU306266	2	0.31	0.34	0.26	-0.05	9S, 9R
GB605	KU306267	5	0.48	0.56	0.43	-0.08	6S
GB606	KU306268	11	0.79	0.66	0.76	0.09	11S
GB614	KU306272	6	0.54	0.54	0.50	0.00	1R
GB616	KU306274	2	0.10	0.10	0.09	-0.02	1R
GB617	KU306275	3	0.64	0.48	0.57	0.15	NA
GB618	KU306276	17	0.84	0.70	0.82	0.10	2R
GB619	KU306277	5	0.70	0.86	0.65	-0.13	1R
GB620	KU306278	2	0.46	0.56	0.35	-0.10	9S, 9R
GB621	KU306279	6	0.64	0.64	0.57	0.00	4S
GB622	KU306280	5	0.68	0.66	0.63	0.02	9R
GB623	KU306281	3	0.46	0.54	0.36	-0.08	2R
GB624	KU306282	5	0.24	0.10	0.23	0.40	NA
GB625	KU306283	11	0.84	0.80	0.82	0.03	11R
GB626	KU306284	4	0.41	0.46	0.36	-0.06	4R
GB627	KU306285	4	0.69	0.70	0.63	-0.01	1S, 1R
GB628	KU306286	10	0.74	0.68	0.70	0.05	4S
GB631	KU306288	2	0.50	0.66	0.37	-0.14	9S
GB633	KU306289	3	0.50	0.62	0.39	-0.11	9S, 9R
GB635	KU306291	5	0.42	0.46	0.39	-0.06	6R
GB636	KU306292	4	0.55	0.58	0.44	-0.04	11S, 11R (poor fit)
GB638	KU306293	4	0.55	0.42	0.46	0.14	9R
GB639	KU306294	7	0.68	0.76	0.63	-0.05	NA
GB640	KU306295	5	0.52	0.14	0.49	0.61	4R
GB641	KU306296	3	0.31	0.38	0.27	-0.10	2R
GB642	KU306297	2	0.33	0.34	0.28	-0.01	7S
GB643	KU306298	6	0.61	0.68	0.54	-0.06	10R
GB645	KU306300	5	0.65	0.76	0.60	-0.08	10S, 10R
GB646	KU306301	7	0.71	0.42	0.67	0.28	5S
GB647	KU306302	7	0.65	0.66	0.60	0.00	9S, 9R
GB649	KU306304	5	0.67	0.42	0.61	0.25	2S, 2R

Continued next page

Table 3. Continued.

Marker	GenBank no.	n ^z	H _e ^y	H _o ^x	PIC ^w	F(null) ^v	LG ^u
GB652	KU306306	9	0.53	0.56	0.49	-0.05	NA
GB653	KU306307	5	0.57	0.80	0.51	-0.20	NA
GB654	KU306308	6	0.57	0.50	0.50	0.08	10R
GB655	KU306309	5	0.63	0.70	0.56	-0.07	11S, 11R
GB657	KU306310	8	0.76	0.74	0.73	0.02	4R
GB658	KU306311	7	0.68	0.78	0.63	-0.08	1R (poor fit)
GB659	KU306312	4	0.65	0.70	0.60	-0.04	5S, 5R
GB660	KU306313	8	0.83	0.86	0.81	-0.02	5S, 5R
GB661	KU306314	3	0.54	0.48	0.48	0.08	1S
GB663	KU306316	3	0.37	0.46	0.34	-0.12	4R
GB664	KU306317	2	0.44	0.42	0.34	0.03	8S
GB665	KU306318	5	0.54	0.60	0.49	-0.06	4S
GB668	KU306320	4	0.45	0.50	0.36	-0.05	NA
GB669	KU306321	3	0.55	0.74	0.47	-0.17	2S
GB670	KU306322	9	0.76	0.56	0.73	0.17	4S, 4R
GB671	KU306323	12	0.69	0.40	0.67	0.25	6S, 6R
GB672	KU306324	4	0.53	0.48	0.49	0.04	NA
GB673	KU306325	7	0.67	0.80	0.63	-0.10	5S, 5R
GB674	KU306326	7	0.66	0.60	0.62	0.06	NA
GB675	KU306327	5	0.67	0.62	0.61	0.02	4S, 4R
GB676	KU306328	4	0.55	0.36	0.51	0.19	2S, 2R
GB678	KU306329	11	0.70	0.70	0.67	0.00	5S, 5R
GB702	KU159313	3	0.47	0.50	0.42	-0.05	2R
GB705	KU159315	2	0.15	0.12	0.14	0.10	NA
GB706	KU159316	6	0.54	0.42	0.49	0.10	1R
GB709	KU159319	14	0.85	0.82	0.84	0.02	6R
GB710	KU159320	3	0.29	0.22	0.26	0.13	NA
GB712	KU159321	7	0.77	0.86	0.74	-0.06	1R
GB716	KU159322	4	0.58	0.58	0.50	0.00	2R, 2S (poor fit)
GB717	KU159323	3	0.38	0.30	0.32	0.12	4R
GB718	KU159324	4	0.65	0.42	0.60	0.21	1R
GB719	KU159325	3	0.44	0.40	0.40	0.05	1S, 1R
GB720	KU159326	3	0.63	0.55	0.56	0.07	NA
GB721	KU159327	5	0.54	0.26	0.48	0.35	2R
GB722	KU159328	12	0.82	0.72	0.80	0.06	2S, 2R
GB723	KU159329	2	0.13	0.10	0.12	0.13	NA
GB724	KU159330	5	0.61	0.60	0.56	0.00	10S, 10R
GB725	KU159331	2	0.33	0.34	0.28	-0.01	9S, 9R
GB726	KU159332	9	0.81	0.90	0.78	-0.06	11S
GB727	KU159333	3	0.66	0.68	0.59	-0.01	1S, 1R
GB729	KU159335	4	0.49	0.56	0.41	-0.06	4R
GB732	KU159336	6	0.53	0.52	0.44	0.01	1S
GB733	KU159337	4	0.34	0.36	0.32	-0.05	unlinked
GB734	KU159338	2	0.11	0.12	0.11	-0.02	5S, 5R
GB735	KU159339	3	0.23	0.22	0.21	0.02	NA
GB737	KU159340	2	0.48	0.42	0.36	0.06	unlinked
GB739	KU159341	5	0.53	0.62	0.47	-0.09	9S, 9R
GB740	KU159342	9	0.77	0.66	0.74	0.08	2S
GB743	KU159345	5	0.52	0.58	0.48	-0.07	NA
GB744	KU159346	6	0.70	0.78	0.64	-0.06	8S, 8R
GB745	KU159347	5	0.62	0.50	0.56	0.10	NA
GB747	KU159349	5	0.62	0.76	0.55	-0.11	NA
GB748	KU159350	9	0.78	0.78	0.76	0.01	9S, 9R
GB749	KU159351	5	0.58	0.68	0.50	-0.08	NA
GB750	KU159352	5	0.57	0.52	0.51	0.06	2R
GB751	KU159353	2	0.38	0.40	0.31	-0.02	9S, 9R
Mean		4.988	0.526	0.507	0.474	0.025	

Continued next page

Table 3. Continued.

Marker	GenBank no.	n ^z	H _e ^y	H _o ^x	PIC ^w	F(null) ^v	LG ^u
<i>Loci with three or more bands in a few accessions</i>							
GB462	KU131650	8	—	—	—	—	4R
GB501	KU159291	4	—	—	—	—	11S, 11R
GB535	KU159298	7	—	—	—	—	2R
GB568	KU159307	8	—	—	—	—	7S (gap)
GB594	KU159312	8	—	—	—	—	NA
GB609	KU306269	7	—	—	—	—	2R
GB610	KU306270	4	—	—	—	—	NA
GB613	KU306271	6	—	—	—	—	1R (poor fit)
GB615	KU306273	7	—	—	—	—	NA
GB634	KU306290	5	—	—	—	—	7S (gap)
GB644	KU306299	6	—	—	—	—	6S (poor fit), 6R
GB648	KU306303	9	—	—	—	—	NA
GB650	KU306305	18	—	—	—	—	1S, 1R (poor fit)
GB662	KU306315	6	—	—	—	—	NA
GB666	KU306319	9	—	—	—	—	4S (poor fit), 4R
GB704	KU159314	3	—	—	—	—	NA
GB707	KU159317	13	—	—	—	—	4S
GB708	KU159318	5	—	—	—	—	NA
GB728	KU159334	6	—	—	—	—	NA
GB741	KU159343	9	—	—	—	—	3S
GB742	KU159344	12	—	—	—	—	NA
GB746	KU159348	3	—	—	—	—	unlinked
GB752	KU159354	7	—	—	—	—	11S, 11R

^zNumber of alleles.^yExpected heterozygosity.^xObserved heterozygosity.^wPolymorphism information content.^vFrequency of null alleles.^uLinkage group.

accessions and the two parents of the mapping population (Table 1). The use of fluorescent primers and PCR products of different sizes allowed efficient post-PCR multiplexing of 5 to 7 primer pairs in a single well. For multiplexing, 2 µL of the PCR products from each primer pair were mixed and diluted with water to make a final volume of 150 µL. An aliquot of 1 to 1.5 µL of multiplexed PCR products was submitted to the Core Laboratories of OSU's Center for Genome Research and Biocomputing (CGRB) for fragment sizing by a capillary electrophoresis instrument (ABI 3730; Life Technologies, Carlsbad, CA) using ROX-500 as the size standard. GeneMapper® software (Life Technologies) was used for allele sizing and sizes were recorded in a spreadsheet. PCR amplification and capillary electrophoresis were repeated if the initial PCR failed or the result was ambiguous, and to verify unique allele sizes.

CHARACTERIZATION OF POLYMORPHIC SSRs. For polymorphic primer pairs that showed the expected one or two PCR products in all cultivars, PowerMarker software (Liu and Muse, 2005) was used to calculate number of alleles (n), observed heterozygosity (H_o), expected heterozygosity (H_e), and polymorphism information content (PIC). Observed heterozygosity is the number of heterozygous genotypes divided by the total number of genotypes. Expected heterozygosity estimates the probability that a randomly chosen individual is heterozygous at a locus and is calculated as $He = 1 - \sum_{i=1}^n p_i^2$, where p_i is the frequency of the i^{th} allele and n is the number of

alleles (Nei, 1973). The PIC value is a measure of marker informativeness and is calculated as $PIC = 1 - \left(\sum_{i=1}^n p_i^2 \right) -$

$\sum_{i=1}^{n-1} \sum_{j=i+1}^n 2p_i^2 p_j^2$, where p_i is the frequency of the i^{th} allele, p_j is the frequency of the j^{th} allele, and n is the number of alleles (Botstein et al., 1980). The frequency of null alleles (r) was calculated using Cervus software (Field Genetics, London, UK), which uses the formula of Kalinowski and Taper (2006). Genetic similarities between pairs of accessions were calculated as the proportion of shared alleles (P_s) and genetic distance was calculated as $(1 - P_s)$, resulting in a frequency-based distance matrix. For SSRs with one or two bands per accession, dendrograms were constructed using PowerMarker (Liu and Muse, 2005) and the unweighted pair-group method using arithmetic averages (UPGMA) algorithms. To include SSRs with more than two PCR products in some accessions, the genotype data for the 50 accessions at all new SSR loci were converted to binary format (i.e., dominant scoring) using an Excel macro (Rinehart, 2004). The dendrograms were visualized using Mega7 software (Kumar et al., 2016).

SEGREGATION AND LINKAGE MAPPING. For the newly developed SSR marker loci at which the parent genotypes of the mapping population [OSU 252.146 x OSU 414.062 (Mehlenbacher et al., 2006)] predicted segregation, all 138 available seedlings were genotyped as described above. The expected allele sizes were known, and genotyping was in multiplex sets of 10 to 14 primer pairs. Each allele was scored as present or absent in each

Fig. 1. UPGMA dendrogram of 50 hazelnut accessions constructed from binary data for 192 simple sequence repeat markers.

seedling, scores were tallied, and the expected ratio (1:1 or 1:1:1:1 or 1:2:1) was noted. Scores for the new SSR markers were added to those for previously mapped random amplified polymorphic DNA (RAPD) and SSR markers (Bhattarai and Mehlenbacher, 2017). Linkage maps were constructed using the

two-way pseudo-testcross method and the BC1 function in JoinMap 4.1 (Kyazma; Wageningen, Netherlands). Markers segregating in a ratio of 1:1 or 1:1:1:1 were scored as h, a or u for presence, absence, or unknown status, respectively, for each allele in each seedling. Similarly, markers segregating in a ratio of 1:2:1 were scored as h if present in homozygous state, a if absent (homozygous), and u if heterozygous or unknown status. Heterozygotes at loci segregating in a 1:2:1 ratio provide no information useful for mapping. Markers were assigned to linkage groups (LGs) using a median logarithm of odds (LOD) score of 12 (range 9 to 15). Maps were constructed separately for each linkage group using the maximum likelihood (ML) algorithm and distances shown in Haldane units (centimorgans). Markers that clustered loosely with the others and fell out at LOD scores <9 were removed. Markers present in repulsion phase were included in the map by creating “dummy variables,” the use of which allowed the merger of the repulsion phase and coupling phase markers, and generation of a single map for each linkage group in each parent. The JoinMap output was inspected for “Fit and Stress” and markers were removed in stepwise manner until the “Nearest Neighbor Stress” value for all markers was less than an arbitrarily set value of 7.60. The “Nearest Neighbor Fit (cM)” values were also inspected, as high values indicate blocks of markers that fit poorly with adjacent markers. In addition, the length of the gaps between markers was inspected, with gaps of >20 cM considered suspicious.

Results

SSR DISCOVERY AND CHARACTERIZATION. A search of the ‘Jefferson’ genome sequence identified 51,268 SSRs with repeat motifs of 2 to 8 bp (Table 2). Dinucleotide repeats (64.90%) were most abundant, followed by trinucleotide (16.99%), tetranucleotide (12.49%), pentanucleotide (3.43%), hexanucleotide (1.82%), heptanucleotide (0.37%), and octanucleotide (0.001%) repeats. The number of repeats in these SSRs ranged from 6 to 14 in the dinucleotide repeats, and decreased as the motif length increased. Among the dinucleotide repeats, AG and AT repeats were most common, representing 49.4% and 40.2% of the total, respectively (Supplemental Table 2). Among the trinucleotide repeats, AAT and AAG were most common, representing 43.1% and 28.4% of the total, respectively. The most common motifs were AAAT (55.0%) among the tetranucleotide repeats, AAAAT (36.3%) and AAAAG (25.7%) among the pentanucleotide repeats, and AAAAAG (18.3%) and AAAAAT (12.6%) among the hexanucleotide repeats. The focus of this study was the tetra-, penta- and

Fig. 2. Linkage maps of the hazelnut reference mapping population (OSU 252.146 x OSU 414.062). The new simple sequence repeat markers are indicated by * and bold font.

hexanucleotide repeats, for which the maximum number of repeats was 8, 6, and 6, respectively. Among the 192 polymorphic SSRs markers developed in this study, the most common motifs were ACGT/TGCA, AAAGG/TTTCC, and AGTTGG/TCAACC for the tetra-, penta-, and hexanucleotide repeats, respectively.

Fig. 2. (Continued)

Initially, the number of sequences containing tetra-, penta-, and hexanucleotide repeats was 9094. The number of sequences was reduced in stepwise manner, resulting in the final set of 192 polymorphic SSR markers (Table 3). Of the 9094 repeats, 4774 were removed because the repeat motifs contained only As and Ts. The removal of short fragments (<400 bp) and those with

Fig. 2. (Continued)

the repeats at the fragment ends further reduced the number to 1013. After alignment with the reference genome, 246 were scored as “polymorphic” as they showed variation in number of repeat units but conserved flanking sequences. An additional 17 were scored as “slightly polymorphic,” and 616 showed no polymorphism in number of repeat motifs. For 114 sequences, the reads of the seven cultivars aligned poorly with the reference, and for 20 sequences none of the reads from the seven cultivars aligned with the reference. Primers were designed for the 246 scored as polymorphic based on visual inspection of aligned sequences. After amplification of 24 diverse accessions followed by separation on agarose gels, 195 were scored as polymorphic. Fluorescent forward primers were ordered for these 195, which were then used to amplify and score allele sizes in 50 accessions after separation by capillary electrophoresis. Two primer pairs gave poor amplification in many cultivars, and one was monomorphic, while 192 new polymorphic SSR markers were pursued, of which 89 were labeled with 6-FAM, 70 with 5-HEX, and 33 with NED (Supplemental Table 1). Of the newly developed SSRs, 60, 66, and 66 consist of tetra-, penta-, and hexanucleotide repeats, respectively. Allele sizes at the 192 new marker loci in the 50 accessions are presented (Supplemental Tables 3 and 4). At 169 SSR loci (88.0%), all 50 accessions showed the one or two alleles expected in a diploid, and diversity parameters were estimated for them (Table 3; Supplemental Table 3). However, at 23 SSRs (12.0%), more than one accession generated more than two PCR products; for these the presence of each allele

Fig. 2. (Continued)

was scored in each accession (Table 3; Supplemental Table 4). In the 169 characterized markers (Table 3), 846 alleles were detected. The number of alleles per locus ranged from 2 to 17 with an average of 4.99. Expected heterozygosity had a mean of 0.53 and a range of 0.04 to 0.85, while observed heterozygosity had a mean of 0.51 and a range of 0.04 to 0.90. The PIC value averaged 0.47 and ranged from 0.04 to 0.84. GB726 was the most polymorphic marker ($H_o = 0.81$), while the four least informative markers (GB404, GB405, GB446, and GB616) had PIC values less than 0.10. Of these, GB405 had four alleles while the other three had only two alleles each. The average frequency of null alleles was 0.03, with values for individual

Fig. 2. (Continued)

Fig. 2. (Continued)

loci ranging from -0.20 to 0.59 . At the 23 primer pairs that gave more than two PCR products in one or more accessions, 170 alleles were present with an average of 7.39 alleles per primer pair (Table 3). Allele size distributions at the 192 polymorphic SSR markers are shown as histograms (Supplemental Fig. 1).

SEGREGATION AND LINKAGE MAPPING. A total of 135 loci segregated in the mapping population, of which 70 (51.9%) segregated in a 1:1 ratio, 35 (25.9%) in a 1:1:1:1 ratio, and 30 (22.2%) in a 1:2:1 ratio (Supplemental Table 5). New markers were placed in each of the 11 linkage groups, and the resulting genetic map included 132 new and 297 previously mapped SSR loci (Fig. 2). Three loci (GB733, GB737, and GB746) showed severe segregation distortion and could not be assigned to a LG (Supplemental Table 4). The lengths of the linkage groups ranged from 63.5 to 277 cM.

GENETIC DIVERSITY IN HAZELNUT ACCESSIONS. A dendrogram was constructed for the 50 accessions using the UPGMA

algorithm (Fig. 1) and allele sizes at 192 loci. The dendrogram confirmed the wide genetic diversity in hazelnut, grouped the accessions according to their geographic origins, and showed the four major groups seen in previous studies: Spanish-Italian, Black Sea, Central European, and English (Bhattarai and Mehlenbacher, 2017; Boccacci et al., 2006; Colburn et al., 2017; Gökirmak et al., 2009; Gürcan et al., 2010). The Central European group includes four cultivars of German origin (Gunslebert, Hall's Giant, Gustav's Zellernuss, and Early Long Zellernuss), as well as 'Bergeri' from Belgium and 'Alli' from Estonia. The Black Sea group includes six accessions from Turkey and one from Republic of Georgia. The English group includes 'Cosford' from Reading, England, 'Rote Zellernuss' from the Netherlands, and 'Buttner's Zellernuss' from Landsberg, Germany. Their adjacent placement in the dendrogram suggests that the latter two might be seedlings of 'Cosford'. The ornamental 'Contorta' originated in England, as did 'Du Chilly', which is grown as 'Kentish Cob' in southeastern England. 'Pellicule Rouge', obtained from France, has leaves and pellicles with anthocyanin, but all other traits and its DNA fingerprint are identical to the English cultivar White Filbert

Fig. 2. (Continued)

Fig. 2. (Continued)

(Gökirmak et al., 2009). ‘Des Anglais’ was obtained from Bordeaux, France, but its name indicates an English origin. All of the Spanish and Italian cultivars were included in the large Spanish-Italian group.

Discussion

The high throughput and low cost of next-generation sequencing allows plant genomes to be sequenced and SSR markers to be developed efficiently as a by-product of genome sequencing. In hazelnut, we identified 9094 ‘Jefferson’ genome sequences that contained tetra-, penta- or hexanucleotide repeats and proceeded in a stepwise manner to develop polymorphic SSR markers from them. Of the 1013 sequences for which aligned sequences were visually inspected, 246 showed variation in number of repeat units but conserved flanking

sequences. After primer design, amplification, allele sizing, and characterization, this number was reduced to the 192 new polymorphic SSR loci described in this paper, of which 169 amplified only one or two bands in all cultivars, as expected in a diploid species. The ratio of single-locus polymorphic SSRs developed to number of primer pairs designed was 68.7% in this study, compared with 28.5% for the mostly trinucleotide repeat SSRs developed from transcriptome sequences (Colburn et al., 2017) without in silico evaluation. The comparison illustrates the improved efficiency that results from this evaluation. For the dinucleotide repeat SSRs developed from enriched libraries, the ratio was an intermediate 57% (Gürçan et al., 2010). Although single nucleotide polymorphism (SNP) markers can be generated in large numbers by procedures including genotyping-by-sequencing [GBS (Elshire et al., 2011)] and double digest RADseq (Peterson et al., 2012), SSR markers continue to have many research and breeding applications in plants. In hazelnut, for example, Öztürk et al. (2017) studied associations of SSR markers with nut and kernel traits in a Slovenian hazelnut collection, and Marinoni et al. (2018) used SSR and SNP markers to identify QTL in a seedling population from ‘Tonda Gentile delle Langhe’ x ‘Merveille de Bollwiller’.

Most of the tetra-, penta-, and hexa- SSRs identified in this study were composed of only As and Ts (52%). The very high

Fig. 2. (Continued)

frequency of A and T bases in SSRs have been observed in many other tree species (Xia et al., 2017). Mononucleotide repeats, although abundant in the hazelnut genome, were not pursued as they tend to be difficult to score. Dinucleotide repeats were not pursued as large numbers had previously been developed (Bassil et al., 2005a, 2005b; Boccacci et al., 2005, 2015; Gürcan et al., 2010; Gürcan and Mehlenbacher, 2010a; Sathuvalli and Mehlenbacher, 2013) and stuttering is a common problem with dinucleotide repeats (Hearne et al., 1992). Colburn et al. (2017) developed 111 SSRs from transcriptome sequences, most of which were trinucleotide repeats, and Bhattarai and Mehlenbacher (2017) developed 150 trirepeat SSRs from the Illumina draft genome sequence for 'Jefferson'. This study adds 192 markers to the 525 previously developed, and further saturates the genetic map. Previous studies (Bassil et al., 2005a, 2013; Boccacci et al., 2005, 2015; Gürcan and Mehlenbacher, 2010b) showed a high rate of transferability to other *Corylus* species, and lower transferability ($\approx 30\%$) to the

Fig. 2. (Continued)

genera *Betula* and *Alnus*, which are also in the family Betulaceae. Thus, the SSR markers developed in this study could have applications beyond *C. avellana*.

Of the new polymorphic SSRs developed in this study, 23 primer pairs amplified more than two bands in some hazelnut accessions. SSRs of this type were previously reported in hazelnut (Bhattarai and Mehlenbacher, 2017; Gürcan and Mehlenbacher, 2010a) and other plant species (Chavarriaga-Aguirre et al., 1998; Kim et al., 2014). We attribute this to either nonspecific amplification or genome duplication events, including paralogous sequences.

The count of private or unique alleles (occurring in only one individual) is 201 at 103 SSR loci (Supplemental Table 6). These unique alleles were confirmed by repeating the PCR and allele sizing. Null alleles, which fail to amplify with PCR, are the result of a mutation in either one or both primer binding sites of the genome sequences. The presence of null alleles leads to errors in pedigree and segregation analysis (Dakin and Avise, 2004; Pemberton et al., 1995). The mean frequency of null alleles was low ($r = 0.03$), although a few loci had high values and 16 (GB405, GB409, GB421, GB454, GB461, GB465, GB505, GB532, GB602, GB624, GB640, GB646, GB649, GB671, GB718, and GB721) had values >0.20 .

The UPGMA dendrogram, based on binary data of allele sizes at 192 SSRs, showed accessions clustered according to their geographic origin into four main groups: Central European, Black Sea, English, and Spanish-Italian. This grouping is

Fig. 2. (Continued)

similar to previous studies (Boccacci et al., 2006; Colburn et al., 2017; Gökirmak et al., 2009; Gürcan et al., 2010). The dendrogram (Fig. 1) shows a high level of diversity in the 50 accessions, including 13 diverse accessions at the top that did not cluster with any of the others (Fig. 1).

Of the 192 new SSR markers, 135 segregated in the mapping population, of which 132 were placed on the map and three with distorted segregation remained unlinked. Segregation ratios at 135 loci (Supplemental Table 4) were examined for goodness-of-fit to expected ratios. Poor fit to Mendelian expectations ($P < 0.05$) was observed at 20 loci, of which 11 showed very poor fit ($P < 0.01$). Several SSRs did not segregate in the reference mapping population. Their map locations may be determined in future research using alternate mapping populations, or by alignment with a mapped genome sequence contig. Linkage groups are presented separately for the female and male parents (Fig. 2). The female parent map consists of 11 distinct linkage groups, while the male parent map initially had 10 distinct groups, with LG2 and LG7 merged into a single large group, as first encountered by Mehlenbacher et al. (2006) and more recently by Beltramo et al. (2016) for a population from 'Tonda Gentile delle Langhe' x 'Merveille de Bollwiller'. Reciprocal translocations are common in hazelnut (Salesses, 1973; Salesses and Bonnet, 1988), and may be responsible for this merger. We separated LG2 and LG7 in the male parent map following the method of Colburn et al. (2017)

and present 11 groups. The newly developed markers were assigned to all 11 LGs (Fig. 2), but were not evenly distributed.

Four markers (GB478, GB456, GB605, and GB671) were placed on LG6 < 20 cM from the locus from 'Gasaway' for resistance to eastern filbert blight (EFB) caused by *Anisogramma anomala* (Mehlenbacher et al., 2006), although none are closer than four SSRs developed from BAC sequences that cosegregate with the allele for resistance (Sathuvalli and Mehlenbacher, 2013). EFB resistance from five other sources maps to the same region (Bhattarai et al., 2017b; Colburn et al., 2015; Sathuvalli et al., 2012). Three other markers (GB467, GB482, and GB642), were assigned to LG7 in the region of the EFB resistance loci from 'Ratoli', 'Yoder #5', and *C. americana* 'Rush' (Bhattarai et al., 2017a; Sathuvalli et al., 2011a). Four markers (GB609, GB618, GB669, and GB740) were placed on LG2 near the EFB resistance locus from Georgian selection OSU 759.010 (Sathuvalli et al., 2011b). These new markers will be useful for mapping additional EFB resistance sources and developing breeder-friendly DNA markers in these regions for use in marker-assisted selection. Additionally, GB646 was placed on LG5 near the S-locus that controls pollen-stigma incompatibility (Ives et al., 2014; Mehlenbacher et al., 2006).

The genomic SSRs developed in this study add to those developed previously and will facilitate research in hazelnut genetics, including cultivar fingerprinting, parentage analysis, studies of genetic diversity, mapping of qualitative trait loci and QTL, marker-assisted breeding, and the fine mapping and cloning of genes. Because SSR markers map to the same location in different populations, they allow the alignment or merger of genetic maps from different crosses. In addition, the mapped SSR markers will allow alignment of the linkage map with the genome sequences and the physical map of BAC contigs.

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Supplemental Fig. 1. Histograms showing allele frequencies at 194 new simple sequence repeat loci in hazelnut.

Supplemental Fig. 1. (Continued)

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Supplemental Fig. 1. (*Continued*)

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Supplemental Table 1. Repeat motifs, amplicon size, primer sequences, and annealing temperatures (Tm) of simple sequence repeat markers developed from the ‘Jefferson’ hazelnut genome sequence.

Locus	Repeat motif	Size	Primers (5–3’)	Tm (°C)
GB401	(AACC) ₄	183–196	[6FAM] CCTTTTCGCTCATCATATCCA TTTGTGTGTGGGTGTAGATTCC	60
GB402	(ACGC) ₄ (TCCT) ₄	166–170	[HEX]AGTACGAAAACTGCGTGTCAAAA AACAAACAAAAACAAACGCCC	59
GB403	(ACGT) ₄	152–156	[HEX]TAATAAATGGCTCCCGAAGAGA GGGTTTAGAGAAGCTCCCTCAT	60
GB404	(AGCA) ₄	122–126	[6FAM]AGAGGGCTCGGCTCTACATAA CTCGATCTCATCCTTGCTTGTT	60
GB405	(AGCT) ₄	173–177	[HEX]GGCCCTATAAATACCTTCTTCTCC CTCTCTCTCTCTCTCTCAAGCC	59
GB407	(AGGG) ₅	175–191	[HEX]CACAGCCTTCTTCCATCTCTTT TGCTCTCTTTTCTTCTCTGCTG	59
GB408	(AGTG) ₅	158–166	[HEX]AGATCAGCTAGAAGCAATTCGG TTGGATAACTTGGGGCTGTTT	60
GB409	(ATCC) ₄	157–161	[HEX]TCTCCTCCCTCTCATCCTT AACGGCTGAAAAAGAAATAGCATC	60
GB410	(ATCC) ₄ AG(CCAT) ₄	157–173	[HEX]CCTCTACTATCTAGGAAGCCCCA ACTTTGGCCTTTTGGACTTTG	60
GB413	(CCAG) ₄	187–197	[6FAM]CTGCTTCATGTGGAATGTTGT ACATAGGGTAGAGCTGTGGAGC	60
GB414	(CCAT) ₆	106–118	[6FAM]CAAGAGAGAGGGATGGTACGTT AGAGGAAGAGGATTGATGGATG	59
GB416	(CCTC) ₅	239–257	[NED]ACCGTATGCTGATTTGTATGGG CTGTGTTCTCTTTTCTCTCCAC	60
GB417	(CTAG) ₄	174–178	[6FAM]TACTGTGAAATGTGGTCACTGC ATGTTGCAGAATTGAAGGAAAA	59
GB418	(CTAG) ₅	205–217	[6FAM]TATTGGAGCCACAGAAGACGTA GAAGCGCACTGGAGTTTATTTT	59
GB420	(CTAG) ₇	211–227	[NED]CAATAGGTGTAGATGACGTGGC AACGAGTTTAAGCAACAATCCC	59
GB421	(CTGC) ₄	230–232	[NED]AGAGACCGCCATCATTCTAAAG ATTAAGATCACAACCTGGCTGGG	59
GB422	(CTTC) ₄	221–237	[6FAM]CTCTCTCCTTGGCACTCACAC CTTTGATGGGTTTGTCTCTTCT	60
GB423	(GAGC) ₅	285–297	[6FAM]GTCAAAGCTGAGGAATGGTTTT TCGGTTGTCACTTGGTCAATTA	59
GB424	(GATA) ₅	278–286	[6FAM]ATCACCTCACATGACACACCTC GCTGAAGAGCCATAAACAGACC	59
GB425	(GATG) ₄	295–299	[6FAM]CTTAGGTTTACGTGGCTGTTCC TCCGAGGTGTGATGTTAAGAAA	60
GB426	(GCCT) ₆	285–300	[6FAM]AAACTGGAAGAGAAAGTGCAGG GAACTGACCTGGCTTGAGTCTT	60
GB427	(GCTA) ₄	199–203	[6FAM]TTCTTCTTCTTCTTCAACGCC TAAAAGCGTGGCAGTAAATCCT	60
GB428	(GCTA) ₅	240–244	[NED]TGATCTGTGTAAGGGAAAGAAGC TAATGGACCCAAAGAAACCAAC	59
GB429	(GCTA) ₆	241–265	[NED]TCCTTCTTCCAAACATCTTGA TCTAATCCATCCACAATGGTTC	59
GB430	(GGAT) ₄	292–304	[6FAM]CTGAGCAAGCCAATAAAGCAT ATCCGGTTCTTCCACAATACAT	59
GB431	(GGCA) ₄	368–379	[6FAM]TCATAGCAAAGGGAATCATCAC GTTTATTGTGGTGTGGGTTCTG	59
GB432	(GGGA) ₅	312–321	[HEX]AAACAAGGGAAATCGTGCC AGGATGAGCTGTGAAAGAAAGG	59
GB433	(GGTT) ₅	147–152	[6FAM]GTCAAACCGTGGTAAAGGAAAA AGAAACCCGAACCTAACCTAGC	60

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Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	T _m (°C)
GB434	(GTAT) ₅ (CATG) ₄	335–347	[HEX]AACCATCTCCCTTCTCTGTGA GCCGAGGTGAGTAAATGGATAC	60
GB435	(GTAT) ₅	89–98	[6FAM]ATTCTATTTCGCACCAAGCAAG ACTTTACCATCACATCAATGGC	59
GB436	(GTCTG) ₅	122–126	[6FAM]AACAGCAAACTACCGATGGAT CTCGTGCAAATGTTGAAAAGTC	59
GB437	(GTGA) ₇	334–340	[HEX]GCTTCTTGGAGGGTTCTGC GCCAGAGCGTAAGAGAGAGAGA,	59
GB438	(GTGC) ₄	311–319	[HEX]AGAAGAAAAGAAGGGACTGAAGC GCTGGTATGAAATTAGCCAAGG	59
GB441	(TGCG) ₅	178–182	[HEX]CATTGCCATCGGTGTATGTG ATGCTTTGGGGCTTCTAAATCT	60
GB444	(GTCT) ₅	305–321	[6FAM]GCAGAAGCAAACAACTATCG TGTCAGGGTTAAGGACTGTTCA	59
GB445	(AGAC) ₄	135–139	[HEX]CCATACTTGCTTCAGAGATGAGAA CGAGCTTACATGGATTTTGGAT	60
GB446	(CCAT) ₄	130–134	[6FAM]AAAGGGTCTGGTTAATGAGTGC GCTCTCTTCGCTCAAAGTACAA	59
GB447	(AAGCA) ₄	172–187	[NED]TGGTAAGAGCATTAAACCCACAA AGCTGGCAATGAAACATCTTCT	60
GB448	(ACACA) ₄	179–184	[NED]ATTCGTTTCATCCCCATTACTTG ACGTCCAGAAAAACAAACATCCT	60
GB450	(AACC) ₅	327–339	[HEX]GACAACTAGGTGGCAAACAGC TTAGTTGATTGGCTGGAAGAA	60
GB452	(ACGC) ₅	203–214	[6FAM]TATACCATCCCCGTTTGCAT CTATCCAGCTGCCATGTGAA	60
GB454	(AGCC) ₅	245–249	[NED]GCGTGGATCAAAGATTGTCA CTCCGGGGAGAACTGTGTA	60
GB456	(AGCT) ₅	104–112	[6FAM]AAAAGCCACACCCACTTCAC GGATGGCTCAACACATACCA	60
GB457	(AGGA) ₄	197–201	[6FAM]GACAATCAGTGGCTGCAAAA TTGTTGTTGTTGTTCCAAAGC	59
GB458	(AGGC) ₄	295–302	[6FAM]TTAGCTGGCTGGTTTGTGTG AGCGTTGAGGAAAAAGGTGA	60
GB461	(CCTG) ₅	273–281	[6FAM]CTAAATCGTGCCGTTGGTTT TTCAAACCTTGGTGATCCGTAA	60
GB462	(CGCT) ₄	224–234	[6FAM]AAACCCTAGGCGAAATCGAG TCCAAACGAACAACACGAAA	60
GB463	(CTAG) ₄	283–296	[6FAM]TGCAGGTACTCCAGCTCCTT TAAGTTGGCTTGGTGGTGCT	60
GB465	(CTCA) ₅	263–277	[NED]GGCGGAGCTAATAGGAAACA TGTGGGTCAATGTGGGTTC	60
GB466	(GAGG) ₄	102–110	[6FAM]TCCATGATCAGGTCTGCTTG TCATCCCATAGAGCAAACCTCAA	60
GB467	(GCAC) ₄	336–352	[HEX]AAAGGACAGGCTGCTTTCAA TGAGGTTTTAACC AAAACACAAAA	60
GB468	(GCAT) ₄	355–377	[HEX]GTCGGACGGCTAATGAAGAA CACACAACCTATTTGGGTTTGAA	60
GB469	(GCAT) ₅	328–340	[HEX]GCTAGCGTGTCACTCTGAGGAT AGACCGAAACTGGTGCAATT	60
GB470	(GCGA) ₄	381–400	[6FAM]CAAACCTTTGACCTCCTCCA GGGCCAAACAGAAACAGAGA	60
GB473	(GGGA) ₄	189–198	[6FAM]GGGGTCCCTTAAACGAAAAA GAGACGATTAAATCAACAGCTTG	60
GB475	(GTCT) ₅	183–187	[HEX]GCTTTGGCGAGAACTACGTC CTGCAAATGCCCAATGAAAT	60

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Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	T _m (°C)
GB476	(TGCA) ₄	295–298	[6FAM]TTTTGGCTTTTGGGTTTGAA CCCATTCATTGCTGTTTCT	60
GB477	(TGCA) ₄	337–345	[HEX]TTTATGGCCTGCATTTCCCTC GAGAAGATGCTGGGGAGGTT	60
GB478	(TGCA) ₆	383–394	[6FAM]AGGCGTCTCACCCAATAAAA TGTTTTTCAGCCCCAAGAATC	60
GB480	(TGCT) ₅	263–277	[NED]TGGAGGCACCCCAACTAATA GGGCCTTTGAGAAAAACAAA	60
GB482	(TGTA) ₄	132–140	[6FAM]TGTTTCATTTTCTTTCGGATCTT TCAGTTGGGGGTAGAGATCG	60
GB483	(TGTA) ₆	355–359	[HEX]TAATGCCATGAACCACCAAA AGACGTTTCCCTCTGCCAAAA	60
GB501	(ACCCA) ₅	178–188	[6FAM]TCCACTTTGTTTAGATCCTCTGC AAAAGCGTGTGTTCAAGAGTCA	60
GB504	(AGAAG) ₄	178–193	[HEX]ACCCCAAGAGGTGTTTGGTATT GAAACGTGAATGGTGGACAAGT	60
GB505	(AGAAG) ₄	271–286	[6FAM]TCTTGGAGACCTCAATGCACTA TTGGACTCTCATTATTCTACGGC	60
GB526	(CATCA) ₅	88–98	[HEX]CAACCGCCATTTTCAATCTACT AACGGCTGACGAAGTTGC	60
GB527	(CCATT) ₄	110–125	[HEX]GGAAACAGAGCAGGAAAAGGAT GGTTAAGATCGTTGTGGGACAT	60
GB532	(CCCTC) ₄	360–377	[HEX]CTCTTCGTGGTTTGGGTAAAA AGGCGATTCTTTGGATGAGTT	60
GB533	(CCCTC) ₅	121–131	[HEX]GTCAGTCCCAGTGATCCAGAG CTGAAAACAATAGGGTGGTCCT	60
GB535	(CCTGC) ₄	203–218	[NED]ACTTGACACTTGGCACTACAGG GGGTTTTGATATTCCTTTCACG	60
GB537	(CCTTG) ₄	181–186	[6FAM]GTCCTTTTCCAATCTCTTTCCC GGAGGTCAGTAGAGCAAGGTGA	61
GB544	(CTGCA) ₅	389–394	[6FAM]CTGGGCATGATAAAACCATAAG ACGGAGGCAGAGCATAAGTATT	60
GB545	(CTGGT) ₄	190–195	[HEX]ATTCCCTCACCACCCATTTT AAAGGTGCATGACAATTACGTG	60
GB548	(CTTTG) ₄	146–151	[6FAM]GAAACTCTCTCACAGCAATTCTG ATGGTGAATGATCTCCCTAACA	59
GB551	(GAAAG) ₄	121–131	[HEX]CCTCGATAAAGAGAGAAAGTGGC GAAGGAAAACATCACGCAATAG	59
GB560	(GAGAA) ₅	164–174	[6FAM]AGAAAGGGAAGAAACGACCAC GCACACACACACACAGAGTT	60
GB563	(GAGAG) ₅	185–195	[HEX]GTCAAGTCTCAGGTAGATCGGC ATCGTTCAGATTGGTACACGG	60
GB565	(GAGGG) ₄	176–181	[HEX]AAGCAGTATCTTCCGACCAAAA GCTCTTTCTCCAACCATTGTCT	60
GB568	(GATGT) ₄	90–108	[HEX]CAGGACATGGAGCATTAGAACC CATGCACGGCCATTGAGT	62
GB577	(GGCCC) ₄	165–170	[6FAM]CTCCTATACCAGGCCACATCC TGGAGTAGTTGCAGAGTGATGG	61
GB580	(GGGTT) ₄	184–189	[HEX]TGTGCCTGATGAAAATACTGGT CCTAATGGGCTTCTTGGTGTAG	60
GB581	(GGGTT) ₄	105–115	[HEX]AGCTTAATCGCCGGATAGTG AAGATGATGAACCCATTCCAAC	60
GB587	(GTGCG) ₄	175–185	[HEX]TAGTTGTCTGAGGGTTTGTGC GTCTTGAGCTGGTCCTTGAAT	60
GB594	(TATGC) ₅	172–186	[6FAM]TGGTCTTACTCTCCTCGTAGGG GTGTTTTGTGATTTCAGCAGGA	60

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Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	T _m (°C)
GB601	(AATTCC) ₄	157–169	[HEX]CCACTCCACTCTCCCTATCTTC AATCTGGTTCTGGCAAATGG	60
GB602	(CAATGT) ₄	234–246	[NED]CCGATGGAGATCGAAAAGAGA GGCGCGATTGTAAATCAAAA	60
GB603	(CCCAAG) ₅	162–180	[HEX]AGAAAAGAGATAGGCTTTTGGGC AATACCTCCTACATAGCCACCG	59
GB604	(GTGACA) ₄	191–197	[HEX}GAGACCAGTCGCATGAAGAAAT GGAAGTTTAGGCACCAAGGAC	60
GB605	(TAGCCA) ₅	118–124	[6FAM]TCGATAGTGGGCATTCTACAAA CAAAACTCAAAAGACAAGACGC	59
GB606	(CTTCTA) ₄	316–330	[6FAM]AAGGAGGAGTGTCTTACCC TCCATGACAATCACTGCAGAA	60
GB609	(GAAATT) ₄	311–341	[6FAM]TTTTTGAGCCAGAGAATGC ATGGAGTACCGCTCGTATGG	60
GB610	(CCAAAC) ₄	86–103	[6FAM]GAACACCCCAAGTAGATCCAAC GAATCATGCTATGTCAATGGCT	59
GB613	(GATTGT) ₅	121–139	[6FAM]GGTGAAGGTCTAGTTTTGTGCC GCCGTACCACGTCTAAAGAAAG	60
GB614	(GGTTGA) ₄	365–371	[HEX]TAAACCTGCACATTCGTCAACT CTGCTTGCTGCTTCTCATTT	60
GB615	(CAGGCT) ₅	269–287	[NED]GACCAGGAACAGGAACAGGA ACGAGAGCCGTCTTCAAAAAG	60
GB616	(CTCCTG) ₄	359–365	[HEX]AAGTCAGAAAACCTGAAACCCC GTTGCTATGAGATGGTTGCTTG	60
GB617	(GCAGAG) ₄	100–118	[6FAM]TCGTATGAAGTGCAAGAGGGTT CTCTCAGCTCTCACCCCATGT	61
GB618	(GTCCCA) ₄	322–328	[6FAM]GACGACATCGTTTCCTGCTT CAAGTGTCACACCGAACCAC	60
GB619	(ACTAGG) ₅	138–150	[6FAM]AGAGGAAGAGAGAGGGTTCGAG CCACTCATCACACGCTAACATT	60
GB620	(TCACTT) ₄	199–221	[6FAM]TCTTGGGCTCCAAGCACTAC TACGCATTTGGACGTCTCTG	60
GB621	(GAGTCG) ₄	100–117	[6FAM]ACTCTTTCAGCACCCCTCTCCTT GGAACCGCTCTCGGTGAT	61
GB622	(CCACAA) ₅	113–125	[6FAM]CAAACAAGAAAGATGGGTGAGC CATAGTGTCTGCGTTGGGAAT	60
GB623	(TCCTTC) ₄	377–383	[HEX]CATCAATCAGAATCACTGCCAT TAGGAAAAGGTAAGGTCGTCA	60
GB624	(CAAGAC) ₄	263–269	[NED]ACCTCAAATCTATGCAAAACGC AGGTGGAATCTCTGCTCACAAC	61
GB625	(AAGCCC) ₄	224–244	[6FAM]CACGAGGAGACTGACGACAA GCGACCTTTGGAGTTGAGAG	60
GB626	(CTGAAC) ₄	139–146	[HEX]TCTATCTCCTCCTCCATACTCCG CAACCTCTCTGTTGGGCTTG	61
GB627	(CTCTTC) ₄	348–360	[HEX]GCAGCAGGTTGTGTCCACT ATTTGCGTCTTCGTAAGTTGGT	60
GB628	(GTGATG) ₄	342–360	[HEX]GCCAGTTCAAAAGATTCCATGT AAAACCCAAACATCATAAACCAA	60
GB631	(TTCTCT) ₄	92–98	[6FAM]CAACAGAGCTAAACGAGAGGAAA CGAAATGAGCTTCGACTAGGAT	60
GB633	(GGGATA) ₄	116–122	[6FAM]GTCAATCCCAAAGACGATAAGC TCTGGTGCGACTAACATCCTC	60
GB634	(CGAGAG) ₄	375–386	[NED]AAAACCACGATTGGAGATGG AAATACCGTCCATCGTGTGG	60
GB635	(GTCGTT) ₆	130–144	[6FAM]CCCATAAAACCTAATCCCCTTT CTGCTATGAATACGAAACGCAA	60

Continued next page

Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	Tm (°C)
GB636	(GAAGAG) ₄	250–262	[NED]GCTTCTCTGTCTCCACACC TCACCGTAATCCTCGTCCTC	60
GB638	(GTGGGA) ₅	318–324	[6FAM]CACGGTGCAGCTCTTATGTG TCTAGGTTTGTGTCCTGTGAATG	60
GB639	(CATCCA) ₄	362–374	[HEX]TCTCGGCAGCAGCAAGAT TTCTTTGGTCCTTAGTGCGAT	60
GB640	(GAAGCC) ₄	346–360	[HEX]GGCCCTTTCTCCGTAATAAAC GTGGATGCAGTTTGAATGTCAG	60
GB641	(ACACTC) ₄	139–152	[HEX]GTTGTAGCTGAGGGAGGGTCTA AGCCTAATTTGCGGGGAA	60
GB642	(GCAACA) ₄	361–367	[NED]CGATCCCTCCGAAACTGTTA TCGCAGAGCACGTAGATGAC	60
GB643	(CAGCCA) ₄	232–250	[NED]TGAAAGGTAGCTGATGGGGTAT AAGCGTCCATGACAACAAAAAC	60
GB644	(CACTCC) ₄	239–257	[NED]TCAGACACCTGATCCCAAAAC GCGTGGTATTAAAGGGAGAGTG	60
GB645	(AATGGC) ₄	286–298	[6FAM]TTAACGCAGGTGGGTGAAT ATTGATTTGCATGCACCGTA	60
GB646	(GCCTGT) ₄	273–291	[6FAM]GTAGCAGACGCAGAGTCACG GAGAGGCATGAGAGGTCTGG	60
GB647	(GTTTGG) ₄	165–177	[HEX]CTTCTCTGGCGATCAAGAAACT TCAAATATCACGTTCTCTCTCC	60
GB648	(CTCTCC) ₅	257–277	[NED]CCTTTTACCAACAGCCCTCTTA CCAACAAACTCACAATAGATAGCG	60
GB649	(GTGAGT) ₅	251–264	[NED]GGACATCTTTGGTGAGATGTGA TAGCTGAGGGAGGGTCTACG	60
GB650	(CATGGG) ₄	314–332	[6FAM]TTAACCCAGCCGAGTTTCC CTCTCGCTACACATGATCC	60
GB652	(CCACAA) ₄	210–230	[6FAM]CAAACGCTGGCCCTTTATTA CTGTTGAGCTTGCGAGAATG	60
GB653	(GATGGT) ₄	199–209	[6FAM]AGGTTTTGATTTTGCCATCG TCCACCATTGGAATCCTACC	60
GB654	(AGGGAG) ₄	273–279	[6FAM]AGGGGTCCATCCCATTAGAA ATCTTTCTGGTTGCAGCTTGAT	60
GB655	(AGCCCG) ₄	235–253	[6FAM]TCATATCTGGCTACTCAGGCAA GACTCTGTCTGGCAACATTT	60
GB657	(CACTCC) ₄	192–203	[6FAM]ATAGCCCTCCATGCCACTACT CGTAAATGAAACAAGCCATCTG	60
GB658	(TCCACC) ₄	330–351	[HEX]ACCACAAAATCAAGCCTTCG CAAGTGAAAATGGGCCAGAT	60
GB659	(CACTCC) ₄	210–222	[6FAM]AATAGCAAAGGAAGCAAGGACA GTTGGTGTGGGGAGATGAGT	60
GB660	(GACGGT) ₄	209–221	[6FAM]GGTCTGTGTGGCTCCTGTTT GTTTCGTAGAAGCGCAGGTC	60
GB661	(AAGGAG) ₄	205–217	[6FAM]AGCTTTCACGAGACCCAGAA GCCAAAGCCCATATCAGAAA	60
GB662	(TGATGC) ₄	252–264	[NED]GGGATTGAGTTGGCCCTAAT AGCCGAAGGATATCGCTGA	60
GB663	(TCTTCC) ₄	133–139	[HEX]GCACTCTTTGTAGATGACCATGA GGTGGGGATAAGAAGAAGATGA	59
GB664	(GATGCC) ₄	302–308	[6FAM]AATAAGAAAAGCCCGAGGA TTAGCCCACTTTGCCATT	60
GB665	(GTGGGC) ₅	175–193	[HEX]AAGGAAGGTAGCTGTTGTCGTC TATCCTCAACGTATCCACCTCC	60
GB666	(CCACTT) ₄	181–196	[HEX]CTGCTTGCCTGAGACGAAT GCAGACCCATTACACAGAGATG	60

Continued next page

Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	T _m (°C)
GB668	(GACTCG) ₄	177–183	[HEX]AAGACGACGCTAACACGTTCTC TCTTCGGATTTAACACCTTTCG	60
GB669	(GGTAGT) ₄	111–117	[6FAM]GTGGAATAAGCAAGAGTGGGTC CTCTACTGTGCAGCTCGATCAC	60
GB670	(TGGCGA) ₄	253–270	[NED]AAATGGGTTTGGTGCAGAA ATGTAAATAAGCGTGGGACCAT	60
GB671	(TTGGGC) ₅	234–302	[NED]TTCCAGTTTAAGACCAGACAAGC CACATTTGGGAAGACCCTAAAA	60
GB672	(GATCAC) ₄	218–230	[6FAM]AAAACATGGTGAGATTTGGGAC CATGAAAACGGCTCTGGATTA	60
GB673	(TCACCA) ₅	354–377	[HEX]CAACAATGGGAATGTTGCAG GGGCCAATAGCAAAAAGTTCA	60
GB674	(CCAACC) ₄	163–173	[HEX]GCATGGTGTGAAAGCAAGAATA GAAAACAGGGGTTTCGATCAAT	60
GB675	(CACCAA) ₅	344–362	[HEX]ACCTCCATTAACACGCCTTG AGAAGGCTAGGCTCACACCA	60
GB676	(ATGAGG) ₄	339–345	[6FAM]ATGGGGTTGATTGTGAGAGC GCTTGTCAAATTGGGTGGTAA	60
GB678	(CCCAGG) ₄	193–225	[6FAM]CCCATGTTCTGTTGTAGCATT TTATGACCCATGACACGAAGAG	60
GB702	(ACCGA) ₄	181–191	[HEX]ACACTCGCTCCGAATTTTCA TTCCTCTGCTACTGCCGTCT	61
GB704	(AGAAC) ₄	107–117	[HEX]AAAGCATAAGCAGAGATAGTCAAACA GTTATTTGTTGCTATTGATTTTT	60
GB705	(AGAAG) ₄	217–220	[NED]CGGTGGGAATTCAAAATCTG CAGATTCAATGTTATGGTCATTTT	60
GB706	(AGAGA) ₅	369–378	[6FAM]CTCGACAGTCCTCTCCTGCT AGTTGTTTCACTGCCCTCCA	60
GB707	(AGATG) ₄	207–241	[NED]AGTCCTGTGAAATGGGTG TTGTTCTTCGGCTCTGTGAA	60
GB708	(CAAAC) ₄	152–172	[HEX]CTAACAGGCATGAGGCATGA TTTGTAGAAATGGGCAACACA	60
GB709	(CACCA) ₄	261–269	[6FAM]GTGGATGACTGGACGTTGTG TTGCGGATTCTTCATCATCA	60
GB710	(CAGCT) ₄	121–126	[HEX]TTCTCTACGTGGCCGTTTTTC TGCTCCTCTCCTCCTCACTC	60
GB712	(CCAAT) ₅	124–139	[6FAM]CGCACTCTGCTTCACTTTCA GAACCCCTCGCTCTAATTC	60
GB716	(CTACT) ₅	140–151	[6FAM]ACAAGCTTGACGACCAAAACC TGGTGCAAATGGGTATCAAA	60
GB717	(CTCAT) ₅	214–224	[HEX]AAGCACGTTTAGGCCTCTCA GGTGTGCACAACCTATGTGGTAA	60
GB718	(CTCCC) ₄	393–405	[6FAM]CGAAGACAGAGAGGGAGGTG AGGGGCTTAGAGGCATGAAT	60
GB719	(CTCCT) ₅	297–311	[6FAM]TTTTCTCTTTGGTTTTGCTTTT TGGTCTCTATTGGGACTTTGC	60
GB720	(CTCGG) ₅	366–376	[HEX]TGGGGTGTAAGATGTGCCTA CGGGCACACACATATATCCA	60
GB721	(CTTCC) ₄	374–388	[6FAM]TCCAATAAAAACAGCGCAAT GGAAGCATATGTGGGTGGTT	59
GB722	(CTTCT) ₄	254–265	[NED]TCCTTGTAACCTGGAGGAC CCTAAATTGGACGCGTTGAT	60
GB723	(CTTGT) ₄	257–262	[NED]CCAGGAATGTCGCTACCACT TTGTTGGTCACCTTCCTATGC	60
GB724	(GAGAG) ₄	209–221	[NED]GCTGCGTGAGACTGTGAGAG CTTGATGCGTGGCTAAAGGT	60

Continued next page

Supplemental Table 1. Continued.

Locus	Repeat motif	Size	Primers (5–3')	T _m (°C)
GB725	(GAGAT) ₅	312–317	[6FAM]CAATCAGAATTGCCCAAGGT TCAAGGAAAAGGCCAATCAC	60
GB726	(GCCAC) ₄	240–268	[NED]GGATTCCAAGTCAAGCCATC GCTCATGCACAGAGAGGTGA	60
GB727	(GCTTG) ₄	372–388	[HEX]TGATCCAAAGCACATCAGGA GCGCAGGAGAATGGTTTACT	60
GB728	(GGAAA) ₅	117–132	[HEX]CACGGTATTTTAATTTTGAGTCCA AAAAACTGCGGTGACTGTCC	60
GB729	(GGCGT) ₅	278–287	[NED]TCCCCGTCTAATCCCTCTTC GGTCGTCTGGTCCCTAATTC	60
GB732	(TCACA) ₄	203–208	[HEX]TGGAAGCAGTGTGACGTTC TCTTGCAAGTGCAAAATTGG	60
GB733	(TCATC) ₄	331–341	[6FAM]TTGCTTGCCGTACAGAACAC GCATTTTGTGGGTGCTTT	60
GB734	(TCATT) ₄	344–349	[HEX]GCATAGAGACCAGGGCAGAC ATTGAGGCGTCCAGCATAA	60
GB735	(TCTCT) ₅	163–168	[6FAM]AAAGCAGTAGAGTCCATCTCCG TGGGTTAGTTGACTTGGGATTT	60
GB737	(TGAGT) ₅	377–392	[6FAM]AGCTGCTGTGCAGACTTTGA GGCAAGCAAAGCTGAGTTTC	60
GB739	(TGGGA) ₅	290–305	[6FAM]GATCACAAGGCGACCATTTC GACGTTTTGGAAACGGAAAA	60
GB740	(TGGGT) ₆	336–356	[HEX]TGGCTCCAAGTATTGACATCC GAGGGGTTATGGAGCTAGCAG	60
GB741	(TTCCT) ₄	339–351	[HEX]ATCCAGAGGGCTAGGCTGTT GAGATCGATGGATGTGGTGA	60
GB742	(TTCGG) ₅	348–375	[HEX]CGGAGAGAACAGACGGAGTC GGTGGGAATTTAACGGCTCT	60
GB743	(TTGCT) ₄	204–210	[NED]CGAACGAATCTCCACCTGTT ATCTCCCCAACACAATCCAG	60
GB744	(TTGGC) ₄	131–144	[6FAM]CTCCCTCTGTCGATGATGATT GAAAAGAAAAGCCAAGCCAAAC	61
GB745	(TTGTG) ₄	313–325	[6FAM]CGTGTTCTACAGCCGATTGA CCCTACCACCATCACTTGCT	60
GB746	(TTTCC) ₄	289–299	[6FAM]AGATCGACCTGGACAAGTGC CCCCACATCCTATTCATTT	60
GB747	(GCTTT) ₄	181–187	[HEX]GAAACTGTGGCCGATTTCTATT AGGAGAAGCAACCCCAATCT	60
GB748	(TTTGG) ₅	334–343	[HEX]CGTTTAGCAAGGTGGGATGT TTTCCGTCCACCTTTTGGAC	60
GB749	(AACAG) ₄	269–274	[6FAM]CCCAATTGGAATCCTTGAGA TGAACCTCCATCACCACGTA	60
GB750	(AACCG) ₅	209–220	[NED]GCACACACACCAGATCCAAC GGGTTTGTAGGAGGTGCGTA	60
GB751	(AAGAG) ₄	272–277	[6FAM]GGGTTTCACCGGGAGATATT CTCTCCCAAGACCCAAA	60
GB752	(AGCAA) ₄	350–358	[HEX]GCAGCTTTTCCTAAGCTCCA CATGCCTCAAACCTCCCAAT	60

Supplemental Table 2. Repeat motifs at SSR in the ‘Jefferson’ hazelnut genome by type and number of repeats.

Repeat motif	Number of repeats											Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14		
<i>Dinucleotide</i>													
AC/GT	—	—	1,271	712	521	350	204	143	129	82	8	3,420	10.28
AG/CT	—	—	3,860	2,798	2,310	2,048	1,743	1,818	1,642	206	6	16,431	49.38
AT/AT	—	—	5,971	3,559	2,131	1,054	393	148	61	60	5	13,382	40.22
CG/CG	—	—	29	10		1						40	0.12
Sum			11,131	7,079	4,962	3,453	2,340	2,109	1,832	348	19	33,273	100.00
<i>Trinucleotide</i>													
AAC/GTT	—	326	117	45	27	5	2					522	5.99
AAG/CTT	—	1,220	625	325	228	74						2,472	28.39
AAT/ATT	—	1,957	975	479	260	85						3,756	43.13
ACC/GGT	—	204	78	46	13	3	4					348	4.00
ACG/CGT	—	52	16	5	3							76	0.87
ACT/AGT	—	66	21	11	1	2	3					104	1.19
AGC/CTG	—	147	70	23	12	4		1				257	2.95
AGG/CCT	—	229	98	52	27	5	5	1				417	4.79
ATC/ATG	—	403	178	93	45	13						732	8.41
CCG/CGG	—	21	3									24	0.28
Sum		4,625	2,181	1,079	616	191	14	2	0	0	0	8,708	100.00
<i>Tetranucleotide</i>													
AAAC/GTTT	378	91	23	2								494	7.72
AAAG/CTTT	658	227	68	13								966	15.09
AAAT/ATTT	2,846	619	51	4								3,520	54.97
AACC/GGTT	39	10	4									53	0.83
AACG/CGTT	2											2	0.03
AACT/AGTT	14	5		1	1							21	0.33
AAGC/CTTG	28	2										30	0.47
AAGG/CCTT	27	8	2	1								38	0.59
AAGT/ACTT		1										1	0.02
AATC/ATTG	43	12	5		1							61	0.95
AATG/ATTC	29	7	2									38	0.59
AATT/AATT	322	97	14	2								435	6.79
ACAG/CTGT	24	11	1		1							37	0.58
ACAT/ATGT	126	36	24	5								191	2.98
ACCC/GGGT	14	1										15	0.23
ACCG/CGGT	4	1										5	0.08
ACCT/AGGT	8	1										9	0.14
ACGC/CGTG	12	2										14	0.22
ACGT/ACGT	12	2										14	0.22
ACTC/AGTG	36	8	1	2	1							48	0.75
ACTG/AGTC	3	1										4	0.06
AGAT/ATCT	36	20	6	2								64	1.00
AGCC/CTGG	9	2										11	0.17
AGCG/CGCT	15	1	1									17	0.27
AGCT/AGCT	79	13	2	1								95	1.48
AGGC/CCTG	8	1	1									10	0.16
AGGG/CCCT	55	15	2	1								73	1.14
ATCC/ATGG	35	11	6									52	0.81
ATCG/ATCG	4	1										5	0.08
ATGC/ATGC	66	8	1									75	1.17
CCCG/CGGG	1											1	0.02
CCGG/CCGG	4											4	0.06
Sum	4,941	1,219	220	41	12	9	10	11	12	13	14	6,403	100.00
<i>Pentanucleotide</i>													
AAAAC/GTTTT	155	36	1									192	10.91
AAAAG/CTTTT	363	88	1									452	25.68

Continued next page

Supplemental Table 2. Continued.

Repeat motif	Number of repeats												Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14			
<i>Pentanucleotide (cont'd)</i>														
AAAAT/ATTTT	574	64											638	36.25
AAACC/GGTTT	11	5											16	0.91
AAACG/CGTTT	2	1											3	0.17
AAACT/AGTTT	3	2											5	0.28
AAAGC/CTTTG	9												9	0.51
AAAGG/CCTTT	12	3											15	0.85
AAAGT/ACTTT	1		1										2	0.11
AAATC/ATTTG	25	1											26	1.48
AAATG/ATTTC	7												7	0.40
AAATT/AATTT	37	5											42	2.39
AACAC/GTGTT	10	1											11	0.63
AACAG/CTGTT	4												4	0.23
AACAT/ATGTT	3	1											4	0.23
AACCC/GGGTT	11	3	2										16	0.91
AACCG/CGGTT	3	2											5	0.28
AACCT/AGGTT	1	2											3	0.17
AACGC/CGTTG	1												1	0.06
AACTC/AGTTG	16	2											18	1.02
AACTG/AGTTC	1												1	0.06
AACTT/AAGTT	1	1											2	0.11
AAGAC/CTTGT	3		1										4	0.23
AAGAG/CTCTT	30	9	2										41	2.33
AAGAT/ATCTT	6	1											7	0.40
AAGCC/CTTGG	5												5	0.28
AAGCT/AGCTT	3												3	0.17
AAGGC/CCTTG	2	1											3	0.17
AAGGG/CCCTT	8	4											12	0.68
AAGGT/ACCTT	3	1											4	0.23
AAGTC/ACTTG	1												1	0.06
AAGTG/ACTTC	1												1	0.06
AATAC/ATTGT	6	1											7	0.40
AATAG/ATTCT	5	1	1										7	0.40
AATAT/ATATT	12												12	0.68
AATCC/ATTGG	5	3											8	0.45
AATCG/ATTCG	3												3	0.17
AATCT/AGATT	11	1	1										13	0.74
AATGC/ATTGC	3												3	0.17
AATGG/ATTCC	2												2	0.11
AATGT/ACATT	1												1	0.06
AATTC/AATTG	7	1											8	0.45
ACACC/GGTGT	3	1											4	0.23
ACACG/CGTGT	2												2	0.11
CACT/AGTGT	2												2	0.11
ACATC/ATGTG	6	1											7	0.40
ACATG/ATGTC	8												8	0.45
ACCAG/CTGGT	2												2	0.11
ACCAT/ATGGT	1		1										2	0.11
ACCCC/GGGGT	6	3											9	0.51
ACCCG/CGGGT	4												4	0.23
ACCCT/AGGGT	1												1	0.06
ACCGC/CGGTG	2												2	0.11
ACCTG/AGGTC	1												1	0.06
ACGAT/ATCGT	1												1	0.06
ACGCC/CGTGG	1	1											2	0.11
ACTAG/AGTCT	1												1	0.06

Continued next page

Supplemental Table 2. Continued.

Repeat motif	Number of repeats											Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14		
<i>Pentanucleotide (cont'd)</i>													
ACTCC/AGTGG	1											1	0.06
ACTCG/AGTCG	1											1	0.06
ACTCT/AGAGT	2	2										4	0.23
ACTGC/AGTGC	1	1										2	0.11
ACTGG/AGTCC	1											1	0.06
AGAGG/CCTCT	11	2										13	0.74
AGATC/ATCTG	1											1	0.06
AGATG/ATCTC	11	4	1									16	0.91
AGCAT/ATGCT	3	1										4	0.23
AGCCC/CTGGG	4											4	0.23
AGCCG/CGGCT	5	1										6	0.34
AGCTC/AGCTG	3											3	0.17
AGGAT/ATCCT	3											3	0.17
AGGCG/CCTCG		1										1	0.06
AGGGC/CCCTG	2	2										4	0.23
AGGGG/CCCCT	6	1										7	0.40
ATATC/ATATG	9	1										10	0.57
ATCCC/ATGGG	4	2	1									7	0.40
ATGCC/ATGGC	3	2										5	0.28
CCCCG/CGGGG	1											1	0.06
CCCGG/CCGGG	1											1	0.06
Sum	1,481	266	13	0	0	0	0	0	0	0	0	1,760	100.00
<i>Hexanucleotide</i>													
AAAAAC/GTTTTT	72	1										73	7.84
AAAAAG/CTTTTT	168	2										170	18.26
AAAAAT/ATTTTT	112	5										117	12.57
AAAACC/GGTTTT	8											8	0.86
AAAACG/CGTTTT			1									1	0.11
AAAAC/AGTTTT	1											1	0.11
AAAAGC/CTTTTG	2											2	0.21
AAAAGG/CCTTTT	11		1									12	1.29
AAAAGT/ACTTTT	2		1									3	0.32
AAAATC/ATTTTG	16	2	1									19	2.04
AAAATG/ATTTTC	6											6	0.64
AAAATT/AATTTT	7											7	0.75
AAACAC/GTGTTT	5	2										7	0.75
AAACAG/CTGTTT	3	1										4	0.43
AAACAT/ATGTTT	4	2										6	0.64
AAACCC/GGGTTT	4	1										5	0.54
AAACTT/AAGTTT	1											1	0.11
AAAGAC/CTTTGT		1										1	0.11
AAAGAG/CTCTTT	23											23	2.47
AAAGAT/ATCTTT	2											2	0.21
AAAGCC/CTTTGG	2											2	0.21
AAAGGG/CCCTTT	2	1										3	0.32
AAAGTG/ACTTTC	3	1										4	0.43
AAAGTT/AACTTT	2											2	0.21
AAATAC/ATTTGT	2											2	0.21
AAATAG/ATTTCT	1											1	0.11
AAATAT/ATATTT	1											1	0.11
AAATCC/ATTTGG	4											4	0.43
AAATGC/ATTTGC	1											1	0.11
AAATGG/ATTGCC	1											1	0.11
AAATTC/AATTTG	10	1										11	1.18
AAATTG/AATTTT	3											3	0.32

Continued next page

Supplemental Table 2. Continued.

Repeat motif	Number of repeats												Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14			
<i>Hexanucleotide (cont'd)</i>														
AACAAG/CTTGTT	7	1											8	0.86
AACAAT/ATTGTT		1											1	0.11
AACACC/GGTGTT	4	2											6	0.64
AACACG/CGTGTT	1												1	0.11
AACAGC/CTGTTG	5	4											9	0.97
AACAGG/CCTGTT		1											1	0.11
AACATC/ATGTTG	4												4	0.43
AACATG/ATG TTC	9	1											10	1.07
AACCAC/GGTTGT	2	2											4	0.43
AACCAG/CTGGTT	1												1	0.11
AACCAT/ATGGTT	1												1	0.11
AACCCC/GGGGTT	1												1	0.11
AACCCG/CGGGTT	1												1	0.11
AACCCT/AGGGTT	9	1											10	1.07
AACCGG/CCGGTT	1												1	0.11
AACCTC/AGGTTG	4												4	0.43
AACCTG/AGG TTC	1												1	0.11
AACGAC/CGTTGT			1										1	0.11
AACGCC/CGTTGG	1												1	0.11
AACGGC/CCGTTG		1											1	0.11
AACTCC/AGTTGG	2	2											4	0.43
AACTCG/AGTTCG	1												1	0.11
AACTCT/AGAGTT	1												1	0.11
AACTTC/AAGTTG	2												2	0.21
AACTTG/AAG TTC	1												1	0.11
AAGAAT/ATTCTT	1												1	0.11
AAGACC/CTTGGT	2												2	0.21
AAGACG/CGTCTT	1												1	0.11
AAGAGC/CTCTTG	1												1	0.11
AAGAGG/CCTCTT	11	1											12	1.29
AAGATG/ATCTTC	6												6	0.64
AAGATT/AATCTT	1	1											2	0.21
AAGCAC/CTTG TG	1												1	0.11
AAGCAG/CTGCTT	1												1	0.11
AAGCCC/CTTGGG	4	2											6	0.64
AAGCCG/CGGCTT	2												2	0.21
AAGCGG/CCGCTT			1										1	0.11
AAGCTC/AGCTTG	1	1											2	0.21
AAGGAG/CCTTCT	10		1										11	1.18
AAGGAT/ATCCTT		2											2	0.21
AAGGGC/CCCTTG	1												1	0.11
AAGGGG/CCCCTT	1												1	0.11
AAGGTG/ACCTTC	1	1											2	0.21
AAGTAG/ACTTCT	2	1											3	0.32
AAGTGC/ACTTGC		1											1	0.11
AAGTGG/ACTTCC	1												1	0.11
AATAGC/ATTGCT	1												1	0.11
AATAGG/ATTCCT	1												1	0.11
AATAGT/ACTATT	3												3	0.32
AATATG/ATATTC	1												1	0.11
AATCAC/ATTGTG	3	1											4	0.43
AATCAG/ATTCTG	1												1	0.11
AATCAT/ATGATT	5	1											6	0.64
AATCCC/ATTGGG	1												1	0.11
AATCCG/ATTCGG	1												1	0.11

Continued next page

Supplemental Table 2. Continued.

Repeat motif	Number of repeats												Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14			
<i>Hexanucleotide (cont'd)</i>														
AATCCT/AGGATT	2												2	0.21
AATCGT/ACGATT	1												1	0.11
AATCTC/AGATTG	2	2											4	0.43
AATCTG/AGATTC	3	1											4	0.43
AATGAC/ATTGTC	2												2	0.21
AATGAG/ATTCTC	2												2	0.21
AATGAT/ATCATT	5												5	0.54
AATGCG/ATTCGC	1												1	0.11
AATGGC/ATTGCC	3												3	0.32
AATGGG/ATTCCC	2												2	0.21
AATGGT/ACCATT		1											1	0.11
AATGTC/ACATTG	1												1	0.11
AATGTG/ACATTG	1	1											2	0.21
AATTAC/AATTGT	2	1											3	0.32
AATTAG/AATTCT	1												1	0.11
AATTAT/AATTAT	2												2	0.21
AATTCC/AATTGG	1												1	0.11
AATTCG/AATTCG	1												1	0.11
ACACAG/CTGTGT	1												1	0.11
ACACAT/ATGTGT	1	2											3	0.32
ACACCC/GGGTGT	6												6	0.64
ACACCG/CGGTGT	2												2	0.21
ACACGC/CGTGTG	3												3	0.32
ACACTC/AGTGTG	3	3											6	0.64
ACAGAG/CTCTGT	20	2											22	2.36
ACAGCC/CTGTGG	5												5	0.54
ACAGGC/CCTGTG	2												2	0.21
ACAGGT/ACCTGT	1												1	0.11
ACAGTC/ACTGTG	1												1	0.11
ACAGTG/ACTGTC	1												1	0.11
ACATAT/ATATGT	4	2											6	0.64
ACATCC/ATGTGG	2												2	0.21
ACATCG/ATGTCG		1											1	0.11
ACATCT/AGATGT	1												1	0.11
ACATGC/ATGTGC	4												4	0.43
ACATGG/ATGTCC	1												1	0.11
ACATGT/ACATGT		1											1	0.11
ACCACG/CGTGGT	2												2	0.21
ACCACT/AGTGGT	1	1											2	0.21
ACCAGC/CTGGTG	1	1											2	0.21
ACCATC/ATGGTG	7	3											10	1.07
ACCATG/ATGGTC	1												1	0.11
ACCCAG/CTGGGT	2												2	0.21
ACCCCT/AGGGGT	1												1	0.11
ACCCTC/AGGGTG	1												1	0.11
ACCCTG/AGGGTC	1												1	0.11
ACCGCG/CGCGGT	1												1	0.11
ACCGGC/CCGGTG	1												1	0.11
ACCGTC/ACGGTG	1												1	0.11
ACCTCC/AGGTGG	6	5											11	1.18
ACGAGG/CCTCGT		1											1	0.11
ACGATC/ATCGTG	1												1	0.11
ACGATG/ATCGTC	3												3	0.32
ACGCCC/CGTGGG		1											1	0.11
ACGTAT/ACGTAT	1												1	0.11

Continued next page

Supplemental Table 2. Continued.

Repeat motif	Number of repeats												Total	Percentage
	4	5	6	7	8	9	10	11	12	13	14			
<i>Hexanucleotide (cont'd)</i>														
ACGTCC/ACGTGG	1												1	0.11
ACTAGG/AGTCCT		1											1	0.11
ACTATC/AGTGAT	2												2	0.21
ACTATG/AGTCAT	1												1	0.11
ACTCAG/AGTCTG	1												1	0.11
ACTCCC/AGTGGG	6	2											8	0.86
ACTCCG/AGTCGG	1	1											2	0.21
ACTCCT/AGGAGT	2												2	0.21
ACTCGG/AGTCCG	1												1	0.11
ACTCTC/AGAGTG	7	2											9	0.97
ACTGCC/AGTGGC	2												2	0.21
ACTGCG/AGTCGC	1												1	0.11
ACTGCT/AGCAGT	1												1	0.11
ACTGGC/AGTGCC	3	1											4	0.43
ACTGGG/AGTCCC	1												1	0.11
AGAGAT/ATCTCT	3	2											5	0.54
AGAGCG/CGCTCT	2												2	0.21
AGAGGC/CCTCTG	2												2	0.21
AGAGGG/CCCTCT	21	3											24	2.58
AGATAT/ATATCT	4												4	0.43
AGATCT/AGATCT	3												3	0.32
AGATGG/ATCTCC	3	1											4	0.43
AGCAGG/CCTGCT	2												2	0.21
AGCATC/ATGCTG	2												2	0.21
AGCATG/ATGCTC	2												2	0.21
AGCCAT/ATGGCT	1	1											2	0.21
AGCCCC/CTGGGG	2												2	0.21
AGCCCG/CGGGCT	2												2	0.21
AGCCCT/AGGGCT	1	1											2	0.21
AGCCGG/CCGGCT	1												1	0.11
AGCCTC/AGGCTG	1	1											2	0.21
AGCCTG/AGGCTC	2	1											3	0.32
AGCTCG/AGCTCG	1												1	0.11
AGGATG/ATCCTC	2	1											3	0.32
AGGCAT/ATGCCT		1											1	0.11
AGGCCC/CCTGGG	1												1	0.11
AGGGAT/ATCCCT	2	1	1										4	0.43
AGGGCC/CCCTGG	1												1	0.11
AGGGGG/CCCCCT	2												2	0.21
ATATGC/ATATGC	2												2	0.21
ATCATG/ATCATG	1												1	0.11
ATCCCC/ATGGGG	1												1	0.11
ATCGCC/ATGGCG	2	1											3	0.32
ATCGGC/ATGCCG	1												1	0.11
ATGCCC/ATGGGC	1												1	0.11
Sum	853	133	50	49	56	63	70	77	84	91	98		931	100.00

Supplemental Table 3. Alleles at 169 simple sequence repeat marker loci in 50 hazelnut accessions. All cultivars showed one or two alleles at each locus.

Cultivar name	Cultivar	GB401	GB402	GB403	GB404	GB405	GB407	GB408		
OSU 495.049	Cv01	183/192	166/166	152/156	122/122	173/177	175/187	158/158		
Albania 55	Cv02	183/192	166/166	156/156	122/122	173/173	187/187	158/166		
Fusco Rubra	Cv03	183/192	166/166	156/156	122/122	169/173	187/187	158/158		
COR187 Finland	Cv04	183/192	166/166	156/156	122/122	173/173	187/191	158/162		
Pendula	Cv05	183/192	166/167	152/156	122/122	173/173	195/195	158/162		
Hall's Giant	Cv06	189/192	166/166	152/152	122/122	173/173	187/187	158/158		
Gasaway	Cv07	192/192	166/166	152/156	122/122	173/173	187/191	162/162		
Rode Zeller	Cv08	183/183	166/166	156/156	122/122	173/173	187/187	158/158		
Cosford	Cv09	183/192	166/166	156/156	122/122	173/173	187/187	158/158		
DuChilly	Cv10	183/196	166/170	156/156	122/122	173/173	187/187	158/158		
Palaz	Cv11	183/192	166/170	156/156	122/122	173/173	187/187	158/158		
Pellicule Rouge	Cv12	183/189	166/170	152/156	122/122	173/173	188/188	158/158		
Imperiale de Trebizonde	Cv13	183/183	166/166	152/152	122/122	173/173	187/191	158/158		
Tombul Ghiaghli	Cv14	183/192	166/170	156/156	122/122	173/173	187/187	158/158		
Tonda Bianca	Cv15	192/196	166/167	152/156	122/126	173/173	191/191	158/158		
Negret	Cv16	183/192	166/170	156/156	122/122	173/173	187/195	158/158		
Tonda G. d. Langhe	Cv17	183/192	166/166	156/156	122/122	173/173	187/191	158/158		
Tonda Romana	Cv18	183/192	166/170	156/156	122/122	173/173	187/191	158/158		
Römische Nuss	Cv19	183/192	166/170	156/156	122/122	173/173	187/191	158/158		
Casina	Cv20	183/192	166/170	156/156	122/122	173/173	187/187	158/158		
Ratoli	Cv21	183/183	166/170	152/156	122/122	173/173	187/187	159/162		
Mortarella	Cv22	183/183	166/166	156/156	122/122	173/173	187/187	158/158		
Tonda di Giffoni	Cv23	183/192	166/170	152/156	122/122	173/173	188/192	158/158		
Barcelona	Cv24	183/196	166/170	152/156	122/122	173/173	188/192	158/166		
Cutleaf	Cv25	183/196	166/166	152/156	122/122	173/173	187/187	158/158		
OSU 681.078	Cv26	183/192	166/166	152/156	122/122	173/173	179/187	158/162		
Barcelloner Zellernuss	Cv27	183/192	166/166	152/156	122/122	173/173	187/187	158/158		
Aurea	Cv28	183/192	166/166	152/156	122/122	173/173	187/191	158/166		
OSU 408.040	Cv29	183/192	166/166	156/156	122/122	173/173	195/195	158/158		
Des Anglais	Cv30	189/192	166/166	152/156	122/122	173/173	175/187	158/158		
OSU 26.072	Cv31	183/196	166/166	156/156	122/122	173/173	175/187	158/158		
Bergeri	Cv32	183/192	166/166	156/156	122/122	173/173	187/187	158/158		
Alli	Cv33	192/192	166/166	156/156	122/122	173/173	175/187	162/166		
Early Long Zeller	Cv34	183/192	166/166	152/156	122/122	173/173	187/187	158/166		
OSU 759.010	Cv35	192/192	166/166	152/156	122/122	173/173	187/187	158/158		
Contorta	Cv36	183/189	166/170	152/156	122/122	173/173	175/195	158/162		
OSU 556.027	Cv37	183/183	166/170	156/156	122/122	173/173	187/187	158/158		
B-3	Cv38	183/183	166/166	156/156	122/122	173/173	187/187	158/158		
OSU 54.039	Cv39	183/192	166/170	152/156	122/122	173/173	187/187	158/158		
Gunslebert	Cv40	183/189	166/170	152/156	122/122	173/173	187/191	158/158		
Sant Jaume	Cv41	183/196	166/166	152/152	122/122	173/173	191/195	158/166		
Iannusa Racinante	Cv42	183/196	166/166	152/156	122/126	173/173	187/191	166/166		
Gem	Cv43	183/196	166/170	156/156	122/122	173/173	187/187	158/158		
Artellet	Cv44	183/192	166/166	156/156	122/122	173/173	187/191	158/166		
Simon	Cv45	183/192	166/170	156/156	122/122	173/173	187/187	159/159		
Gustav's Zellernuss	Cv46	189/192	166/166	152/156	122/122	173/173	187/187	158/166		
Buttner's Zellernuss	Cv47	183/196	166/166	156/156	122/122	173/173	187/187	159/159		
Tapparona di SCC	Cv48	183/192	166/166	152/156	122/122	173/173	187/187	158/158		
OSU 252.146	Cv49	183/196	166/170	156/156	122/126	173/173	187/187	158/158		
OSU 414.062	Cv50	183/196	166/170	152/156	122/126	173/173	187/187	158/166		
Cultivar	GB409	GB410	GB413	GB414	GB416	GB417	GB418	GB420	GB421	GB422
Cv01	157/157	161/161	191/191	106/106	256/256	174/174	204/205	211/211	230/230	223/223
Cv02	157/157	161/161	187/191	106/114	239/239	174/174	216/216	215/215	230/230	221/225
Cv03	157/157	165/165	191/201	110/114	239/251	178/178	205/233	211/215	230/230	221/227
Cv04	157/157	161/169	187/192	110/114	239/239	174/178	205/216	211/227	230/230	221/223
Cv05	157/157	161/173	191/192	110/110	239/239	178/178	205/205	211/215	234/234	249/249
Cv06	157/161	169/173	187/191	110/114	239/243	174/174	205/205	211/215	230/230	221/225

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Supplemental Table 3. Continued.

Cultivar	GB409	GB410	GB413	GB414	GB416	GB417	GB418	GB420	GB421	GB422
Cv07	157/157	165/169	187/198	110/110	239/239	174/178	205/216	215/215	230/230	223/227
Cv08	157/157	165/173	192/192	114/114	239/239	174/178	205/205	211/223	230/230	221/227
Cv09	157/157	161/173	192/192	114/118	239/239	174/174	205/205	211/215	230/230	221/221
Cv10	157/157	161/169	191/192	106/114	239/239	178/178	205/217	211/227	230/230	225/231
Cv11	161/161	161/169	192/192	106/114	243/254	174/178	205/205	223/227	230/230	225/237
Cv12	157/161	161/161	187/192	106/106	239/243	178/178	205/205	211/215	230/230	225/225
Cv13	157/161	161/165	188/192	106/118	239/254	174/174	205/205	223/227	230/230	225/249
Cv14	157/157	161/169	192/192	114/118	239/243	174/178	205/205	211/215	230/230	225/237
Cv15	157/157	161/169	192/192	114/114	239/243	174/174	205/205	211/227	230/232	223/223
Cv16	157/157	169/169	187/192	110/110	239/239	174/178	205/217	223/227	230/230	225/237
Cv17	157/157	157/169	187/192	118/118	239/254	174/178	205/205	223/227	230/230	233/237
Cv18	157/157	161/161	187/192	114/118	239/239	174/178	205/216	215/227	230/230	235/237
Cv19	157/157	161/161	187/192	110/118	239/239	174/178	205/205	223/227	230/230	223/237
Cv20	157/157	161/161	191/192	114/118	239/239	174/178	205/205	215/227	230/230	223/237
Cv21	157/157	161/169	187/192	110/118	239/254	174/178	205/216	215/227	230/230	225/237
Cv22	157/157	161/169	192/192	110/118	239/254	174/174	205/205	211/227	230/230	235/237
Cv23	157/157	161/169	187/192	110/114	243/254	174/178	205/205	227/227	230/232	223/237
Cv24	157/157	161/169	187/191	110/118	239/254	174/178	205/216	211/227	230/230	235/237
Cv25	157/157	161/165	187/192	114/114	243/243	174/174	205/205	211/227	230/230	225/237
Cv26	157/157	161/165	187/192	110/114	239/239	174/174	205/206	223/223	230/230	221/227
Cv27	157/157	161/173	192/192	114/114	239/239	174/174	205/205	215/223	230/230	221/223
Cv28	157/157	161/165	187/192	110/110	239/243	174/174	205/205	211/227	230/230	221/221
Cv29	157/157	165/165	191/192	106/110	239/239	174/174	205/216	211/223	230/230	223/229
Cv30	157/157	161/161	187/192	106/106	239/243	174/174	205/205	215/223	230/230	223/223
Cv31	157/162	149/161	187/192	106/106	239/256	174/174	205/205	211/211	230/230	229/249
Cv32	157/157	161/169	187/187	114/118	239/239	174/174	205/217	215/215	230/230	221/225
Cv33	157/157	165/169	191/192	110/118	239/239	174/174	205/206	211/223	234/234	225/249
Cv34	157/157	161/169	187/191	110/114	239/239	174/174	205/205	215/223	230/234	225/249
Cv35	149/157	161/169	192/193	106/106	243/243	174/174	205/216	223/231	230/230	223/249
Cv36	157/157	165/169	187/192	106/110	239/243	174/178	205/216	215/215	230/230	225/225
Cv37	157/157	169/169	192/192	114/114	239/239	174/178	205/205	211/223	230/230	231/237
Cv38	157/157	165/169	187/192	110/110	239/254	174/174	205/216	215/215	230/230	225/225
Cv39	157/157	161/169	192/192	106/110	239/239	174/174	205/205	215/215	230/230	215/223
Cv40	157/161	161/169	187/192	114/118	243/243	174/174	205/205	211/215	230/232	223/223
Cv41	157/157	161/169	187/192	110/110	239/239	174/174	205/216	211/215	230/230	225/237
Cv42	157/157	161/161	187/192	110/118	239/243	174/174	205/205	211/235	230/230	235/237
Cv43	157/157	161/161	191/191	114/118	239/254	174/178	217/218	211/211	230/230	231/237
Cv44	157/157	165/169	187/192	110/118	239/239	174/178	216/216	211/227	230/230	229/249
Cv45	157/157	169/169	187/191	110/118	239/239	178/178	217/218	227/227	230/230	221/225
Cv46	157/157	169/173	187/191	110/114	239/239	174/174	205/205	215/215	230/234	221/249
Cv47	157/161	161/169	192/192	114/118	239/243	174/174	205/205	215/223	230/230	221/231
Cv48	157/157	161/169	187/192	110/118	243/254	174/178	205/205	211/215	230/230	227/237
Cv49	157/157	169/169	191/192	110/118	239/239	174/178	205/216	211/227	230/230	221/237
Cv50	157/157	161/165	187/197	110/110	239/239	174/178	205/205	211/227	230/230	237/237
Cultivar	GB423	GB424	GB425	GB426	GB427	GB428	GB429	GB430	GB431	GB432
Cv01	283/294	278/278	299/299	285/297	199/199	240/241	263/274	304/304	375/379	313/317
Cv02	287/294	278/278	299/299	297/297	199/199	244/244	251/259	296/304	375/379	319/319
Cv03	294/294	278/286	295/299	293/297	199/199	240/241	261/261	292/296	367/375	315/319
Cv04	294/294	278/286	299/299	297/297	199/199	240/240	259/261	288/304	368/375	315/325
Cv05	294/294	286/286	299/299	289/297	199/199	241/244	260/260	304/304	375/379	313/315
Cv06	289/292	286/286	299/299	285/297	203/203	240/244	259/265	288/304	375/379	313/314
Cv07	285/292	278/286	299/299	285/297	199/199	240/244	251/260	304/304	369/375	317/319
Cv08	292/294	278/278	295/299	297/297	199/199	244/244	260/260	288/304	367/375	314/315
Cv09	292/297	278/278	299/299	297/297	199/199	244/244	251/259	304/304	368/375	314/321
Cv10	294/297	278/286	299/299	285/297	199/199	240/244	259/259	300/304	375/379	313/315
Cv11	292/294	278/286	299/299	297/297	199/199	244/244	258/265	296/300	368/379	311/315
Cv12	292/294	286/286	299/299	297/297	199/199	240/244	258/258	296/300	368/379	315/321

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Supplemental Table 3. Continued.

Cultivar	GB423	GB424	GB425	GB426	GB427	GB428	GB429	GB430	GB431	GB432
Cv13	294/294	278/278	295/299	285/297	199/199	244/244	259/266	296/304	367/379	315/321
Cv14	285/294	286/286	296/299	293/297	199/199	240/240	258/265	296/300	368/379	315/315
Cv15	287/294	286/286	299/299	297/297	199/199	244/244	251/260	292/304	375/379	313/319
Cv16	285/294	278/278	299/299	297/297	199/199	240/244	251/258	292/296	368/369	315/321
Cv17	285/294	278/278	299/299	289/297	199/199	240/244	259/259	296/304	367/379	315/315
Cv18	294/297	278/286	299/299	297/297	199/203	240/244	251/258	296/304	368/375	315/315
Cv19	285/294	278/286	295/299	297/297	199/200	240/240	258/261	296/304	368/375	313/315
Cv20	287/294	278/278	299/299	297/300	199/199	240/240	260/260	296/304	368/379	315/321
Cv21	285/294	278/278	299/299	297/297	199/199	240/244	260/260	296/300	368/379	315/315
Cv22	285/294	278/286	299/299	297/297	199/199	240/244	258/260	292/304	368/375	313/315
Cv23	285/287	278/286	299/299	297/297	199/199	244/244	258/260	296/304	368/379	315/319
Cv24	285/294	278/286	299/299	297/297	199/203	240/244	258/260	292/296	368/375	313/315
Cv25	292/294	278/278	299/299	285/297	203/203	240/240	260/260	292/304	367/375	315/321
Cv26	294/294	278/278	299/299	297/300	199/199	244/244	251/263	288/304	375/379	315/325
Cv27	294/294	278/286	299/299	297/297	199/199	240/244	261/261	292/292	368/375	321/321
Cv28	294/294	278/286	299/299	297/300	199/199	240/240	251/261	304/304	375/375	319/319
Cv29	294/294	286/286	295/299	297/297	199/199	240/244	260/260	288/300	375/375	315/317
Cv30	292/294	286/286	299/299	297/297	199/199	240/244	259/261	292/296	368/375	315/317
Cv31	287/294	278/278	299/299	297/297	199/199	244/244	259/261	292/292	375/379	315/319
Cv32	294/294	278/278	299/299	289/297	199/203	240/240	260/260	304/304	375/379	315/319
Cv33	294/297	278/278	299/299	297/297	199/199	240/244	259/265	304/304	375/379	313/319
Cv34	294/294	278/278	299/303	297/297	199/203	240/244	260/265	300/304	379/379	313/313
Cv35	294/294	278/278	296/296	297/297	199/199	240/240	260/265	304/304	379/379	315/317
Cv36	292/294	278/286	299/299	297/297	199/199	240/244	261/261	292/300	375/379	314/321
Cv37	294/294	278/286	296/299	293/297	199/199	240/244	258/261	300/304	367/367	315/319
Cv38	294/294	278/286	299/299	297/297	199/199	240/244	263/265	304/304	379/379	315/319
Cv39	292/294	286/286	296/299	297/297	199/199	244/244	265/266	296/296	368/379	315/317
Cv40	294/294	286/286	299/299	297/297	199/203	240/240	260/265	304/304	375/375	313/319
Cv41	285/294	278/286	295/299	297/297	199/199	244/244	259/259	292/300	368/375	313/313
Cv42	292/294	278/286	299/299	297/297	199/199	240/240	258/260	292/304	375/375	313/315
Cv43	285/297	286/286	299/299	297/297	199/203	240/240	259/259	292/300	375/375	315/315
Cv44	294/294	278/286	299/303	297/297	199/199	240/240	258/263	292/296	368/375	313/323
Cv45	285/294	278/286	299/299	297/297	199/203	244/244	251/260	296/296	368/375	315/321
Cv46	289/294	278/286	299/303	297/297	199/203	240/244	260/265	304/304	375/379	313/314
Cv47	292/294	278/278	299/303	297/297	199/199	240/244	260/260	304/304	368/375	313/321
Cv48	285/294	278/286	299/299	297/297	199/199	240/244	251/258	288/304	375/379	315/317
Cv49	294/297	278/286	299/299	297/297	199/199	240/244	259/260	292/296	375/375	313/315
Cv50	292/294	278/286	299/299	297/297	199/199	244/244	258/265	296/300	375/375	317/319
Cultivar	GB433	GB434	GB435	GB436	GB437	GB438	GB441	GB444	GB445	GB446
Cv01	147/147	335/347	90/90	122/122	334/334	315/315	178/178	317/321	135/135	130/130
Cv02	147/147	347/347	90/90	122/122	334/336	315/315	178/178	313/317	135/139	130/130
Cv03	147/147	339/347	90/96	122/122	336/338	315/315	178/178	317/321	135/135	130/130
Cv04	147/147	335/343	90/94	122/126	336/336	315/315	178/182	317/321	135/135	130/130
Cv05	147/147	339/339	90/96	122/122	334/338	319/319	178/178	309/317	135/135	130/130
Cv06	147/152	335/343	94/96	122/122	334/346	315/319	178/178	317/321	135/139	130/130
Cv07	147/152	339/347	90/92	122/126	334/334	315/315	178/178	309/321	135/135	130/130
Cv08	147/152	335/339	90/90	122/122	334/336	315/319	178/178	309/321	135/135	130/134
Cv09	147/152	335/347	90/92	122/122	334/340	315/319	178/178	309/313	135/135	130/134
Cv10	147/147	335/335	90/94	122/122	334/334	315/319	178/178	317/321	135/135	130/130
Cv11	147/147	335/347	90/94	122/122	334/334	311/319	182/182	313/321	139/139	130/130
Cv12	147/147	335/335	90/94	122/122	334/334	315/319	178/182	313/321	135/135	130/130
Cv13	147/147	335/347	90/94	122/122	334/334	315/319	178/178	309/317	135/139	130/130
Cv14	147/147	335/347	90/94	122/126	334/334	311/315	178/182	313/321	139/139	130/130
Cv15	147/147	336/347	90/90	122/122	336/336	315/315	178/178	309/317	135/135	130/130
Cv16	147/147	339/347	94/94	122/122	334/336	311/315	178/182	313/317	135/139	130/130
Cv17	147/147	335/347	90/94	122/122	334/338	315/315	178/182	313/317	135/135	130/130
Cv18	147/147	335/347	90/94	122/122	334/334	315/315	178/178	313/317	135/139	130/130

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Cultivar	GB433	GB434	GB435	GB436	GB437	GB438	GB441	GB444	GB445	GB446
Cv19	147/147	335/347	94/94	122/122	334/334	315/315	178/178	313/321	135/139	130/130
Cv20	147/147	335/343	90/94	122/122	334/336	315/315	178/178	313/313	135/135	130/130
Cv21	147/147	335/347	94/94	122/122	334/334	311/315	178/182	313/313	135/135	130/130
Cv22	147/147	347/347	94/98	122/122	334/334	315/315	178/182	313/313	135/135	130/130
Cv23	147/147	335/336	94/94	122/122	334/336	315/315	178/178	309/313	135/135	130/130
Cv24	147/149	335/347	94/98	122/122	334/338	315/315	178/178	313/317	135/135	130/130
Cv25	147/147	347/347	90/94	122/122	334/336	307/315	178/178	315/315	135/135	130/130
Cv26	147/149	347/347	90/90	122/122	334/334	315/315	178/178	309/321	135/135	130/130
Cv27	147/147	339/347	90/90	122/122	334/334	315/315	178/178	309/321	135/135	130/130
Cv28	152/152	347/347	90/90	122/122	334/334	315/315	178/178	309/317	135/139	130/134
Cv29	147/147	339/347	90/90	122/122	334/336	315/315	178/178	317/317	135/135	130/130
Cv30	147/152	335/339	90/90	122/122	334/346	315/319	178/178	313/321	135/135	130/130
Cv31	147/147	347/347	90/102	122/122	334/336	315/315	178/182	317/317	135/135	130/130
Cv32	147/147	335/335	90/90	122/122	334/334	315/315	178/178	317/317	135/135	130/130
Cv33	147/147	347/347	90/92	122/122	336/338	315/315	178/178	313/317	135/135	130/130
Cv34	147/147	347/347	90/92	122/122	336/338	315/315	178/178	313/321	135/135	130/130
Cv35	147/147	347/347	90/90	122/122	334/334	319/319	178/182	313/321	135/139	130/130
Cv36	147/152	339/339	94/94	122/122	334/336	315/315	178/178	313/313	135/135	130/130
Cv37	147/147	347/347	90/94	122/122	334/334	311/315	178/182	313/317	135/135	130/130
Cv38	147/149	335/347	94/94	122/122	334/336	315/315	178/178	313/317	135/139	130/130
Cv39	147/147	335/347	90/94	122/126	334/334	315/315	178/182	313/321	135/135	130/130
Cv40	147/147	347/347	90/94	122/122	336/336	315/315	178/178	313/321	135/135	130/130
Cv41	147/149	339/347	90/94	122/126	334/334	315/315	178/178	313/317	135/139	130/130
Cv42	147/147	347/347	98/98	122/126	336/336	315/315	178/178	313/313	135/135	130/130
Cv43	147/149	335/335	94/98	122/122	334/334	315/319	178/178	317/317	135/135	130/130
Cv44	147/147	347/347	90/98	122/122	334/338	315/315	178/178	309/315	135/135	130/130
Cv45	147/147	347/347	92/94	122/122	334/338	311/315	178/182	313/317	135/135	130/130
Cv46	147/147	343/343	90/96	122/122	334/336	315/315	178/178	313/321	135/135	130/130
Cv47	147/147	335/347	90/92	122/122	334/334	315/319	178/178	313/321	135/135	130/130
Cv48	147/147	335/347	94/94	122/122	334/334	315/315	178/178	313/317	135/135	130/130
Cv49	147/149	335/347	94/98	122/126	334/340	311/319	178/182	313/317	135/139	130/130
Cv50	147/152	347/347	94/98	122/122	334/338	311/315	178/178	313/321	135/135	130/130
Cultivar	GB450	GB452	GB454	GB456	GB457	GB458	GB461	GB463	GB465	GB466
Cv01	335/335	214/214	245/245	104/112	201/201	299/303	278/278	285/285	274/274	102/110
Cv02	335/335	213/214	248/248	104/104	201/201	299/299	277/277	289/289	274/274	110/110
Cv03	327/335	210/213	248/252	112/112	201/201	298/299	277/277	283/292	274/274	110/110
Cv04	335/343	214/214	250/250	112/112	197/201	295/295	277/277	285/289	270/270	102/102
Cv05	335/335	213/214	248/248	112/112	197/201	295/299	273/273	289/289	270/270	102/110
Cv06	335/335	214/214	248/248	104/112	201/201	295/295	273/273	289/289	274/274	102/110
Cv07	335/335	213/214	245/245	112/112	201/201	299/299	273/273	283/298	262/270	110/110
Cv08	335/335	214/214	249/249	112/112	201/201	302/303	277/277	289/289	270/270	110/110
Cv09	335/335	214/214	249/249	112/112	201/201	303/303	277/277	283/289	270/270	110/110
Cv10	335/335	213/213	245/245	104/112	201/201	302/303	277/277	283/289	274/274	102/110
Cv11	335/339	213/214	249/249	104/112	201/201	299/302	273/277	289/289	274/274	102/102
Cv12	335/335	213/214	245/245	104/112	201/201	302/302	277/277	283/289	274/274	102/102
Cv13	335/335	203/210	245/248	104/112	201/201	299/303	277/277	283/289	274/274	110/110
Cv14	335/335	203/214	245/245	104/112	197/201	299/302	277/277	283/289	272/272	102/102
Cv15	335/339	213/214	245/249	104/112	197/201	295/299	273/277	289/289	264/274	102/102
Cv16	335/335	213/213	245/248	104/112	201/201	299/302	273/277	283/289	274/274	102/110
Cv17	335/335	214/214	249/249	112/112	201/201	302/303	277/277	289/292	270/274	102/102
Cv18	335/335	213/213	248/249	104/112	201/201	299/302	273/277	283/289	270/282	102/102
Cv19	335/339	213/214	245/245	112/112	197/201	299/302	277/277	283/283	274/274	102/102
Cv20	335/335	213/214	248/249	104/112	201/201	302/303	277/277	283/289	270/278	102/102
Cv21	335/339	213/213	249/249	104/104	201/201	299/299	277/277	283/289	274/274	102/102
Cv22	335/335	213/214	245/249	104/104	201/201	295/302	273/277	289/289	274/274	102/102
Cv23	339/339	213/214	245/245	104/112	201/201	295/302	273/277	289/289	274/274	102/102
Cv24	335/339	213/214	245/249	104/112	197/201	295/302	273/277	289/289	274/274	102/110

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Cultivar	GB450	GB452	GB454	GB456	GB457	GB458	GB461	GB463	GB465	GB466
Cv25	335/339	213/213	248/248	112/112	197/197	303/303	273/277	289/289	274/274	102/110
Cv26	335/335	213/214	248/248	112/112	201/201	299/299	281/281	289/289	263/274	102/102
Cv27	327/335	213/214	249/249	112/112	201/201	302/303	273/273	283/289	270/270	110/110
Cv28	335/335	213/214	248/248	112/112	201/201	295/303	273/277	289/298	270/274	102/110
Cv29	335/335	213/213	248/248	112/112	201/201	299/303	274/274	289/289	270/270	102/110
Cv30	335/335	213/214	245/248	104/112	201/201	302/303	277/281	283/289	274/274	102/102
Cv31	327/335	213/213	245/248	112/112	201/201	303/303	273/277	288/288	264/282	102/102
Cv32	335/335	210/214	248/248	104/112	201/201	295/303	273/277	289/294	274/274	102/110
Cv33	335/335	214/214	248/248	104/112	201/201	295/299	277/277	289/289	274/274	110/110
Cv34	335/335	214/214	248/248	104/112	201/201	295/299	281/281	289/294	274/274	110/110
Cv35	327/335	214/214	245/246	104/104	201/201	299/302	277/277	285/289	274/274	102/102
Cv36	335/335	214/214	245/245	104/112	201/201	298/303	273/277	283/289	274/274	102/110
Cv37	335/335	203/214	245/245	112/112	197/201	299/302	277/277	283/294	274/274	102/102
Cv38	335/335	213/214	245/248	112/112	197/201	299/299	273/273	289/294	270/278	102/110
Cv39	335/335	203/213	245/249	112/112	201/201	299/299	277/277	285/296	270/270	102/102
Cv40	335/339	214/214	250/250	112/112	201/201	295/302	273/277	289/289	270/274	102/110
Cv41	335/339	213/213	245/248	112/112	197/201	299/302	273/273	289/289	262/274	102/102
Cv42	335/335	213/214	244/249	104/104	201/201	299/302	277/277	289/289	274/274	102/102
Cv43	335/339	213/214	245/249	104/112	201/201	295/302	277/277	289/289	274/274	102/110
Cv44	335/339	213/214	244/249	112/112	201/201	295/302	273/277	289/289	270/274	102/110
Cv45	335/335	213/214	245/245	104/112	201/201	299/302	277/281	289/289	274/274	102/102
Cv46	335/335	214/214	248/248	104/112	201/201	295/299	273/273	289/289	274/274	110/110
Cv47	335/339	214/214	245/249	112/112	201/201	302/303	273/273	289/289	270/270	110/110
Cv48	335/335	213/214	244/249	112/112	197/201	299/299	277/277	289/289	270/274	102/102
Cv49	335/339	213/214	245/249	104/112	197/201	295/303	273/277	283/283	274/274	102/102
Cv50	335/339	203/214	244/245	112/112	197/201	299/302	273/273	289/289	274/274	102/110
Cultivar	GB467	GB468	GB469	GB470	GB473	GB475	GB476	GB477	GB478	GB480
Cv01	336/336	359/377	328/336	383/400	189/189	183/183	298/298	345/345	389/389	272/273
Cv02	336/352	377/377	328/336	383/383	189/189	187/187	298/298	338/345	389/389	273/273
Cv03	336/336	377/377	327/340	383/383	189/194	187/187	298/298	345/345	383/383	272/272
Cv04	336/352	359/359	332/336	383/383	189/189	183/183	298/298	338/345	383/392	272/272
Cv05	336/336	355/377	322/336	383/400	189/189	183/187	298/298	338/345	383/392	272/272
Cv06	336/336	377/377	340/340	383/397	189/198	183/187	295/298	338/345	389/389	272/272
Cv07	336/336	377/377	336/340	383/397	194/198	187/187	298/298	345/345	392/392	272/272
Cv08	336/352	372/377	340/340	395/395	189/189	187/187	296/296	338/345	383/389	272/272
Cv09	336/352	377/377	336/340	383/383	189/194	183/187	296/297	338/345	389/392	272/272
Cv10	352/352	359/377	340/340	395/395	189/189	187/187	298/298	345/345	383/389	272/272
Cv11	336/352	359/377	336/340	395/395	189/189	183/187	296/298	345/345	389/389	272/272
Cv12	336/352	359/359	332/340	395/395	189/189	187/187	296/298	345/345	383/389	272/273
Cv13	336/352	359/379	340/340	395/395	189/198	187/187	296/298	345/345	389/389	262/273
Cv14	352/352	359/359	328/340	395/395	189/189	183/187	296/298	345/345	389/389	272/273
Cv15	336/336	355/359	336/340	383/383	189/194	183/187	298/298	345/345	392/392	272/273
Cv16	336/352	359/377	332/336	383/395	189/189	183/183	296/298	345/345	383/389	272/272
Cv17	336/352	359/377	340/340	383/383	189/189	183/187	296/296	338/345	389/392	272/272
Cv18	336/352	359/377	332/340	383/395	189/194	187/187	296/298	338/345	383/389	273/273
Cv19	336/352	359/359	332/340	395/395	189/189	183/187	296/298	345/345	383/389	272/273
Cv20	336/352	359/377	336/340	397/397	189/189	187/187	296/298	338/345	383/383	272/273
Cv21	352/352	359/377	332/336	383/395	189/189	183/183	295/298	345/345	389/389	272/272
Cv22	336/352	359/359	336/340	383/383	189/198	183/183	298/298	345/345	389/389	273/273
Cv23	336/352	359/359	332/340	383/395	189/189	187/187	296/298	345/345	389/392	272/272
Cv24	336/352	359/359	332/340	383/395	189/189	183/183	294/298	345/345	389/392	272/272
Cv25	336/336	364/377	340/340	383/383	189/198	187/187	297/297	338/345	392/392	272/272
Cv26	336/336	359/377	328/336	383/383	189/194	183/187	298/298	338/345	392/392	272/272
Cv27	336/352	377/377	336/340	383/383	189/194	187/187	295/297	338/345	383/389	272/273
Cv28	336/352	359/377	332/336	383/383	189/189	187/187	298/298	338/345	383/392	272/272
Cv29	336/352	377/377	340/340	383/395	189/194	187/187	298/298	338/345	383/383	272/272
Cv30	336/352	359/377	332/336	383/395	189/194	187/187	298/298	345/345	389/392	272/273

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Cultivar	GB467	GB468	GB469	GB470	GB473	GB475	GB476	GB477	GB478	GB480
Cv31	336/336	377/377	328/328	385/385	189/189	183/183	298/298	338/345	389/389	272/272
Cv32	336/336	359/359	336/340	395/400	189/194	187/187	298/298	338/345	392/392	272/272
Cv33	336/352	359/377	336/339	383/398	189/189	183/187	298/298	345/345	392/392	272/273
Cv34	336/340	377/377	336/340	382/382	189/198	187/187	298/298	338/345	389/392	272/273
Cv35	336/340	359/359	336/340	395/406	189/189	183/187	296/298	345/345	389/389	272/274
Cv36	352/352	377/377	332/336	383/395	189/189	187/187	297/299	338/345	392/392	272/272
Cv37	336/336	359/359	328/340	383/395	189/189	183/187	296/298	345/345	389/392	272/272
Cv38	336/336	359/359	332/340	395/399	189/189	183/187	298/298	345/345	383/392	272/272
Cv39	336/336	355/359	328/340	398/398	189/189	183/183	298/298	345/345	389/389	272/272
Cv40	336/352	355/359	340/340	395/395	189/198	183/187	295/298	338/345	383/392	272/272
Cv41	352/352	377/377	332/336	395/395	189/189	183/183	294/298	345/345	383/389	273/273
Cv42	336/352	359/359	340/340	383/383	189/189	187/187	298/298	336/345	389/392	272/272
Cv43	352/352	359/359	340/340	383/395	189/189	183/187	294/298	345/345	389/389	272/273
Cv44	336/336	377/377	339/340	393/400	189/189	183/187	298/298	338/345	383/383	272/272
Cv45	336/352	359/377	336/340	381/383	189/189	183/187	294/298	345/345	383/389	272/273
Cv46	336/340	377/377	336/340	381/383	189/198	183/187	298/298	338/345	389/389	272/273
Cv47	336/352	377/377	332/335	381/383	189/194	183/187	296/298	338/345	389/389	272/272
Cv48	336/352	355/359	332/336	381/383	189/189	183/187	298/298	345/345	383/392	272/272
Cv49	336/352	359/359	336/340	383/383	189/194	183/183	295/297	345/345	389/389	272/273
Cv50	336/352	355/377	332/340	395/397	189/198	183/187	298/298	338/345	389/392	272/276
Cultivar	GB482	GB483	GB504	GB505	GB526	GB527	GB532	GB533	GB537	GB544
Cv01	131/136	355/355	183/183	275/275	79/89	120/120	360/360	121/126	181/181	389/392
Cv02	138/140	356/356	183/183	272/281	85/89	120/125	360/360	121/126	181/181	392/394
Cv03	131/138	343/355	193/193	271/271	89/94	120/125	360/369	121/126	181/186	389/392
Cv04	131/138	355/355	183/188	275/275	85/89	120/120	360/360	121/121	181/181	389/389
Cv05	138/138	355/356	193/193	275/275	83/88	120/125	360/369	121/121	181/186	389/389
Cv06	138/138	355/355	183/188	275/275	85/89	125/125	360/360	121/131	181/186	389/389
Cv07	131/140	355/355	193/193	271/271	85/88	120/125	360/360	121/126	181/186	389/389
Cv08	138/140	355/359	183/193	271/276	89/98	120/125	368/368	121/121	181/181	392/392
Cv09	131/140	359/359	183/183	275/275	88/98	120/125	368/368	121/126	181/181	389/392
Cv10	131/140	355/359	183/183	286/286	89/98	120/125	368/368	121/121	181/181	394/399
Cv11	131/140	355/355	183/193	276/286	88/98	120/120	368/368	126/126	181/181	389/394
Cv12	140/140	355/359	183/183	276/286	88/98	120/120	363/363	121/126	181/181	389/394
Cv13	136/140	356/359	183/193	271/286	88/98	120/120	363/363	121/121	181/181	389/394
Cv14	136/140	356/359	183/193	276/286	88/98	110/120	360/360	126/126	181/186	389/394
Cv15	131/138	355/355	183/188	271/271	88/88	120/120	368/368	121/126	181/186	384/394
Cv16	138/140	355/356	183/193	275/280	88/98	120/120	369/369	126/126	181/181	394/394
Cv17	136/140	355/355	183/183	275/275	94/99	120/120	368/368	126/131	181/181	389/394
Cv18	136/140	355/356	183/183	271/276	89/99	120/125	360/360	126/126	181/181	389/394
Cv19	138/140	355/355	183/183	275/275	89/99	120/125	369/369	126/131	181/181	389/394
Cv20	140/140	355/355	183/193	275/275	89/94	120/120	360/360	126/126	181/181	389/394
Cv21	138/140	356/359	188/193	275/275	89/99	120/120	363/369	126/126	181/181	389/394
Cv22	138/140	355/356	183/193	275/275	85/89	120/120	363/369	121/126	181/181	389/392
Cv23	138/140	355/356	183/193	271/276	89/99	120/120	368/368	121/126	181/186	384/389
Cv24	131/140	355/356	183/193	276/276	89/89	120/125	363/368	121/126	181/181	389/394
Cv25	140/140	355/359	178/178	275/275	85/89	125/125	360/369	121/126	181/186	389/389
Cv26	131/140	355/355	183/193	271/280	89/99	120/120	360/360	121/126	181/181	389/392
Cv27	131/140	355/355	183/193	275/275	89/89	125/125	368/368	121/126	181/181	389/394
Cv28	140/140	355/355	188/188	271/276	85/89	115/125	360/369	121/121	181/186	389/389
Cv29	138/138	355/355	183/193	275/280	89/89	120/120	360/360	126/126	181/181	389/389
Cv30	131/140	359/359	183/183	275/275	85/89	120/125	352/360	121/126	181/181	389/389
Cv31	138/140	355/355	183/183	272/276	85/89	120/120	360/368	121/126	181/181	389/394
Cv32	138/138	354/359	183/193	274/276	99/99	125/125	363/369	121/121	181/186	389/389
Cv33	138/140	355/359	188/193	275/275	85/89	120/125	360/369	121/126	181/181	389/389
Cv34	138/138	355/359	193/193	275/275	89/99	125/125	352/360	121/131	181/186	389/389
Cv35	131/140	355/356	183/183	286/286	89/99	120/120	368/368	121/126	181/186	389/394
Cv36	140/140	355/355	193/193	271/271	85/89	120/125	368/368	121/126	181/181	389/394

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Supplemental Table 3. Continued.

Cultivar	GB482	GB483	GB504	GB505	GB526	GB527	GB532	GB533	GB537	GB544
Cv37	131/136	355/359	183/193	275/275	89/99	110/120	369/369	126/126	181/186	389/394
Cv38	131/131	355/355	183/183	275/275	94/99	120/125	360/360	126/126	181/181	389/389
Cv39	136/136	356/359	178/183	276/286	94/99	120/120	368/368	126/126	186/186	389/389
Cv40	138/140	355/355	188/193	276/276	89/89	120/125	360/360	121/126	181/186	384/389
Cv41	131/140	355/355	183/188	276/276	89/99	125/125	368/377	126/126	181/181	394/399
Cv42	140/140	355/355	178/183	271/276	89/94	120/120	368/368	126/126	181/186	392/394
Cv43	140/140	355/355	183/183	275/275	89/89	120/125	368/368	121/121	181/181	389/399
Cv44	131/131	355/355	183/193	275/275	87/99	120/120	352/360	121/126	181/181	392/392
Cv45	131/140	355/355	193/193	276/276	89/99	120/125	368/368	126/126	181/181	389/394
Cv46	138/138	355/355	188/193	275/275	89/89	125/125	360/360	121/131	181/186	389/390
Cv47	140/140	355/359	183/183	274/276	89/99	125/125	368/368	121/126	181/181	389/392
Cv48	138/140	356/356	183/193	275/280	88/88	120/125	363/363	121/126	181/181	389/389
Cv49	131/140	355/355	183/183	275/286	98/98	120/120	368/368	121/126	181/181	389/394
Cv50	131/140	355/359	193/193	271/275	88/88	120/120	360/368	126/126	186/186	389/394
Cultivar	GB545	GB548	GB551	GB560	GB563	GB565	GB577	GB580	GB581	GB587
Cv01	195/195	151/151	131/131	164/174	190/190	181/181	165/168	184/184	110/115	175/175
Cv02	185/195	151/151	121/131	164/174	190/190	176/176	168/170	184/184	105/110	175/175
Cv03	195/195	151/151	126/131	164/174	190/190	176/181	156/160	184/184	105/105	175/180
Cv04	185/195	151/151	126/131	179/179	185/190	176/176	168/168	184/184	105/110	175/180
Cv05	190/195	151/151	131/131	168/174	185/190	176/176	160/170	184/184	105/110	175/180
Cv06	185/195	151/151	131/131	164/174	190/195	176/181	160/160	184/184	105/115	175/180
Cv07	195/195	151/151	131/131	158/164	185/190	176/176	168/170	184/184	110/115	175/175
Cv08	190/195	151/151	121/131	164/174	185/185	176/176	160/170	184/184	105/115	175/180
Cv09	190/190	151/151	121/131	164/164	185/185	176/176	170/170	184/184	110/115	175/180
Cv10	195/195	151/151	121/131	164/164	185/190	181/181	168/184	184/189	105/110	180/180
Cv11	195/195	151/151	121/131	168/174	185/190	176/176	160/168	184/184	105/120	175/180
Cv12	195/195	151/151	121/131	164/174	185/190	176/181	160/168	184/189	105/110	175/180
Cv13	195/195	146/151	121/131	164/174	185/190	176/181	160/170	184/184	95/110	175/185
Cv14	195/195	146/151	121/131	164/174	190/195	176/181	165/170	184/189	105/110	180/180
Cv15	195/195	151/151	121/131	168/174	185/190	176/181	168/168	184/184	110/115	175/175
Cv16	195/195	151/151	121/131	174/174	185/190	176/181	165/168	184/184	110/110	175/180
Cv17	195/195	151/151	121/131	158/164	185/185	176/181	168/170	184/184	105/110	180/180
Cv18	185/195	146/151	121/131	164/174	190/190	176/181	170/170	184/184	110/115	175/180
Cv19	195/195	146/151	121/131	158/164	190/190	176/181	168/170	184/184	110/115	179/180
Cv20	195/195	146/151	121/121	158/164	190/196	176/181	168/170	184/184	105/110	175/180
Cv21	195/195	146/151	121/121	164/174	190/196	176/176	168/170	184/184	110/110	180/180
Cv22	195/195	146/151	121/131	158/164	185/190	176/181	170/170	184/184	105/110	170/180
Cv23	195/195	146/151	121/121	164/174	185/190	176/181	165/168	184/184	110/115	175/180
Cv24	195/195	146/156	121/131	164/164	190/195	176/181	170/170	184/184	105/110	175/180
Cv25	195/195	151/151	121/121	158/164	190/190	176/181	168/168	184/184	105/115	175/175
Cv26	190/195	151/151	121/121	164/174	185/195	181/181	162/170	184/184	105/110	174/180
Cv27	190/195	151/151	121/121	174/174	190/190	176/181	160/170	184/184	110/115	175/180
Cv28	185/195	151/156	121/131	168/174	190/190	181/181	168/168	184/184	110/115	180/180
Cv29	190/195	151/151	121/121	158/164	190/190	181/181	168/169	184/184	105/110	175/175
Cv30	195/195	151/151	121/121	158/164	190/190	181/181	168/170	184/189	110/115	175/180
Cv31	190/195	151/151	121/121	158/164	185/185	176/181	168/168	184/184	105/115	180/180
Cv32	190/195	151/151	131/131	164/174	185/190	176/181	160/167	184/184	105/110	180/180
Cv33	190/195	151/151	121/131	168/174	185/190	176/181	168/170	184/184	110/115	180/180
Cv34	195/195	151/151	131/131	168/174	190/190	176/176	160/170	184/184	115/115	175/180
Cv35	190/195	151/151	121/131	164/174	185/190	176/176	168/169	184/184	105/110	175/180
Cv36	195/195	151/151	121/131	174/174	185/190	176/181	160/160	184/189	110/110	175/180
Cv37	195/195	146/151	121/131	159/164	190/196	181/181	165/168	184/184	105/105	175/180
Cv38	195/195	151/151	121/131	159/164	185/190	181/181	165/169	184/189	110/115	180/180
Cv39	195/195	151/151	121/121	174/174	190/190	181/181	165/168	184/184	105/110	180/180
Cv40	195/195	151/151	131/131	174/174	185/185	176/176	160/170	184/184	105/115	175/180
Cv41	195/195	146/151	121/131	164/174	190/196	176/176	168/170	184/184	110/110	175/175
Cv42	195/195	146/151	131/131	158/164	190/190	176/181	168/170	184/184	105/115	180/180

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Cultivar	GB545	GB548	GB551	GB560	GB563	GB565	GB577	GB580	GB581	GB587
Cv43	195/195	151/156	121/131	164/164	185/195	176/181	170/184	184/184	105/110	180/180
Cv44	195/195	151/156	121/131	179/179	190/195	176/181	165/170	184/184	105/110	170/175
Cv45	195/195	151/156	121/121	174/179	190/190	176/181	165/170	184/184	105/110	175/180
Cv46	185/195	151/151	131/131	164/174	190/190	176/181	160/170	184/184	115/115	175/180
Cv47	190/195	151/151	121/131	164/164	185/190	176/181	168/170	184/184	110/110	175/180
Cv48	185/195	146/151	121/131	174/174	190/195	176/176	168/170	184/184	110/120	180/180
Cv49	195/195	151/156	131/131	164/174	185/195	176/176	168/169	184/184	105/105	175/180
Cv50	195/195	146/151	131/131	164/164	190/190	176/181	165/168	184/184	110/115	175/180
Cultivar	GB601	GB602	GB603	GB604	GB605	GB606	GB614	GB616	GB617	GB618
Cv01	163/163	234/240	174/174	191/191	124/124	330/331	371/372	359/359	100/106	322/322
Cv02	163/163	234/240	162/174	191/191	118/124	316/319	371/371	359/359	100/106	322/328
Cv03	163/169	234/234	174/174	191/191	124/136	318/330	371/371	359/359	106/106	313/322
Cv04	163/163	240/240	174/174	191/191	118/124	328/331	371/371	359/359	106/106	323/329
Cv05	163/163	234/240	174/174	191/191	124/130	316/331	368/371	359/359	100/100	322/322
Cv06	163/163	240/246	174/174	191/191	118/130	329/330	365/371	359/359	100/112	323/330
Cv07	163/163	234/246	162/174	191/191	124/124	328/330	371/372	359/359	100/106	322/322
Cv08	163/163	234/240	174/174	191/191	118/124	316/330	365/371	359/359	112/112	323/330
Cv09	163/163	240/240	174/174	191/191	118/124	316/328	371/371	359/359	100/112	323/329
Cv10	163/163	234/240	162/174	191/197	124/124	328/328	371/371	359/359	106/112	316/329
Cv11	163/163	234/240	162/174	191/197	124/124	330/330	365/365	359/359	106/112	321/329
Cv12	163/163	234/240	162/174	191/197	118/124	328/330	365/371	359/359	112/112	316/323
Cv13	163/169	234/240	162/174	191/191	124/124	330/330	368/371	359/365	106/106	322/329
Cv14	163/163	240/240	162/174	191/197	118/124	330/330	365/368	359/365	112/112	321/329
Cv15	163/163	240/240	174/180	191/191	124/124	330/331	371/372	359/359	100/106	322/322
Cv16	163/163	240/240	174/174	191/197	118/124	328/331	371/371	359/359	100/112	322/322
Cv17	157/163	234/240	174/174	191/191	124/124	328/328	365/371	359/359	106/112	322/330
Cv18	151/163	234/234	174/174	191/197	124/124	316/328	371/371	359/359	100/112	321/329
Cv19	157/163	234/234	174/174	191/197	118/124	326/326	371/372	359/359	106/106	321/329
Cv20	163/163	234/234	174/174	191/197	124/124	328/330	371/372	359/359	100/112	322/329
Cv21	163/163	240/240	174/174	191/197	118/124	326/326	371/371	359/359	106/112	328/328
Cv22	163/163	240/240	174/180	191/191	118/124	328/330	371/372	359/359	112/112	321/321
Cv23	163/163	234/240	174/180	191/197	118/124	331/332	371/371	359/359	100/112	310/322
Cv24	163/163	240/240	174/174	191/197	118/124	326/326	371/371	359/359	112/112	321/322
Cv25	163/163	240/240	162/174	191/191	124/124	328/331	371/371	359/359	100/100	322/322
Cv26	163/163	234/234	174/174	191/191	124/124	331/332	371/372	359/359	100/100	328/334
Cv27	163/163	240/240	162/174	191/191	112/124	330/331	371/371	359/359	106/112	330/330
Cv28	157/163	234/240	162/174	191/191	124/124	331/332	371/371	359/359	106/106	323/330
Cv29	163/163	240/240	174/174	191/191	112/124	328/331	365/371	359/359	106/106	322/329
Cv30	163/163	240/240	162/174	191/191	118/124	328/337	368/371	359/359	106/112	315/334
Cv31	163/163	234/240	162/174	191/191	124/130	328/331	371/371	359/359	106/106	311/323
Cv32	163/163	234/240	174/174	191/191	124/124	316/316	371/371	359/359	106/112	322/330
Cv33	163/163	234/240	174/174	191/191	124/124	328/328	365/371	359/359	100/106	322/354
Cv34	163/163	234/240	174/174	191/191	118/124	316/328	371/371	359/359	106/106	322/328
Cv35	163/163	234/240	174/180	191/191	118/124	330/330	365/365	359/359	106/112	321/335
Cv36	163/163	234/240	162/174	191/197	112/124	320/328	365/371	359/359	100/100	322/330
Cv37	163/163	234/240	162/162	191/197	124/124	330/331	365/368	359/365	112/112	322/322
Cv38	163/163	240/240	174/174	191/191	124/124	330/331	371/371	359/359	100/112	324/330
Cv39	163/163	234/234	162/174	191/191	124/130	330/331	365/368	359/365	106/106	317/329
Cv40	163/163	234/240	174/174	191/197	124/124	316/331	365/371	359/359	106/106	322/322
Cv41	163/163	240/240	174/174	191/191	124/124	328/328	371/371	359/359	106/112	321/336
Cv42	163/163	240/240	174/174	191/191	124/124	328/328	365/371	359/359	112/112	321/321
Cv43	163/163	240/240	174/174	191/197	118/124	328/328	371/371	359/359	112/112	322/330
Cv44	163/163	234/234	162/174	191/191	124/124	328/328	371/372	359/359	106/112	321/329
Cv45	163/163	240/240	174/174	197/197	118/124	328/330	371/372	359/359	112/112	321/321
Cv46	163/163	240/246	174/174	191/191	118/130	316/328	362/373	359/359	106/112	330/330
Cv47	163/163	240/240	174/174	191/191	112/118	328/330	365/371	359/359	100/112	329/329

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Cultivar	GB601	GB602	GB603	GB604	GB605	GB606	GB614	GB616	GB617	GB618
Cv48	163/163	234/240	168/174	191/191	124/124	331/331	371/371	359/359	106/106	321/329
Cv49	163/163	240/240	174/174	191/197	118/124	316/330	371/371	359/359	112/112	322/328
Cv50	163/163	240/246	174/174	191/197	124/124	330/330	368/371	359/365	112/112	321/328
Cultivar	GB619	GB620	GB621	GB622	GB623	GB624	GB625	GB626	GB627	GB628
Cv01	144/150	207/221	105/117	113/113	383/383	257/257	227/233	146/146	348/354	342/366
Cv02	138/144	207/207	105/117	113/113	377/377	263/269	222/232	139/146	360/360	346/355
Cv03	137/150	207/207	105/117	108/119	377/383	269/269	221/233	146/146	360/360	348/354
Cv04	137/150	207/207	117/117	119/125	377/377	263/263	226/232	146/146	348/360	348/366
Cv05	144/150	207/207	105/101	113/125	377/377	269/269	233/233	139/146	360/360	360/360
Cv06	137/144	207/207	105/105	108/119	377/377	269/269	226/232	139/146	354/360	342/348
Cv07	138/138	207/207	117/117	113/119	377/383	269/269	227/233	133/139	348/354	360/360
Cv08	144/144	207/221	105/105	108/125	377/377	269/269	226/226	146/146	366/366	342/354
Cv09	144/150	207/221	101/105	113/125	377/377	269/269	227/233	140/146	354/366	342/360
Cv10	138/144	207/221	105/101	119/125	377/383	269/269	222/232	146/146	348/354	342/360
Cv11	137/144	207/221	117/117	113/125	377/383	269/269	221/245	146/146	348/366	342/348
Cv12	144/144	207/221	105/117	113/125	377/383	269/269	232/244	146/146	354/366	342/360
Cv13	137/144	207/221	105/117	119/125	377/383	263/269	221/227	139/146	348/354	342/360
Cv14	138/144	207/221	117/117	113/113	377/383	269/269	233/245	139/146	354/360	348/360
Cv15	137/144	207/207	111/117	125/125	377/377	269/269	227/233	139/146	354/360	348/354
Cv16	137/144	207/221	105/117	119/125	377/383	269/269	232/244	146/146	360/366	348/360
Cv17	138/138	207/221	117/117	113/125	383/383	269/269	233/244	146/146	348/366	360/360
Cv18	144/144	207/221	112/117	113/125	371/383	269/269	227/245	146/146	354/360	360/360
Cv19	137/144	207/221	117/117	108/125	377/383	269/269	227/227	146/146	354/360	354/360
Cv20	137/144	207/221	117/117	119/125	377/383	269/269	232/244	146/146	354/360	360/360
Cv21	137/144	207/221	105/117	125/125	377/377	269/269	221/227	146/146	354/360	348/360
Cv22	137/150	207/221	117/112	119/125	377/383	269/269	232/244	139/146	354/360	348/360
Cv23	138/144	207/221	111/117	125/125	377/383	269/269	227/245	139/146	354/354	348/360
Cv24	144/150	207/221	112/117	125/125	377/383	269/269	227/233	146/146	354/360	348/360
Cv25	138/144	207/207	112/117	119/119	377/377	269/269	226/232	139/146	348/354	342/342
Cv26	137/150	207/207	105/117	112/119	377/383	269/269	233/233	146/146	348/354	360/372
Cv27	138/144	207/207	105/101	113/125	377/383	269/269	226/244	146/146	348/360	342/354
Cv28	144/150	207/221	101/105	113/119	377/377	269/269	227/233	139/146	360/360	354/360
Cv29	142/144	207/207	105/117	113/113	377/377	269/269	233/233	146/146	354/354	348/360
Cv30	138/144	221/221	105/105	119/125	377/383	269/269	226/232	139/146	354/354	342/342
Cv31	137/144	207/207	100/105	113/119	377/383	263/269	227/233	146/146	348/366	360/360
Cv32	137/144	207/221	100/105	108/113	377/377	264/264	232/232	139/146	360/360	360/368
Cv33	137/144	207/207	105/117	113/119	377/377	269/269	226/232	139/146	360/360	360/360
Cv34	138/144	207/207	105/117	113/119	377/377	259/259	223/226	140/146	360/360	360/360
Cv35	137/150	207/221	112/117	119/125	377/383	269/269	227/245	140/146	354/366	348/354
Cv36	138/144	207/221	100/105	119/125	377/377	269/269	227/233	139/146	354/366	360/360
Cv37	144/144	207/207	117/117	113/113	383/383	263/269	233/239	146/146	348/354	336/348
Cv38	138/144	207/221	117/112	119/125	377/383	269/269	232/244	139/146	354/360	360/360
Cv39	137/144	221/221	117/117	113/119	377/377	269/269	233/233	146/146	348/360	342/348
Cv40	137/144	207/207	105/117	119/125	377/383	269/269	227/233	139/139	354/354	354/360
Cv41	137/144	207/221	117/117	125/125	377/383	269/269	217/227	146/146	354/360	348/354
Cv42	137/150	207/221	105/105	125/125	377/383	269/269	245/245	140/146	354/354	354/354
Cv43	144/150	207/221	105/117	125/125	377/383	269/269	226/232	140/146	348/360	342/360
Cv44	138/144	207/221	117/117	125/125	377/383	263/269	223/226	139/146	360/360	348/348
Cv45	138/144	221/221	117/117	125/125	377/383	269/269	232/244	146/146	354/360	348/348
Cv46	138/144	207/207	100/105	113/119	377/377	269/269	233/233	146/146	360/360	348/360
Cv47	138/144	207/207	105/105	113/113	377/377	269/269	226/232	146/146	354/360	342/348
Cv48	138/144	221/221	105/117	113/125	377/377	269/269	217/227	146/146	354/360	348/360
Cv49	150/150	207/221	105/117	125/125	377/377	269/269	227/227	146/146	354/360	342/348
Cv50	138/144	207/221	117/117	113/125	377/383	269/269	227/233	139/146	354/366	348/348
Cultivar	GB631	GB633	GB635	GB636	GB638	GB639	GB640	GB641	GB642	GB643
Cv01	98/98	122/122	124/130	250/250	318/318	368/368	355/355	139/139	368/368	238/244
Cv02	92/98	122/122	136/136	250/250	318/318	362/368	355/355	139/139	362/368	238/244

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Cultivar	GB631	GB633	GB635	GB636	GB638	GB639	GB640	GB641	GB642	GB643
Cv03	92/98	116/122	130/136	262/262	306/318	368/368	355/355	139/139	368/368	238/238
Cv04	92/98	122/122	124/130	250/262	306/318	368/374	355/355	139/139	362/368	238/244
Cv05	92/98	122/122	130/136	262/262	318/318	368/368	355/355	139/139	362/362	238/238
Cv06	92/98	116/122	130/136	250/262	318/318	362/368	355/355	139/139	362/368	238/244
Cv07	92/98	116/122	136/142	250/262	306/318	368/368	354/354	139/139	368/368	238/238
Cv08	92/98	116/122	130/130	250/250	306/318	362/371	355/355	139/139	368/368	238/244
Cv09	92/92	116/122	130/136	250/262	318/318	362/371	355/355	139/139	362/368	238/244
Cv10	92/98	116/122	130/130	250/262	318/318	362/362	355/355	133/139	362/368	244/244
Cv11	98/98	116/116	130/130	262/263	318/324	369/371	360/360	139/152	368/368	238/244
Cv12	92/98	116/122	130/130	250/262	318/318	362/371	360/360	139/139	368/368	238/244
Cv13	98/98	116/122	130/136	250/262	318/318	368/371	356/360	139/152	368/368	238/244
Cv14	92/98	116/122	130/130	262/262	318/324	371/372	360/360	139/152	368/368	238/238
Cv15	92/98	116/122	130/136	262/262	324/324	368/368	354/354	139/139	362/368	232/244
Cv16	98/98	116/116	118/130	250/262	318/324	368/371	355/355	139/152	368/368	232/238
Cv17	92/98	116/122	130/136	250/250	324/324	362/371	355/355	139/152	368/368	238/244
Cv18	92/92	116/116	130/136	250/262	318/324	368/371	356/360	139/152	368/368	232/238
Cv19	92/98	116/122	130/130	262/262	318/324	368/371	355/355	139/152	368/368	238/238
Cv20	98/98	116/122	130/130	250/250	306/324	368/371	354/360	139/152	368/368	232/238
Cv21	92/98	116/122	130/130	262/262	318/324	368/371	355/355	139/152	362/368	238/238
Cv22	92/98	122/122	130/136	250/262	324/324	368/371	355/355	139/139	368/368	238/244
Cv23	92/98	116/122	130/136	250/262	324/324	368/371	354/354	139/152	368/368	232/238
Cv24	92/98	116/122	130/130	250/262	324/324	368/371	355/355	139/152	368/368	238/244
Cv25	92/98	116/122	130/130	250/262	318/324	362/362	355/355	139/139	368/368	244/244
Cv26	98/98	122/122	130/136	250/256	318/318	362/368	355/355	139/139	362/368	237/244
Cv27	92/98	116/116	130/130	250/262	318/318	362/371	355/355	139/139	362/368	238/238
Cv28	92/98	116/122	130/130	256/262	318/324	368/368	355/355	139/139	368/368	232/238
Cv29	92/92	116/116	130/130	262/262	318/324	368/368	355/355	139/139	368/368	238/250
Cv30	92/98	122/122	130/130	250/262	318/318	362/371	355/355	139/139	362/368	238/243
Cv31	92/98	110/122	130/130	256/256	297/306	362/368	355/355	139/139	362/368	244/250
Cv32	92/98	116/122	130/136	250/250	318/318	362/368	354/360	139/139	362/368	238/244
Cv33	92/98	122/122	130/130	250/262	318/318	362/368	355/355	139/139	362/368	238/244
Cv34	92/92	122/122	130/130	250/250	318/318	362/362	355/355	139/139	362/368	244/244
Cv35	92/98	116/122	130/130	262/262	306/318	368/374	356/360	139/139	368/368	238/244
Cv36	92/92	116/116	130/130	262/262	318/318	362/368	355/355	139/139	368/368	238/244
Cv37	98/98	116/122	130/130	262/262	318/318	368/371	356/360	139/152	368/368	238/244
Cv38	92/92	116/122	130/130	250/262	318/324	368/372	355/355	139/139	368/368	238/250
Cv39	92/92	116/122	130/136	250/262	324/324	371/373	346/346	139/139	368/368	238/238
Cv40	92/98	116/122	124/130	250/262	318/324	362/371	354/354	139/139	362/368	238/244
Cv41	92/98	122/122	130/130	250/262	318/324	368/371	355/355	139/152	362/368	238/244
Cv42	92/98	122/122	130/130	250/262	324/324	362/368	360/360	139/152	368/368	244/244
Cv43	92/92	116/122	130/130	250/262	318/324	362/368	360/360	139/152	368/368	244/244
Cv44	92/98	116/122	118/130	250/262	324/324	362/371	355/355	139/152	362/362	238/244
Cv45	92/98	116/116	118/130	250/250	324/324	368/371	355/355	139/152	368/368	237/237
Cv46	92/98	122/122	130/136	250/250	318/318	362/368	355/355	139/139	368/368	238/244
Cv47	92/98	116/122	130/130	250/262	318/318	371/374	355/355	139/139	368/368	238/244
Cv48	92/92	116/122	118/130	262/262	318/318	362/368	355/355	139/139	368/368	244/244
Cv49	92/98	116/122	130/130	250/262	324/324	368/368	355/355	139/139	362/368	244/244
Cv50	98/98	116/122	130/142	250/262	318/324	368/368	346/354	139/152	368/368	238/244
Cultivar	GB645	GB646	GB647	GB649	GB652	GB653	GB654	GB655	GB657	GB658
Cv01	298/298	279/285	171/177	250/250	224/224	195/203	269/279	237/247	200/206	333/351
Cv02	292/292	273/273	165/183	250/250	224/224	203/209	279/279	235/235	200/200	339/342
Cv03	292/306	271/271	165/177	251/252	211/224	195/203	275/279	241/247	200/206	342/342
Cv04	292/292	273/273	165/177	250/250	218/224	195/203	275/290	235/235	192/200	342/345
Cv05	292/292	271/271	177/177	250/250	214/214	203/209	277/279	235/247	198/204	339/342
Cv06	286/298	271/271	177/177	250/250	218/224	203/209	273/275	235/247	192/200	342/342
Cv07	286/292	271/271	177/177	250/250	218/224	203/209	273/279	247/247	200/206	339/342
Cv08	292/293	271/277	177/177	252/252	224/224	203/209	275/279	247/247	192/200	330/342

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Cultivar	GB645	GB646	GB647	GB649	GB652	GB653	GB654	GB655	GB657	GB658
Cv09	292/293	273/279	177/177	250/250	218/226	203/209	275/279	247/253	198/204	339/342
Cv10	286/292	271/277	171/177	250/250	218/223	195/203	275/275	253/253	198/204	330/339
Cv11	286/293	273/273	177/177	252/264	210/224	203/203	275/275	235/247	200/200	330/339
Cv12	286/293	271/271	171/178	252/252	224/224	203/203	275/275	247/253	200/206	330/342
Cv13	292/292	271/271	177/177	252/264	224/224	203/209	279/279	247/247	194/200	342/342
Cv14	286/292	271/291	171/178	252/264	210/224	195/203	275/275	235/247	200/206	330/342
Cv15	292/293	271/283	177/177	249/250	212/224	203/209	275/279	235/247	192/204	333/339
Cv16	292/293	273/273	171/183	252/264	218/224	203/209	275/275	247/253	198/204	333/342
Cv17	292/298	273/273	165/177	252/264	224/224	195/203	269/275	247/253	198/204	330/339
Cv18	292/298	273/285	165/171	252/264	218/224	203/209	275/275	247/253	198/204	339/342
Cv19	292/293	271/271	165/171	252/264	218/224	203/209	275/279	235/235	204/204	333/342
Cv20	292/293	271/271	171/177	252/264	224/230	203/209	275/275	247/253	198/204	342/342
Cv21	292/293	273/273	165/171	252/264	224/224	203/209	275/275	235/235	198/204	339/342
Cv22	292/293	271/271	165/177	250/250	223/223	203/209	275/279	247/253	200/200	330/345
Cv23	292/293	273/273	171/177	251/264	212/224	203/209	275/275	235/247	192/204	339/342
Cv24	292/298	271/283	171/177	251/264	224/224	203/209	275/279	235/247	198/204	342/342
Cv25	292/292	273/273	177/177	250/250	218/224	203/203	275/279	235/247	200/212	333/333
Cv26	292/292	273/285	177/177	250/250	224/224	203/203	275/275	247/247	198/204	339/339
Cv27	292/292	273/279	177/177	252/252	224/224	203/209	275/275	235/247	200/206	339/342
Cv28	292/292	271/271	165/177	252/252	218/224	195/203	275/279	235/247	198/204	339/342
Cv29	292/293	273/273	174/177	250/250	218/224	195/203	273/279	235/247	200/206	339/342
Cv30	292/293	273/279	177/178	252/252	224/224	203/209	275/279	247/253	198/198	342/342
Cv31	292/292	273/273	165/171	250/250	218/224	195/203	275/279	247/247	200/212	339/342
Cv32	286/292	273/291	177/177	250/250	210/224	203/203	275/275	235/247	204/204	339/345
Cv33	292/292	273/279	165/177	250/250	224/224	203/209	273/279	235/247	204/204	339/342
Cv34	286/292	273/273	165/177	250/250	224/224	203/203	273/275	247/247	198/204	339/342
Cv35	293/298	271/277	177/178	250/250	210/224	196/203	275/275	235/247	198/198	327/330
Cv36	286/292	273/273	171/171	250/250	224/224	203/209	275/275	235/247	204/204	333/342
Cv37	286/292	273/291	171/177	251/264	212/224	203/203	275/275	235/247	198/204	330/342
Cv38	286/292	271/271	165/177	250/250	218/224	195/203	279/279	247/247	200/206	342/342
Cv39	286/293	271/271	171/178	250/250	224/224	203/209	275/275	247/247	200/206	339/342
Cv40	292/292	271/271	172/177	250/250	224/224	203/209	275/279	235/247	204/204	330/342
Cv41	293/298	277/283	171/177	252/264	218/224	203/209	275/279	235/235	198/204	339/342
Cv42	292/293	279/285	165/177	252/264	210/224	203/209	275/279	247/253	204/204	342/342
Cv43	292/298	271/277	171/177	252/264	218/224	203/209	279/279	235/253	198/204	339/342
Cv44	286/293	271/277	177/177	252/264	224/224	203/203	275/275	235/247	198/204	333/342
Cv45	292/293	271/271	171/183	252/264	218/224	195/203	275/279	235/253	200/200	333/342
Cv46	286/292	271/271	177/177	252/252	218/224	203/203	273/273	235/247	198/204	339/342
Cv47	292/293	273/279	177/177	250/250	224/224	203/203	275/275	235/253	192/198	330/339
Cv48	286/298	273/273	165/165	252/252	218/224	195/203	275/275	253/253	204/210	342/342
Cv49	292/298	273/291	171/177	251/252	224/224	199/209	279/279	235/247	198/198	339/342
Cv50	292/293	285/285	171/177	252/264	224/224	199/203	273/279	235/247	198/204	339/342
Cultivar	GB659	GB660	GB661	GB663	GB664	GB665	GB668	GB669	GB670	GB671
Cv01	210/210	208/210	217/217	133/139	302/302	181/193	177/183	111/117	247/253	253/257
Cv02	210/216	208/209	217/217	133/139	302/302	181/181	177/183	111/117	265/265	248/253
Cv03	210/210	208/208	205/211	127/133	302/302	181/187	177/183	111/111	250/256	247/247
Cv04	210/216	210/210	217/217	127/133	302/308	175/181	177/177	111/117	265/265	291/291
Cv05	210/222	203/211	205/217	133/133	302/308	181/181	177/183	106/111	250/256	249/249
Cv06	210/210	208/208	205/205	127/133	302/302	181/193	177/183	111/117	250/250	247/248
Cv07	210/216	203/208	217/217	127/133	302/302	181/187	177/183	111/117	250/268	247/247
Cv08	210/210	203/208	211/217	127/133	302/308	181/193	177/177	111/117	250/250	247/247
Cv09	210/210	203/210	211/217	127/133	308/308	181/193	177/177	111/117	253/253	247/247
Cv10	210/219	203/209	205/217	127/133	302/308	181/193	177/177	111/117	250/250	247/247
Cv11	210/219	210/214	217/217	133/133	302/308	181/193	177/183	106/111	253/259	247/247
Cv12	216/219	208/208	217/217	127/133	302/302	181/193	177/183	111/117	250/250	247/247
Cv13	210/216	203/209	211/217	133/133	302/302	187/193	183/183	106/111	250/250	247/247
Cv14	210/219	210/214	217/217	133/133	302/302	181/181	177/183	111/111	250/256	234/247

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Cultivar	GB659	GB660	GB661	GB663	GB664	GB665	GB668	GB669	GB670	GB671
Cv15	210/216	209/221	217/217	133/133	302/308	181/181	177/183	111/111	250/250	257/297
Cv16	210/222	209/209	217/217	127/133	302/302	181/187	177/177	111/117	253/259	247/256
Cv17	210/222	209/214	217/217	133/133	302/308	181/181	177/177	106/111	253/253	248/248
Cv18	216/222	209/214	211/217	133/133	302/308	181/181	177/177	106/111	253/259	247/248
Cv19	210/222	208/209	217/217	133/133	302/302	181/181	177/177	111/111	250/250	247/253
Cv20	222/222	204/209	211/217	133/133	308/308	181/181	177/177	111/117	250/262	248/248
Cv21	210/222	210/214	217/217	133/133	302/308	181/181	177/177	111/117	253/259	247/291
Cv22	210/216	210/214	217/217	133/133	308/308	175/181	177/177	106/111	250/256	247/247
Cv23	210/210	214/221	217/217	127/133	302/308	175/181	177/177	106/111	253/253	247/247
Cv24	222/222	209/221	205/217	133/139	308/308	181/181	177/183	111/111	250/250	247/297
Cv25	210/210	208/209	205/211	133/133	302/308	181/187	177/177	111/117	253/265	247/248
Cv26	210/216	203/221	217/217	133/133	302/302	181/187	177/183	111/117	253/270	247/247
Cv27	210/216	203/208	205/205	133/133	302/308	181/181	177/183	111/111	265/265	247/247
Cv28	210/210	209/209	205/217	133/133	302/302	181/187	177/183	111/117	250/250	247/294
Cv29	210/210	203/210	205/217	133/133	302/308	181/181	177/183	117/117	253/259	247/247
Cv30	216/219	209/210	211/217	127/133	302/302	181/193	177/183	111/117	253/265	247/248
Cv31	216/216	203/208	211/211	127/133	302/302	187/187	177/177	106/111	253/259	247/291
Cv32	210/210	203/208	211/217	127/133	302/302	181/193	183/183	111/117	253/259	247/291
Cv33	210/216	208/209	211/217	133/133	302/302	187/193	177/177	117/117	253/265	247/247
Cv34	210/216	208/209	205/211	133/133	302/302	187/193	177/183	111/117	259/265	247/247
Cv35	219/222	208/210	217/217	133/133	302/302	169/181	177/183	111/117	250/250	247/253
Cv36	216/219	208/211	217/217	127/133	302/308	181/181	183/183	117/117	259/265	247/247
Cv37	219/222	210/210	211/217	133/133	302/302	181/181	176/183	111/111	259/265	234/234
Cv38	210/210	203/214	217/217	127/133	302/302	181/181	177/183	111/117	250/262	248/248
Cv39	210/216	208/214	217/217	127/133	302/302	181/193	177/195	106/111	250/250	271/271
Cv40	210/222	208/214	205/217	133/133	302/308	181/193	177/183	111/117	250/256	291/291
Cv41	210/222	208/221	205/217	133/133	302/308	181/181	177/183	111/117	250/250	297/297
Cv42	210/222	214/221	217/217	133/133	302/308	181/181	177/177	111/117	253/253	270/270
Cv43	210/222	203/209	205/205	133/133	308/308	181/193	177/177	111/117	250/250	247/247
Cv44	210/222	210/214	205/217	133/139	302/308	181/187	177/177	111/117	250/250	249/249
Cv45	210/222	209/214	217/217	133/139	302/308	181/187	177/183	111/117	250/256	247/256
Cv46	210/216	208/209	205/211	133/133	302/302	181/193	177/183	111/111	250/256	247/247
Cv47	210/210	203/209	205/211	127/133	308/308	187/193	177/177	111/117	253/253	247/253
Cv48	210/216	203/214	205/217	133/133	302/308	181/181	177/177	111/111	253/265	248/248
Cv49	219/222	210/221	205/211	133/133	302/308	181/193	177/177	111/117	253/259	234/247
Cv50	210/222	214/221	217/217	133/139	302/302	181/181	177/177	111/111	259/270	234/247
Cultivar	GB672	GB673	GB674	GB675	GB676	GB678	GB702	GB705	GB706	GB709
Cv01	218/218	354/365	163/179	350/350	340/340	194/209	181/191	217/217	369/369	261/267
Cv02	222/222	365/377	163/167	350/350	339/341	196/199	181/191	217/217	369/375	265/268
Cv03	218/218	354/365	167/169	356/356	340/340	201/201	181/181	217/220	369/375	262/271
Cv04	218/222	354/365	169/173	344/356	341/341	196/196	181/181	217/217	375/375	263/266
Cv05	218/218	354/365	169/173	356/356	339/339	196/199	181/181	217/217	369/369	266/267
Cv06	218/224	354/365	163/163	344/344	339/339	196/199	181/191	217/217	375/375	261/266
Cv07	218/218	365/365	164/175	350/356	339/339	199/201	191/191	217/217	369/375	262/263
Cv08	218/224	354/371	164/169	345/345	339/341	199/199	181/181	217/217	369/369	266/271
Cv09	218/224	354/371	163/167	345/350	339/341	199/201	181/181	217/217	369/369	264/266
Cv10	218/218	354/354	169/173	345/356	339/339	199/201	181/196	217/217	369/369	257/261
Cv11	218/230	354/371	173/173	344/356	339/345	196/199	181/181	217/217	368/369	263/266
Cv12	218/218	354/377	169/173	344/356	339/341	196/199	181/196	217/217	369/369	261/266
Cv13	218/218	354/377	173/173	344/356	345/345	196/199	191/191	217/217	369/378	262/263
Cv14	218/230	354/354	169/173	356/356	339/345	194/209	181/196	217/217	378/378	261/263
Cv15	218/224	354/354	169/169	350/356	339/339	199/202	181/191	217/220	369/369	268/270
Cv16	218/230	354/354	173/173	356/356	339/339	196/199	181/181	217/217	369/375	261/262
Cv17	222/230	371/377	169/169	345/356	339/339	196/196	181/181	217/217	369/375	261/262
Cv18	218/230	354/365	173/173	356/361	339/339	199/199	181/181	217/217	369/375	261/268
Cv19	222/230	354/371	173/173	350/356	339/339	199/199	181/181	217/217	369/369	261/267
Cv20	218/230	354/354	173/173	356/356	339/341	199/199	181/181	217/217	369/375	264/264

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Cultivar	GB672	GB673	GB674	GB675	GB676	GB678	GB702	GB705	GB706	GB709
Cv21	218/230	354/377	163/173	356/356	339/345	196/199	181/181	217/217	369/369	261/262
Cv22	218/218	377/377	169/173	356/361	339/345	196/201	181/191	217/217	369/369	261/268
Cv23	224/230	354/377	169/173	356/356	339/339	196/202	181/191	217/217	369/369	261/269
Cv24	218/230	354/377	173/173	356/356	339/339	196/199	181/191	217/220	369/369	261/269
Cv25	218/218	354/371	173/173	356/361	339/339	193/205	181/191	217/217	369/375	261/262
Cv26	218/224	354/354	163/173	350/356	341/341	199/199	181/181	217/217	376/376	264/266
Cv27	218/218	354/365	163/167	350/356	339/341	199/225	181/191	217/217	369/369	262/262
Cv28	218/218	359/371	163/167	356/356	339/339	199/199	181/181	217/217	369/375	268/269
Cv29	218/218	354/365	163/173	344/344	339/341	193/199	181/191	217/217	369/375	267/267
Cv30	218/218	371/377	169/173	344/350	341/341	196/196	181/196	217/217	369/378	262/262
Cv31	218/224	354/365	167/173	350/356	339/339	187/194	181/181	217/220	369/383	261/261
Cv32	218/218	354/377	169/173	350/356	339/341	196/199	181/196	217/217	375/375	262/267
Cv33	218/218	339/354	163/173	350/350	339/339	193/199	181/191	217/217	375/375	262/262
Cv34	218/218	354/365	163/173	350/356	339/339	196/199	181/191	217/217	369/375	262/262
Cv35	218/224	354/371	173/173	350/356	340/340	199/199	181/181	217/217	369/369	263/268
Cv36	224/224	354/377	173/173	350/356	341/341	196/199	181/196	217/217	369/369	264/267
Cv37	218/218	354/354	167/173	356/356	339/340	209/213	181/196	217/217	378/378	263/284
Cv38	218/224	365/347	169/169	344/356	341/345	196/199	181/196	217/217	369/369	261/267
Cv39	218/230	354/365	169/169	344/344	345/345	196/199	181/196	217/217	368/368	266/268
Cv40	218/218	339/354	169/173	350/350	339/339	199/202	181/181	217/217	369/375	261/262
Cv41	230/230	354/365	163/173	350/356	339/339	199/199	181/181	217/220	369/369	261/261
Cv42	218/230	354/371	169/173	344/350	339/339	199/225	181/181	217/220	369/369	262/269
Cv43	218/218	354/377	173/173	344/356	339/339	196/201	181/196	217/217	369/369	258/261
Cv44	218/230	354/365	173/173	350/356	339/339	199/199	181/181	217/217	369/375	261/269
Cv45	218/230	354/377	173/173	356/356	339/339	196/196	181/191	217/217	369/375	261/262
Cv46	218/218	354/365	163/173	344/350	339/339	199/199	191/191	217/217	369/375	261/262
Cv47	218/224	354/365	167/173	344/356	339/341	196/201	181/181	217/217	369/369	262/266
Cv48	218/218	365/377	167/169	350/356	339/345	196/199	181/191	217/217	369/375	261/267
Cv49	218/218	354/371	173/173	344/356	339/341	199/209	181/181	217/217	369/369	263/263
Cv50	230/230	354/354	173/173	344/350	339/345	199/209	181/191	220/220	369/378	262/269
Cultivar	GB710	GB712	GB716	GB717	GB718	GB719	GB720	GB721	GB722	GB723
Cv01	121/126	129/134	130/140	219/219	393/403	306/306	??	379/379	254/254	257/257
Cv02	126/126	134/140	140/151	214/214	393/398	306/306	366/371	379/388	254/259	257/257
Cv03	121/131	129/134	140/151	214/214	393/398	306/306	366/376	385/385	248/259	257/257
Cv04	121/121	119/129	140/140	214/214	398/398	306/306	376/376	385/385	250/255	257/257
Cv05	121/121	129/134	140/140	214/214	405/405	311/311	366/366	385/385	253/265	257/257
Cv06	121/121	129/134	140/140	214/214	393/393	306/306	366/366	385/385	253/259	257/257
Cv07	126/126	119/129	140/151	214/214	393/393	311/311	366/376	385/385	251/252	257/257
Cv08	121/121	129/134	145/151	214/214	393/405	306/311	376/376	383/383	253/259	257/257
Cv09	121/121	129/134	140/145	224/224	398/405	306/311	371/376	385/385	249/249	257/257
Cv10	121/121	122/129	140/145	214/224	393/398	306/306	366/366	383/383	250/250	257/257
Cv11	121/126	129/134	145/151	214/214	393/393	306/306	376/376	379/385	249/265	257/257
Cv12	121/121	122/134	145/151	214/224	393/403	297/306	366/376	374/383	250/255	257/257
Cv13	121/121	134/139	140/151	214/214	403/403	306/306	366/376	379/385	259/265	257/257
Cv14	121/121	134/139	140/145	214/224	393/393	306/306	371/376	379/385	259/265	257/257
Cv15	121/131	134/134	140/140	214/214	393/393	306/306	371/371	379/385	249/250	257/257
Cv16	121/121	129/134	145/151	214/214	403/403	297/306	376/376	385/385	254/259	257/257
Cv17	121/121	122/139	140/145	214/214	398/398	306/311	376/376	385/385	259/259	257/257
Cv18	121/126	122/134	140/145	214/224	393/403	297/311	376/376	385/385	254/259	257/257
Cv19	121/121	124/140	140/145	224/224	403/403	297/306	371/376	385/385	253/259	257/257
Cv20	121/121	134/140	140/145	214/224	393/393	306/306	366/376	383/385	259/259	257/257
Cv21	121/126	119/140	145/145	214/224	393/403	297/297	376/376	383/383	254/265	257/262
Cv22	121/121	134/139	140/145	214/214	403/403	306/306	366/366	385/385	254/259	257/257
Cv23	121/121	140/140	140/145	214/224	403/403	297/306	371/376	385/385	254/259	257/257
Cv24	121/121	134/139	140/145	214/224	398/403	297/306	366/371	385/385	254/259	257/257
Cv25	121/121	122/129	140/140	214/214	398/398	306/311	366/371	383/383	254/254	262/262
Cv26	121/121	122/129	140/140	214/214	393/398	306/306	371/376	383/385	250/250	257/257

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Cultivar	GB710	GB712	GB716	GB717	GB718	GB719	GB720	GB721	GB722	GB723
Cv27	121/121	119/129	140/145	214/214	398/403	306/306	366/376	385/385	250/251	257/257
Cv28	121/126	129/140	140/151	214/214	393/393	306/306	366/371	385/385	250/251	257/257
Cv29	121/126	129/134	140/151	214/214	393/393	306/306	371/376	383/385	253/259	257/262
Cv30	121/121	122/129	140/151	214/224	393/393	306/311	366/366	383/383	253/253	257/257
Cv31	121/126	134/134	140/140	214/224	393/393	306/306	376/376	383/385	254/254	257/257
Cv32	121/121	122/129	140/140	214/224	393/405	306/311	366/376	383/383	252/252	257/262
Cv33	121/126	129/134	140/140	214/214	393/405	306/306	371/376	385/385	253/254	257/262
Cv34	121/121	122/129	140/140	214/214	393/393	306/306	366/366	385/385	253/259	257/257
Cv35	121/121	129/134	140/145	214/214	393/393	306/306	371/376	379/379	259/259	257/257
Cv36	121/121	122/134	145/145	214/214	403/403	297/306	366/376	385/385	254/259	257/257
Cv37	121/121	134/139	140/140	214/214	393/398	306/306	376/376	385/385	254/259	257/257
Cv38	121/121	122/139	140/140	214/224	393/403	297/306	366/376	383/383	259/265	257/262
Cv39	121/121	134/139	140/140	214/224	393/393	306/306	371/371	379/379	265/265	257/257
Cv40	121/121	134/139	140/145	214/214	393/393	306/306	366/371	385/385	253/259	257/257
Cv41	121/121	119/139	140/145	214/214	393/403	297/306	371/376	385/385	254/259	257/257
Cv42	121/121	139/139	145/145	224/224	393/393	306/306	366/376	385/385	254/259	257/257
Cv43	121/121	129/134	145/145	224/224	393/398	306/306	366/371	385/385	254/259	257/257
Cv44	121/126	124/129	140/140	214/214	393/405	306/306	366/366	383/385	250/256	257/257
Cv45	121/121	129/129	140/145	214/214	393/393	297/306	366/376	385/385	254/259	257/257
Cv46	121/121	124/134	140/140	214/214	393/393	306/306	366/366	385/385	259/259	257/257
Cv47	121/121	129/134	145/145	214/214	398/405	297/306	366/376	383/385	253/253	257/257
Cv48	121/121	134/134	145/145	214/224	405/405	297/306	366/366	385/385	250/262	257/257
Cv49	121/121	134/134	140/145	214/214	398/398	306/311	376/376	383/383	253/254	257/257
Cv50	126/126	134/139	140/145	214/224	393/403	297/311	376/376	379/385	259/265	257/257
Cultivar	GB724	GB725	GB726	GB727	GB729	GB732	GB733	GB734	GB735	GB737
Cv01	211/216	312/317	247/266	388/388	273/287	203/208	336/336	344/344	163/168	392/392
Cv02	211/216	312/312	247/259	372/388	287/287	203/221	326/336	344/344	168/168	377/392
Cv03	211/216	312/312	247/281	388/388	287/287	198/208	336/341	344/344	163/163	392/392
Cv04	216/216	312/312	247/255	372/372	287/287	208/208	336/341	344/344	163/168	392/392
Cv05	216/216	312/312	240/247	372/387	287/287	203/208	336/341	344/344	163/163	377/377
Cv06	211/211	312/312	240/268	387/388	273/278	203/203	331/336	344/344	163/163	377/392
Cv07	211/216	312/312	240/247	388/388	287/287	208/208	336/336	344/344	163/163	377/392
Cv08	217/217	312/312	247/268	387/387	287/287	203/203	336/336	344/344	163/163	392/392
Cv09	216/216	312/312	240/268	372/387	287/287	203/203	336/336	344/344	163/168	377/392
Cv10	211/216	312/312	259/268	372/387	278/278	208/208	336/341	344/344	163/163	392/392
Cv11	209/216	312/317	247/259	387/388	278/287	203/208	336/336	344/344	163/163	377/377
Cv12	211/216	312/312	247/268	372/387	278/278	208/208	336/336	344/344	163/163	377/392
Cv13	211/216	312/317	259/268	387/388	278/287	208/208	336/336	344/344	163/163	392/392
Cv14	216/216	312/312	247/256	387/388	278/287	203/203	336/336	344/344	163/163	377/377
Cv15	211/216	312/317	247/256	372/388	287/287	203/208	331/336	344/349	163/163	377/392
Cv16	216/217	312/317	247/268	372/372	287/287	208/208	336/336	344/344	163/168	377/392
Cv17	216/216	312/317	254/268	372/388	287/287	203/208	336/336	344/344	163/163	392/392
Cv18	216/216	312/317	256/268	372/388	278/287	208/208	336/336	344/344	163/163	392/392
Cv19	216/217	312/317	259/259	372/388	278/287	208/208	336/336	344/344	163/163	377/392
Cv20	216/217	312/317	247/268	388/388	278/287	203/208	336/341	344/344	163/163	377/392
Cv21	216/221	312/317	259/268	372/372	278/287	208/208	336/336	344/344	163/163	392/392
Cv22	216/217	312/312	256/268	372/388	287/287	203/208	336/341	344/344	163/163	392/392
Cv23	211/216	317/317	256/268	372/388	278/287	203/208	331/336	344/344	163/163	392/392
Cv24	211/216	312/317	259/268	372/388	278/287	208/208	336/336	344/349	163/163	392/392
Cv25	216/216	312/312	247/259	372/388	287/287	208/238	336/341	344/344	163/163	377/392
Cv26	216/216	312/312	255/255	372/387	273/287	203/208	336/341	344/344	163/168	377/377
Cv27	216/216	312/312	247/254	372/387	278/287	203/238	336/336	344/344	163/168	377/377
Cv28	216/216	312/312	240/259	387/388	278/287	208/208	336/341	344/344	163/168	392/392
Cv29	211/221	312/312	247/254	372/387	278/287	208/208	336/336	344/344	163/163	392/392
Cv30	216/217	312/312	240/268	387/387	278/287	203/208	336/341	344/344	163/163	377/392
Cv31	216/216	312/312	247/268	372/387	287/287	208/214	331/331	344/344	163/168	377/392
Cv32	211/211	312/312	259/268	388/388	278/287	203/208	336/336	344/344	163/163	392/392

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Cultivar	GB724	GB725	GB726	GB727	GB729	GB732	GB733	GB734	GB735	GB737
Cv33	216/221	312/312	240/254	388/388	278/287	203/208	331/336	344/344	163/163	377/392
Cv34	211/221	312/312	240/259	387/388	278/287	203/208	336/336	344/344	163/163	377/377
Cv35	209/216	312/312	247/254	372/388	284/287	203/208	336/336	344/344	153/163	377/392
Cv36	211/211	312/317	247/268	372/387	278/287	203/208	336/336	344/344	163/163	377/377
Cv37	216/216	312/317	255/259	387/388	287/287	203/203	336/336	344/344	163/163	377/377
Cv38	211/211	312/312	255/268	372/372	278/287	203/208	336/336	344/344	163/168	392/392
Cv39	209/216	312/312	259/259	387/388	278/287	203/203	331/336	344/344	163/163	392/392
Cv40	216/216	312/317	240/247	387/388	287/287	203/203	336/336	344/344	163/163	377/377
Cv41	211/216	312/312	268/268	372/387	287/287	208/208	336/336	344/349	163/163	377/392
Cv42	211/216	312/312	256/268	388/388	278/287	203/203	336/341	344/349	163/163	377/392
Cv43	211/216	312/312	259/268	372/387	278/278	208/208	336/336	344/344	163/163	392/392
Cv44	211/216	312/317	259/268	387/387	287/287	203/208	336/336	344/344	163/163	377/392
Cv45	216/221	317/317	259/268	372/372	287/287	208/208	336/336	344/344	163/163	392/392
Cv46	211/221	312/312	259/268	387/388	273/278	203/208	336/336	344/344	163/163	377/392
Cv47	216/216	312/312	254/268	372/372	278/287	203/208	336/336	344/344	163/168	377/392
Cv48	211/211	312/312	259/259	372/387	278/287	203/208	336/336	344/344	163/163	377/392
Cv49	211/216	312/317	259/268	387/388	287/287	203/208	336/336	344/349	163/163	392/392
Cv50	209/211	312/317	256/268	372/388	278/287	208/208	336/341	344/349	163/163	377/392
Cultivar	GB739	GB740	GB743	GB744	GB745	GB747	GB748	GB749	GB750	GB751
Cv01	290/305	352/354	204/209	143/143	323/323	184/184	338/339	269/279	210/215	272/277
Cv02	305/305	344/344	209/209	143/143	313/313	182/182	338/338	269/274	209/211	272/272
Cv03	290/305	356/361	209/209	132/143	318/323	182/184	336/338	269/274	210/210	272/272
Cv04	305/305	344/349	204/209	144/144	313/313	182/182	338/338	269/274	209/210	272/272
Cv05	305/305	344/356	209/209	132/144	313/323	182/182	338/338	274/274	210/210	272/272
Cv06	305/305	344/349	204/209	132/144	318/318	182/182	338/338	269/274	210/210	272/272
Cv07	305/305	336/344	209/210	143/144	313/323	182/187	336/338	274/274	209/210	272/272
Cv08	290/305	336/351	209/209	132/144	313/323	182/184	338/338	269/279	210/210	272/272
Cv09	305/305	344/351	209/209	132/132	313/313	182/182	338/342	274/279	210/210	272/272
Cv10	300/305	351/351	209/209	132/143	313/323	182/183	338/339	269/274	210/210	272/277
Cv11	285/305	349/349	209/214	143/143	323/328	183/184	335/343	269/279	209/220	272/277
Cv12	300/305	349/351	209/210	143/143	323/323	182/186	338/343	269/269	209/210	272/277
Cv13	300/305	349/349	209/209	143/143	323/323	184/184	335/336	264/275	209/220	272/277
Cv14	300/305	349/349	209/209	132/143	323/323	183/184	338/343	269/274	209/220	277/277
Cv15	305/305	336/336	209/209	117/144	313/328	182/182	347/352	274/274	210/210	272/272
Cv16	300/305	349/349	210/210	132/144	323/323	182/184	335/338	269/274	209/209	272/277
Cv17	290/303	349/349	209/209	132/143	323/323	182/184	335/338	269/274	209/210	272/272
Cv18	300/305	349/356	209/210	131/143	323/323	182/184	338/339	269/274	209/210	272/277
Cv19	290/300	336/349	209/210	132/132	313/323	182/184	335/339	269/269	209/210	272/277
Cv20	300/305	349/356	209/209	143/144	323/323	183/184	335/338	274/274	210/210	272/277
Cv21	290/300	351/351	209/210	143/144	328/328	182/184	335/338	269/269	210/210	272/277
Cv22	290/305	336/349	209/209	143/144	313/323	182/184	335/336	269/274	209/210	272/272
Cv23	300/305	336/349	209/210	117/132	313/323	182/184	335/336	274/274	209/210	272/277
Cv24	300/305	336/349	209/210	143/144	313/323	182/184	335/336	269/274	209/210	272/277
Cv25	305/305	336/352	209/209	132/144	313/318	182/184	338/338	274/274	210/210	272/272
Cv26	305/305	344/349	204/209	132/144	313/323	182/187	338/338	269/274	210/220	272/272
Cv27	305/305	344/356	209/209	132/144	318/323	182/186	338/338	269/274	210/210	272/272
Cv28	305/305	356/356	204/209	132/144	313/313	182/184	335/342	274/274	209/210	272/272
Cv29	305/305	336/336	204/204	132/144	313/323	182/182	338/339	274/274	210/210	272/272
Cv30	305/305	344/349	204/210	132/143	313/323	182/183	339/342	269/274	209/210	272/272
Cv31	290/305	351/356	209/209	142/143	318/323	182/182	338/338	269/274	210/215	272/277
Cv32	305/305	336/351	199/209	132/144	313/313	182/184	338/342	269/274	210/210	272/272
Cv33	305/305	344/344	204/210	143/144	318/323	183/184	336/336	269/274	209/209	272/272
Cv34	305/305	344/356	204/209	132/144	318/323	182/184	336/342	269/274	210/210	272/272
Cv35	290/305	346/349	204/209	143/143	323/323	183/183	335/338	269/274	220/220	272/277
Cv36	300/300	336/349	209/210	132/144	313/318	183/186	339/342	269/274	210/210	272/277
Cv37	300/305	344/349	209/210	132/143	323/323	182/183	339/343	269/274	209/211	277/277
Cv38	290/305	351/356	209/210	143/144	323/328	182/184	336/339	274/279	210/220	272/272

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Supplemental Table 3. Continued.

Cultivar	GB739	GB740	GB743	GB744	GB745	GB747	GB748	GB749	GB750	GB751
Cv39	300/305	349/349	209/214	132/143	323/323	182/184	338/338	264/269	220/220	277/277
Cv40	300/305	344/349	209/209	132/143	318/323	182/184	335/342	269/274	210/210	272/277
Cv41	300/305	349/349	209/210	144/144	323/323	182/184	335/336	269/279	209/210	272/272
Cv42	300/305	344/349	209/210	132/143	323/323	182/184	335/336	269/274	209/210	272/272
Cv43	300/305	349/351	209/209	132/143	313/323	182/184	335/338	269/274	209/210	272/277
Cv44	300/305	344/349	209/209	143/144	323/323	182/184	335/336	274/274	209/210	272/272
Cv45	300/305	349/349	209/210	132/144	323/323	182/184	335/336	269/269	209/210	272/277
Cv46	305/305	349/356	204/209	132/144	323/323	182/184	340/347	274/274	210/210	272/272
Cv47	305/305	351/356	209/210	132/132	313/318	182/182	338/342	274/279	210/210	272/272
Cv48	290/305	349/349	209/210	143/144	313/323	182/184	340/347	269/274	209/209	272/272
Cv49	300/305	336/351	209/209	143/144	313/313	183/184	335/336	274/274	210/210	272/277
Cv50	300/305	349/349	209/210	131/144	325/325	182/184	335/343	269/269	209/220	272/277

Supplemental Table 4. Alleles at 23 simple sequence repeat marker loci in 50 hazelnut accessions. Some cultivars showed more than two alleles.

Cultivar name	Cultivar	GB462	GB501	GB535	GB568
OSU 495.049	Cv01	224/232	179/179	211/213	100/100
Albania 55	Cv02	228/233	179/179	211/213	102/102
Fusco Rubra	Cv03	224/228/232	189/189	211/213	102/102
COR187 Finland	Cv04	224/232	179/189	211/213	92/92
Pendula	Cv05	224/232	189/199	211/213	102/102
Hall's Giant	Cv06	224/233/240	189/189	218/218	102/102
Gasaway	Cv07	224/233/240	189/194	202/213	92/102
Rode Zeller	Cv08	224/232/240	179/189	213/213	102/102
Cosford	Cv09	224/224	179/189	211/213	102/102
DuChilly	Cv10	224/233	179/194	211/213	100/102
Palaz	Cv11	224/233	179/179	206/208/211/213	87/100/107
Pellicule Rouge	Cv12	224/232	179/194	211/213	87/100
Imperiale de Trebizonde	Cv13	224/228/232	179/194	202/211/213	87/102
Tombul Ghiaghli	Cv14	224/233	179/194	208/213	87/100
Tonda Bianca	Cv15	224/233	179/194	211/213	87/102
Negret	Cv16	224/224	179/179	213/213	87/102
Tonda G. d. Langhe	Cv17	224/234	179/194	211/213	90/100
Tonda Romana	Cv18	224/234	179/189	202/211/213	87/100
Römische Nuss	Cv19	224/234	179/194	211/213	87/102/107
Casina	Cv20	224/234	179/179	211/213	102/102
Ratoli	Cv21	224/234	179/189	206/208	87/102
Mortarella	Cv22	224/234	179/189/194	211/213	87/102/107
Tonda di Giffoni	Cv23	224/234	179/179	213/213	87/100
Barcelona	Cv24	224/238/234	179/179	213/213	87/100
Cutleaf	Cv25	224/234	189/189	211/213	100/100
OSU 681.078	Cv26	224/234/238	189/189	211/213	87/100
Barcelloner Zellernuss	Cv27	224/234	179/179	211/213	100/100
Aurea	Cv28	224/228/242	179/179	211/213/218	102/102
OSU 408.040	Cv29	224/234	179/189	211/213	102/102
Des Anglais	Cv30	224/234/242	179/189/194	211/213	92/102
OSU 26.072	Cv31	224/234	189/189	213/213	102/102
Bergeri	Cv32	224/228/234	189/189	202/213	102/102
Alli	Cv33	228/234/224	189/189	213/218	102/102
Early Long Zeller	Cv34	224/228/234	189/194	213/218	102/102
OSU 759.010	Cv35	224/234	179/179	211/213	87/102
Contorta	Cv36	224/228/234/242	179/189	202/203	102/102
OSU 556.027	Cv37	224/234	179/179	211/213	92/92
B-3	Cv38	224/234/238	179/179	203/206/208	102/102
OSU 54.039	Cv39	224/228/234	179/189	206/208	92/92
Gunslebert	Cv40	224/228/234	179/189	213/218	86/100
Sant Jaume	Cv41	224/228/234/238	179/189	213/213	87/100
Iannusa Racinante	Cv42	224/228/234	179/179	213/213	87/100
Gem	Cv43	224/234/238	179/179	213/213	87/100
Artellet	Cv44	224/228/234	179/189	202/213	102/102
Simon	Cv45	224/234	179/189	211/213	87/100/107
Gustav's Zellernuss	Cv46	228/234/224	189/189	213/218	102/102
Buttner's Zellernuss	Cv47	224/228/234	179/179	213/213	87/100
Tapparona di SCC	Cv48	224/228/234	179/199	208/213	92/102
OSU 252.146	Cv49	224/234/238	179/189	213/213	100/102
OSU 414.062	Cv50	224/228/234/242	179/189	208/213	102/108
Cultivar	GB594	GB609	GB610	GB613	GB615
Cv01	176/176	315/316	86/103	127/127	281/281
Cv02	177/177	316/316	86/103	127/133	257/263/281/287
Cv03	182/182	316/317	86/103	121/126	287/287
Cv04	182/182	316/316	86/91/103	127/133	281/281
Cv05	182/182	316/316	86/103	127/133	281/281

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Supplemental Table 4. Continued.

Cultivar	GB594	GB609	GB610	GB613	GB615
Cv06	177/177	315/315	86/103	127/133	275/281
Cv07	182/182	315/316	86/91/103	127/127	275/275
Cv08	172/182/187	316/323/329/311/342	86/103	127/133	275/275
Cv09	177/177	323/329/311/342	103/103	127/133	275/281
Cv10	176/176	315/329/323/311	86/103	127/127	281/287
Cv11	176/176	316/316	86/103	127/127	275/275
Cv12	176/176	315/329/323/311	86/103	127/133	275/275
Cv13	176/176	316/323/329/311	86/103	127/133	269/275/281
Cv14	172/182	316/323/329/311	103/103	127/127	269/275/281
Cv15	182/182	316/316	86/103	133/139	275/281/287
Cv16	182/182	315/316	86/103	133/133	275/281
Cv17	176/176	315/316	86/103	127/130	281/287/275
Cv18	176/176	315/316	86/103	127/133	275/281
Cv19	176/176	315/316	86/103	127/133	275/275
Cv20	182/182	315/316	86/103	127/133	275/281/287
Cv21	173/182/189	316/323/329/311	86/103	121/127	275/275
Cv22	176/176	316/316	86/103	121/127	275/275
Cv23	176/182	316/316	103/103	127/133	275/275
Cv24	177/177	316/316	86/91/103	133/139	275/275
Cv25	177/182	316/323/329	86/103	127/133	275/281
Cv26	177/182	315/316	86/103	127/133	281/281
Cv27	182/187	315/316	86/103	127/133	275/275
Cv28	176/176	315/316	86/103	127/133	275/281
Cv29	172/176/182/187	316/316	86/103	127/127	275/275
Cv30	173/184	323/329/311/342	103/103	121/127	275/275
Cv31	177/177	315/316	86/103	121/127	275/281
Cv32	172/176	316/323/329/311/342	86/103	127/133	275/275
Cv33	173/187	316/323/329/311/342	86/103	121/127	275/281
Cv34	177/177	315/323/329/311/342	103/	127/133	275/281/287
Cv35	176/176	316/316	91/103	127/127	275/281
Cv36	173/176	316/316	86/103	121/127	281/281
Cv37	176/176	316/323/329/311/342	86/103	127/127	275/275
Cv38	176/176	316/316	103/103	133/139	275/281
Cv39	176/182	316/323/329/311	86/103	127/127	269/275/281
Cv40	182/182	315/316	86/99/103	127/127	275/275
Cv41	176/182	315/316	86/91/103	121/127	275/275
Cv42	176/176	316/316	86/91/103	127/133/139	281/287/275
Cv43	176/176	315/316	103/103	127/133/139	275/275
Cv44	176/182	315/316	103/103	127/133/139	275/281/287
Cv45	182/182	315/316	86/103	127/133	281/281
Cv46	173/173	315/315	86/103	127/133	275/275
Cv47	182/187	315/323/329/311/342	86/103	127/133	281/287
Cv48	176/176	316/316	91/103	121/127	269/275
Cv49	176/176	316/316	86/103	127/139	275/287/281
Cv50	182/182	315/329/323/311	86/91/103	127/127	269/275/280
Cultivar	GB634	GB644	GB648	GB650	GB662
Cv01	380/380	251/257	257/271/264	324/332	258/264
Cv02	380/386	239/239	271/271	322/322	264/270
Cv03	380/380	245/251	265/271	316/324	258/264
Cv04	380/386	239/245	257/271/264	322/329	258/258
Cv05	386/386	239/245	257/257	316/328	258/264
Cv06	380/386	251/251	257/271/277	322/329	252/258
Cv07	380/380	239/245/251/257	271/271	316/328	258/258
Cv08	380/386	251/251	257/271/264	325/328	252/258
Cv09	386/386	239/251	257/271/264	314/328	252/264
Cv10	375/386	245/245	271/271	324/332	258/264
Cv11	375/382/386/392	245/251	257/271/264	328/328	258/258

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Supplemental Table 4. Continued.

Cultivar	GB634	GB644	GB648	GB650	GB662
Cv12	375/375	245/251	271/271	325/332	252/264
Cv13	375/386	245/251	257/264/271/278	328/328	258/258
Cv14	375/382	239/245	257/271/264	325/328	252/258
Cv15	380/380	245/251	271/278	316/328	258/264
Cv16	375/380/386	245/245	271/271	328/332	252/252
Cv17	375/380	239/245	257/257	328/328	258/264
Cv18	375/382/386/392	245/251	271/271	316/324/332/339	264/264
Cv19	382/386	245/251	272/272	316/324/332/339	252/264
Cv20	375/382/386/392	245/251	257/277	317/324/329/336	258/264
Cv21	375/382/386/392	245/251	271/278	316/323/325/332	252/258
Cv22	375/380/386	245/251	249/258	316/328	252/264
Cv23	375/380/386	245/245	271/278	325/328/332/335	252/264
Cv24	375/380/386	245/257	271/278	322/332	252/258
Cv25	375/380/386	239/245	272/272	317/324/332/339	258/258
Cv26	380/380	245/247	271/278	316/316	252/258
Cv27	380/386	239/245	271/271	314/328	252/258
Cv28	380/386	239/245	271/271	316/325	258/264
Cv29	386/386	239/251	271/271	316/328	258/258
Cv30	375/386	239/245/251	257/264/271	317/324/332/339	252/258
Cv31	380/386	245/251	257/271	316/328	258/264
Cv32	380/386	239/245	257/264/271	311/324	258/258
Cv33	380/386	245/251	257/264/271	314/323	252/268/258/262
Cv34	380/386	239/251	257/264/271	314/322	252/268/258/262
Cv35	375/375	245/257	257/264/271	325/329	252/258
Cv36	375/386	239/245	271/272	314/319/326/332	264/270
Cv37	375/375	245/251	257/264/271	325/329	264/264
Cv38	375/380	245/251	271/272	322/332	264/270
Cv39	375/375	251/251	257/264/271	325/328	258/264
Cv40	375/380	239/245	257/264/271	322/328	258/264
Cv41	375/382/386/392	245/245	271/272	316/332	258/258
Cv42	375/382/386/392	245/257	257/264/271	314/329	264/264
Cv43	375/380	245/245	271/278	316/322/329	252/258
Cv44	380/386	245/257	271/271	314/322	258/264
Cv45	375/380/386	245/245	271/272	316/322/328/334	252/252
Cv46	380/380	239/251	257/264/271	314/322	252/258
Cv47	386/386	239/251	257/264/271	314/320/325/332	252/270
Cv48	375/380/386	245/251	271/271	328/332	264/264
Cv49	375/382/386/392	239/245	271/277	314/317/319/322	252/252
Cv50	375/380/386	239/245/257/263	271/271	316/332	258/258
Cultivar	GB666	GB704	GB707	GB708	GB728
Cv01	186/190/182	112/112	214/219/240/245	167/172	125/127
Cv02	186/190/182	112/112	214/214	167/167	117/127
Cv03	185/190/186/182	112/117	238/238	167/167	117/127
Cv04	186/190/182	117/117	214/238	167/172	117/127/132
Cv05	190/196/203/186	117/117	227/227	167/167	127/127
Cv06	185/190/182	112/117	208/238	167/172	127/132
Cv07	186/190/182	107/112	238/240	157/167	127/132
Cv08	185/190/182	112/112	238/238	167/172	117/127/132
Cv09	186/196/182	112/112	208/238	167/172	117/127/132
Cv10	186/190/182	112/112	214/238	167/167	127/132
Cv11	182/196	112/112	214/219/238/243	157/167/172	117/127/132
Cv12	186/190/182	112/112	214/238	167/172	117/127/132
Cv13	186/190/182	112/112	225/238	157/167	117/127
Cv14	190/196/186/182	112/112	214/219	157/167/172	117/127
Cv15	185/190/186/182	112/112	214/239	167/172	117/127
Cv16	190/196/185/182	112/112	214/219/227/232	167/172	117/127
Cv17	186/190	107/112	214/241	167/172	117/127/132

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Supplemental Table 4. Continued.

Cultivar	GB666	GB704	GB707	GB708	GB728
Cv18	186/190	112/112	214/238	167/172	127/132
Cv19	186/190	112/112	214/214	167/172	127/132
Cv20	186/190	112/117	214/227	167/167	117/127/132
Cv21	190/196/186/182	112/112	214/219	167/172	117/127
Cv22	190/196/186/182	112/112	214/219/238/243	167/172	127/132
Cv23	186/190/185	112/112	214/239	167/172	117/127
Cv24	190/196/186	112/112	214/238	167/172	117/127/132
Cv25	190/191/186/182	107/112/117	214/238	167/167	127/132
Cv26	186/190	112/112	214/238	167/172	127/127
Cv27	186/190/182	112/117	240/241	167/167	117/127
Cv28	186/190	112/112	214/238	167/167	127/127
Cv29	186/190/182	117/117	239/240	167/167	127/132
Cv30	186/190/182	112/112	238/238	167/172	117/127
Cv31	190/200/186/182	112/112	238/240	167/172	122/127
Cv32	186/190	112/117	214/239	167/167	117/127
Cv33	186/191/182	112/117	238/239	167/167	117/127
Cv34	190/191/186/182	112/117	238/239	167/172	117/127
Cv35	182/182	107/107	214/219	167/172	117/127
Cv36	186/190/196/182	112/112	214/238	167/174	117/127
Cv37	186/196/182	112/112	207/214/219	157/167	117/127
Cv38	186/190	112/112	214/239	167/167	117/132
Cv39	186/190/182	112/112	238/239	167/172	112/117/127
Cv40	186/190/182	112/117	238/239	167/167	117/127
Cv41	185/190/186	112/112	207/238	167/172	117/127/132
Cv42	190/196/186/185	107/112	214/240	167/167	117/127
Cv43	186/190/182	112/112	214/238	167/172	127/132
Cv44	186/196/190/182	112/112	207/238	167/172	117/127/132
Cv45	186/196/182	112/112	214/219	167/172	117/127
Cv46	186/190/182	112/117	207/239	167/172	117/127/132
Cv47	185/190/182	107/107	225/238	167/172	117/127/132
Cv48	186/190	112/112	214/240	167/167	127/132
Cv49	181/196	112/112	214/219/238/243	157/167/172	117/127
Cv50	190/196/181/186	112/112	238/239	157/162	117/127/132
Cultivar	GB741	GB742	GB746	GB752	
Cv01	346/346	353/357/370	294/299	353/353	
Cv02	346/346	369/369	294/299	353/353	
Cv03	346/354	348/368/375	294/299	353/357	
Cv04	346/346	368/368	294/299	353/357	
Cv05	346/346	359/369	299/299	357/358	
Cv06	339/346	363/375/368	294/299/289	358/358	
Cv07	339/351	359/369/368	294/299/289	353/353	
Cv08	339/351	353/375/368	289/294	357/358	
Cv09	339/351	353/363/369/368	294/299/289	353/357	
Cv10	339/351	363/369	294/299/289	353/353	
Cv11	345/351	363/368	294/299/289	350/354	
Cv12	346/351	363/368	289/294/299	350/353	
Cv13	345/345	359/368	294/299	353/357	
Cv14	339/345/351	359/368/369	294/299	350/357	
Cv15	346/351	359/369/368	294/299	350/353/358/361	
Cv16	345/345	363/375/368	294/299/289	350/353	
Cv17	345/345	359/363/369	289/299/294	350/353	
Cv18	346/346	363/369	289/294/299	350/353	
Cv19	345/345	353/359/369/368	294/299	353/357/358	
Cv20	346/346	363/369	294/299/289	350/357	
Cv21	345/345	359/368	289/294/299	353/353	
Cv22	346/346	363/369/368	294/299/289	350/353	
Cv23	345/352	359/363/369/368	289/294/299	350/357/361	

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Supplemental Table 4. Continued.

Cultivar	GB741	GB742	GB746	GB752
Cv24	346/346	359/363/368	294/299/289	353/353
Cv25	346/346	353/375/368	294/299	353/357
Cv26	339/346	353/375/368	294/299	353/357
Cv27	339/346	359/368	294/299	350/357
Cv28	339/339	358/368/375	294/299	353/357
Cv29	339/346	363/368	294/299	353/357
Cv30	346/346	363/369/368	289/294/299	353/357
Cv31	346/346	353/369/368	294/299/289	353/354
Cv32	346/351	353/363/375	294/299	353/357
Cv33	346/346	353/378	294/299	353/358
Cv34	346/351	353/368/377	294/299	353/353
Cv35	345/351	353/358/363/368	294/299/289	350/354
Cv36	339/346	348/353/368/363	294/299	358/358
Cv37	345/345	359/369	294/299	357/357
Cv38	345/345	353/363/369	294/299/289	350/353
Cv39	345/345	358/368/369/363	294/299	353/357
Cv40	339/351	353/359/363/375	294/299	357/361
Cv41	345/345	363/369/368	289/299/294	353/357
Cv42	346/346	363/369	294/299/289	350/350
Cv43	340/347	359/363/369/368	294/299/289	353/353
Cv44	336/336	359/363/369	294/299	352/352
Cv45	345/345	363/375/368/369	294/299/289	350/353
Cv46	339/346	363/375/368	294/299/289	353/357
Cv47	346/351	363/369/368	289/294	353/353
Cv48	339/346	353/359/363	294/299	353/357
Cv49	345/351	353/363/368/369	294/299/289	353/357
Cv50	351/351	363/368/369	294/299/289	353/353

Supplemental Table 5. Segregation at new simple sequence repeat markers and linkage group assignments in the hazelnut mapping population (OSU 252.146 x OSU 414.062).

Locus	Alleles (Female × Male)	Expected ratio	Observed ratio	χ^2	P	Linkage group and alleles
GB401	183/196 × 183/196	1:2:1	28:78:32	2.58	0.28	196 on 5S, 183 on 5R
GB402	166/170 × 166/170	1:2:1	36:72:30	0.78	0.68	166 on 9S, 170 on 9R
GB404	122/126 × 122/126	1:2:1	30:59:49	8.13	0.02	126 on 7S, 122 on 2R (falls out at LOD = 4)
GB408	158/158 × 158/166	1:1	70:66	0.12	0.73	166d on 5R
GB410	169/169 × 161/165	1:1	63:71	0.48	0.49	165 on 4R
GB413	191/192 × 187/197	1:1:1:1	36:25:35:39	3.28	0.35	191 on 1S, 187 on 1R
GB414	110/118 × 110/110	1:1	74:63	0.88	0.35	118d on 8S
GB417	174/178 × 174/178	1:2:1	39:69:30	0.60	0.74	174 on 9S, 178 on 9R
GB418	205/216 × 205/205	1:1	55:77	3.67	0.06	216 on 1S
GB420	211/227 × 211/227	1:2:1	34:76:28	1.94	0.38	211 on 9S, 211 on 9R
GB422	221/237 × 237/237	1:1	80:53	5.48	0.02	221 on 7S
GB423	294/297 × 292/294	1:1:1:1	33:31:42:29	2.93	0.40	297 on 6S, 292 on 6R
GB424	278/286 × 278/286	1:2:1	32:78:28	2.58	0.28	286 on 9S, 286 on 9R
GB428	240/244 × 244/244	1:1	71:67	0.12	0.73	240d on 8S
GB430	292/296 × 296/300	1:1:1:1	38:38:31:30	1.66	0.65	292 on 9S, 300 on 9R
GB432	313/315 × 317/319	1:1:1:1	33:33:34:37	0.31	0.96	313 on 4S, 319 on 4R
GB433	147/149 × 147/152	1:1:1:1	30:30:35:39	1.70	0.64	149 on 10S, 152d on 10R
GB434	335/347 × 347/347	1:1	63:72	0.60	0.44	335 on 4S
GB435	94/98 × 94/98	1:2:1	27:70:41	2.87	0.24	98 on 9S, 94 on 9R
GB436	122/126 × 122/122	1:1	72:64	0.47	0.49	126d on 4S
GB437	334/340 × 334/338	1:1:1:1	37:35:28:32	1.39	0.71	340 on 4S, 338d on 4R
GB438	311/319 × 311/315	1:1:1:1	33:39:26:30	2.81	0.42	319 on 4S, 315 on 4R
GB441	178/182 × 178/178	1:1	68:69	0.01	0.93	182d on 4S
GB444	313/317 × 313/321	1:1:1:1	48:31:31:25	8.73	0.03	317 on 1S
GB447	182/187 × 182/187	1:2:1	35:65:38	0.59	0.74	187 on 1S, 182 on 1R
GB450	335/339 × 335/339	1:2:1	41:77:20	8.25	0.02	339 on 11S, 339 on 11R
GB456	104/112 × 112/112	1:1	66:70	0.12	0.73	104 on 6S
GB457	197/201 × 197/201	1:2:1	36:71:31	0.48	0.79	201 on 6S, 201 on 6R
GB458	295/303 × 299/302	1:1:1:1	35:28:34:39	1.82	0.61	295 on 2S, 299 on 2R
GB461	273/277 × 273/273	1:1	64:74	0.72	0.39	277d on 4S
GB462	224/224 × 224/228	1:1	59:78	2.64	0.10	228d on 4R
GB466	102/102 × 102/110	1:1	69:69	0.00	1.00	110d on 8R
GB467	336/352 × 336/352	1:2:1	42:63:33	2.22	0.33	336 on 7S, 336 on 7R
GB468	359/359 × 355/377	1:1	68:68	0.00	1.00	359d on 4S, 377 on 4R
GB469	336/340 × 332/340	1:1:1:1	43:34:34:23	6.00	0.11	336d on 1S, 332 on 1R
GB470	383/383 × 395/397	1:1	70:64	0.27	0.60	395 on 1R
GB473	189/194 × 189/198	1:1:1:1	35:36:22:31	3.94	0.27	194d on 1S, 198d on 1R
GB475	183/183 × 183/187	1:1	84:53	7.01	0.01	187 on 4R (gap at end)
GB477	345/345 × 338/345	1:1	61:77	1.86	0.17	338d on 3R
GB478	389/389 × 389/392	1:1	61:76	1.64	0.20	392 on 6R
GB482	132/140 × 132/140	1:2:1	40:63:35	1.41	0.50	132 on 7S, 132 on 7R
GB483	355/355 × 355/359	1:1	24:22	0.09	0.77	359 on 2R
GB501	178/188 × 178/188	1:2:1	20:76:42	8.43	0.01	179 on 11S, 179 on 11R
GB505	275/286 × 271/275	1:1:1:1	28:35:36:34	1.17	0.76	286d on 8S, 271d on 8R
GB532	368/368 × 360/368	1:1	75:62	1.23	0.27	360d on 3R
GB533	121/126 × 126/126	1:1	62:76	1.42	0.23	121 on 1S
GB535	213/213 × 208/213	1:1	69:67	0.03	0.86	208 on 2R
GB544	389/394 × 389/394	1:2:1	28:80:30	3.57	0.17	394 on 5S, 389 on 5R
GB548	151/156 × 146/151	1:1:1:1	36:33:40:27	2.65	0.45	156 on 1S, 146 on 1R
GB563	185/195 × 190/190	1:1	79:59	2.90	0.09	195 on 1S
GB565	176/176 × 176/181	1:1	75:61	1.44	0.23	181 on 2R
GB568	100/102 × 102/108	1:1:1:1	31:94:9:0	160.87	0.00	100d on 7S (large gap on map)
GB581	105/105 × 110/115	1:1	75:61	1.44	0.23	110 on 1R
GB587	175/180 × 175/180	1:2:1	33:67:38	0.48	0.79	175 on 4S, 175 on 4R
GB602	240/240 × 240/246	1:1	64:72	0.47	0.49	246 on 6R
GB604	191/197 × 191/197	1:2:1	39:70:29	1.48	0.48	191 on 9S, 197 on 9R
GB605	118/124 × 124/124	1:1	67:70	0.07	0.80	118 on 6S

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Supplemental Table 5. Continued.

Locus	Alleles (Female × Male)	Expected ratio	Observed ratio	χ^2	<i>P</i>	Linkage group and alleles
GB606	316/330 × 330/330	1:1	73:48	5.17	0.02	316d on 11S
GB609	316/316 × 315/329	1:1	71:66	0.18	0.67	329 on 2R
GB613	139/139 × 127/139	1:1	69:69	0.00	1.00	127d on 1R (poor fit)
GB614	371/371 × 368/371	1:1	73:65	0.46	0.50	368 on 1R
GB616	359/359 × 359/365	1:1	70:65	0.19	0.67	365 on 1R
GB618	322/328 × 321/328	1:1:1:1	36:37:27:31	1.98	0.58	321d on 2R
GB619	150/150 × 138/144	1:1	62:75	1.23	0.27	144 on 1R
GB620	207/221 × 207/221	1:2:1	31:80:27	3.74	0.15	207 on 9S, 221 on 9R
GB621	105/117 × 117/117	1:1	76:61	1.64	0.20	105 on 4S
GB622	125/125 × 113/125	1:1	65:72	0.36	0.55	113 on 9R
GB623	377/377 × 377/383	1:1	24:22	0.09	0.77	383d on 2R
GB625	226/226 × 226/232	1:1	90:47	13.50	0.00	232d on 11R
GB626	146/146 × 139/146	1:1	66:60	0.29	0.59	139 on 4R
GB627	354/360 × 354/366	1:1:1:1	37:35:37:27	2.00	0.57	360 on 1S, 366 on 1R
GB628	342/348 × 348/348	1:1	65:73	0.46	0.50	342 on 4S
GB631	92/98 × 98/98	1:1	67:70	0.07	0.80	92 on 9S
GB633	116/122 × 116/122	1:2:1	29:78:31	2.41	0.30	122 on 9S, 116 on 9R
GB634	386/382 × 380/386	1:1:1:1	75:6:32:0	123.64	0.00	382d on 7S (large gap)
GB635	130/130 × 130/144	1:1	63:72	0.60	0.44	144 on 6R
GB636	250/261 × 250/261	1:2:1	16:53:69	48.13	0.00	261 on 11S, 250 on 11R (poor fit)
GB638	324/324 × 318/324	1:1	68:69	0.01	0.93	318 on 9R
GB640	355/355 × 346/354	1:1	67:70	0.07	0.80	346d on 4R
GB641	139/139 × 139/152	1:1	71:66	0.18	0.67	152d on 2R
GB642	361/367 × 367/367	1:1	57:77	2.99	0.08	361 on 7S
GB643	244/244 × 238/244	1:1	72:64	0.47	0.49	238d on 10R
GB644	239/245 × 245/257	1:1:1:1	36:37:28:32	1.53	0.68	239 on 6S (poor fit), 257d on 6R
GB645	292/298 × 292/293	1:1:1:1	20:23:50:43	19.24	0.00	298 on 10S, 293 on 10R
GB646	273/291 × 285/285	1:1	67:68	0.01	0.93	273 on 5S
GB647	171/177 × 171/177	1:2:1	27:71:40	2.57	0.28	177 on 9S, 171 on 9R
GB649	251/252 × 252/264	1:1:1:1	35:30:39:29	1.95	0.58	251 on 2S, 264d on 2R
GB650	314/322 × 316/332	1:1:1:1	35:41:22:35	5.80	0.12	322 on 1S, 316 on 1R (poor fit)
GB654	279/279 × 273/279	1:1	72:66	0.26	0.61	273d on 10R
GB655	235/247 × 235/247	1:2:1	20:78:40	8.14	0.02	235 on 11S, 235 on 11R
GB657	198/198 × 198/204	1:1	59:77	2.38	0.12	204d on 4R
GB658	339/342 × 339/342	1:2:1	38:68:32	0.55	0.76	342 on 1R (poor fit)
GB659	219/222 × 210/222	1:1:1:1	35:39:39:24	4.40	0.22	219d on 5S, 210 on 5R
GB660	210/221 × 214/221	1:1:1:1	41:39:21:23	10.58	0.01	210d on 5S, 214 on 5R
GB661	205/211 × 217/217	1:1	70:68	0.03	0.86	205 on 1S
GB663	133/133 × 133/139	1:1	67:70	0.07	0.80	139d on 4R
GB664	302/308 × 302/302	1:1	67:70	0.07	0.80	308 on 8S
GB665	181/193 × 181/181	1:1	64:74	0.72	0.39	193 on 4S
GB666	181/196 × 190/196	1:1:1:1	17:30:46:35	13.56	0.00	181 on 4S (poor fit), 190 on 4R
GB669	111/117 × 111/111	1:1	70:67	0.07	0.80	117d on 2S
GB670	253/259 × 259/270	1:1:1:1	28:30:33:42	3.45	0.33	253 on 4S, 270 on 4R
GB671	234/247 × 234/247	1:2:1	34:75:29	1.41	0.50	247 on 6S, 247 on 6R
GB673	354/371 × 354/354	1:1	65:73	0.46	0.50	371 on 5S
GB675	344/356 × 344/350	1:1:1:1	30:30:29:42	3.50	0.32	356d on 4S, 350 on 4R
GB676	339/341 × 339/345	1:1:1:1	36:25:36:34	2.53	0.47	341d on 2S, 345 on 2R
GB678	199/209 × 199/209	1:2:1	32:67:39	0.83	0.66	199 on 5S, 199 on 5R
GB702	181/181 × 181/191	1:1	71:66	0.18	0.67	191 on 2R
GB706	369/369 × 369/378	1:1	72:61	0.91	0.34	378 on 1R
GB707	219/238 × 238/239	1:1:1:1	46:26:33:31	6.41	0.09	219d on 4S
GB709	263/263 × 262/269	1:1	58:77	2.67	0.10	269d on 6R
GB712	134/134 × 134/139	1:1	74:62	1.06	0.30	139d on 1R
GB716	140/145 × 140/145	1:2:1	41:63:34	1.75	0.42	140 on 2R, 145 on 2S (poor fit)
GB717	214/214 × 214/224	1:1	64:73	0.59	0.44	224d on 4R
GB718	398/398 × 393/403	1:1	68:70	0.03	0.86	393d on 1R

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Supplemental Table 5. Continued.

Locus	Alleles (Female × Male)	Expected ratio	Observed ratio	χ^2	<i>P</i>	Linkage group and alleles
GB719	306/311 × 297/311	1:1:1:1	38:38:23:33	4.55	0.21	306 on 1S, 297 on 1R
GB721	383/383 × 379/385	1:1	71:66	0.18	0.67	379 on 2R
GB722	253/254 × 259/265	1:1:1:1	34:37:36:30	0.84	0.84	254 on 2S, 265 on 2R
GB724	211/216 × 209/211	1:1:1:1	32:36:28:42	3.10	0.38	216d on 10S, 209 on 10R
GB725	312/317 × 312/317	1:2:1	37:69:32	0.36	0.83	312 on 9S, 312 on 9R
GB726	259/268 × 256/268	1:1:1:1	48:66:10:12	67.06	0.00	259 on 11S
GB727	387/388 × 372/388	1:1:1:1	31:18:29:45	11.99	0.00	387 on 1S, 372 on 1R
GB729	287/287 × 278/287	1:1	68:70	0.03	0.86	278d on 4R
GB732	203/208 × 208/208	1:1	80:57	3.86	0.05	203d on 1S
GB733	336/336 × 336/341	1:1	21:116	65.88	0.00	unlinked
GB734	344/349 × 344/349	1:2:1	25:80:33	4.43	0.11	349 on 5S, 344 on 5R
GB737	392/392 × 377/392	1:1	15:118	79.77	0.00	unlinked
GB739	300/305 × 300/305	1:2:1	27:74:37	2.17	0.34	9R, 9S
GB740	336/351 × 349/349	1:1	72:63	0.60	0.44	336 on 2S
GB741	345/351 × 351/351	1:1	63:62	0.01	0.93	345 on 3S
GB744	143/144 × 131/144	1:1:1:1	29:32:32:32	0.22	0.97	143d on 8S, 131 on 8R
GB746	294/299 × 294/299	1:2:1	6:132:0	115.57	0.00	unlinked
GB748	334/335 × 334/343	1:1:1:1	34:30:38:36	1.01	0.80	335 on 9S, 343 on 9R
GB750	210/210 × 209/220	1:1	69:68	0.01	0.93	220 on 2R
GB751	272/277 × 272/277	1:2:1	41:68:29	2.12	0.35	272 on 9S, 277 on 9R
GB752	353/357 × 353/353	1:1	67:67	0.00	1.00	357d on 11S

Supplemental Table 6. Private (unique) alleles at SSR loci in 50 hazelnut accessions. At 103 loci, a total of 201 unique alleles were observed.

No.	Locus	Allele	Accessions
1	GB405	169	Fusco Rubra
		177	OSU 495.049
2	GB407	179	OSU 681.078
3	GB409	149	OSU 759.010
		162	OSU 26.072
4	GB410	149	OSU 26.072
		157	Tonda G. d. Langhe
5	GB413	188	Imperiale de Trebizonde
		193	OSU 759.010
		197	OSU 414.062
		198	Gasaway
		201	Fusco Rubra
6	GB416	251	Fusco Rubra
7	GB418	204	OSU 495.049
		233	Fusco Rubra
8	GB420	231	OSU 759.010
		235	Iannusa Racinante
9	GB422	215	OSU 54.039
		233	Tonda G. d. Langhe
10	GB423	283	OSU 495.049
11	GB427	200	Römische Nuss
12	GB429	274	OSU 495.049
13	GB432	311	Palaz
		323	Artellet
14	GB435	102	OSU 26.072
15	GB438	307	Cutleaf
16	GB447	181	Albania 55
17	GB450	343	Ala Kieri (COR187)
18	GB454	246	OSU 759.010
		252	Fusco Rubra
19	GB463	296	OSU 54.039
20	GB465	263	OSU 681.078
21	GB468	364	Cutleaf
		372	Rode Zeller
		379	Imperiale de Trebizonde
22	GB469	322	Pendula
		327	Fusco Rubra
		335	Buttner's Zellernuss
23	GB470	393	Artellet
		399	B-3
		406	OSU 759.010
24	GB476	299	Contorta
25	GB477	336	Iannusa Racinante
26	GB480	262	Imperiale de Trebizonde
		274	OSU 759.010
		276	OSU 414.062
27	GB483	343	Fusco Rubra
		354	Bergeri
28	GB505	281	Albania 55
29	GB526	79	OSU 495.049
		83	Pendula
		87	Artellet
30	GB527	115	Aurea
31	GB532	377	Sant Jaume
32	GB544	390	Gustav's Zellernuss
33	GB568	86	Gunslebert

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Supplemental Table 6. Continued.

No.	Locus	Allele	Accessions
		90	Tonda G. d. Langhe
		108	OSU 414.062
34	GB577	156	Fusco Rubra
		162	OSU 681.078
		167	Bergeri
35	GB581	95	Imperiale de Trebizonde
36	GB587	174	OSU 681.078
		179	Römische Nuss
		185	Imperiale de Trebizonde
37	GB594	184	Des Anglais
		189	Ratoli
38	GB601	151	Tonda Romana
39	GB603	168	Tapparona di SCC
40	GB605	136	Fusco Rubra
41	GB606	318	Fusco Rubra
		319	Albania 55
		320	Contorta
		329	Hall's Giant
		337	Des Anglais
42	GB609	317	Fusco Rubra
43	GB610	99	Gunslebert
44	GB613	126	Fusco Rubra
		130	Tonda G. d. Langhe
45	GB614	362	Gustav's Zellernuss
		373	Gustav's Zellernuss
46	GB615	257	Albania 55
		263	Albania 55
		280	OSU 414.062
47	GB618	310	Tonda di Giffoni
		311	OSU 26.072
		313	Fusco Rubra
		315	Des Anglais
		317	OSU 54.039
		324	B-3
		335	OSU 759.010
		336	Sant Jaume
		354	Alli
48	GB619	142	OSU 408.040
49	GB622	112	OSU 681.078
50	GB623	371	Tonda Romana
51	GB625	239	OSU 556.027
52	GB626	133	Gasaway
53	GB628	336	OSU 556.027
		346	Albania 55
		355	Albania 55
		368	Bergeri
		372	OSU 681.078
54	GB633	110	OSU 26.072
55	GB636	263	Palaz
56	GB638	297	OSU 26.072
57	GB639	369	Palaz
		373	OSU 54.039
58	GB641	133	DuChilly
59	GB643	243	Des Anglais
60	GB644	247	OSU 681.078
		263	OSU 414.062
61	GB645	306	Fusco Rubra

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Supplemental Table 6. Continued.

No.	Locus	Allele	Accessions
62	GB647	172	Gunslebert
		174	OSU 408.040
63	GB648	249	Mortarella
		258	Mortarella
		265	Fusco Rubra
64	GB649	249	Tonda Bianca
65	GB650	311	Bergeri
		320	Buttner's Zellernuss
		326	Contorta
		334	Simon
		335	Tonda di Giffoni
		336	Casina
66	GB652	211	Fusco Rubra
		226	Cosford
		230	Casina
67	GB653	196	OSU 759.010
68	GB654	277	Pendula
		290	Ala Kieri (COR187)
69	GB655	237	OSU 495.049
		241	Fusco Rubra
70	GB657	194	Imperiale de Trebizonde
		210	Tapparona di SCC
71	GB658	327	OSU 759.010
		351	OSU 495.049
72	GB660	204	Casina
73	GB665	169	OSU 759.010
74	GB666	200	OSU 26.072
		203	Pendula
75	GB668	176	OSU 556.027
		195	OSU 54.039
76	GB670	247	OSU 495.049
		268	Gasaway
77	GB671	294	Aurea
78	GB673	347	B-3
		359	Aurea
79	GB674	175	Gasaway
		179	OSU 495.049
80	GB678	187	OSU 26.072
		205	Cutleaf
		213	OSU 556.027
81	GB706	383	OSU 26.072
82	GB707	232	Negret
		245	OSU 495.049
83	GB708	162	OSU 414.062
		174	Contorta
84	GB709	257	DuChilly
		258	Gem
		265	Albania 55
		270	Tonda Bianca
		284	OSU 556.027
85	GB712	123	Gustav's Zellernuss
		138	Barcelona
86	GB716	130	OSU 495.049
87	GB721	374	Pellicule Rouge
		388	Albania 55
88	GB722	248	Fusco Rubra
		256	Artellet

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Supplemental Table 6. Continued.

No.	Locus	Allele	Accessions
		262	Tapparona di SCC
89	GB726	266	OSU 495.049
		281	Fusco Rubra
90	GB728	112	OSU 54.039
		122	OSU 26.072
		125	OSU 495.049
91	GB729	284	OSU 759.010
92	GB732	198	Fusco Rubra
		214	OSU 26.072
		221	Albania 55
93	GB733	326	Albania 55
94	GB735	153	OSU 759.010
95	GB739	285	Palaz
		303	Tonda G. d. Langhe
96	GB740	346	OSU 759.010
		354	OSU 495.049
		361	Fusco Rubra
97	GB741	336	Artellet
		340	Gem
		347	Gem
		352	Tonda di Giffoni
		354	Fusco Rubra
98	GB742	357	OSU 495.049
		370	OSU 495.049
		377	Early Long Zeller
		378	Alli
99	GB743	199	Bergeri
100	GB744	142	OSU 26.072
101	GB748	352	Tonda Bianca
102	GB749	275	Imperiale de Trebizonde
103	GB752	352	Artellet