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Introduction

It defines the objectives and the importance of the research. It focus on the the application of Next Generation Sequencing to molecular biology, wheat genetics and ultimately to breeding programs. It also mentions the current status of the wheat reference genome and other resources (genetic maps, markers) the need of tools to query them effectively.

Literature review

It describes the current status of the wheat genome, genetics and other resources.

2.1 Wheat Breeding

An overview of how breeding is carried on currently, the different sources of genetic diversity and the relevance of fixing agriculturally important traits.

2.2 Wheat Genetics

The section describes alleles an the concept of gene, both as a locus in the genome (Quantitative Trait Locus, QTL) and an specific transcript (central dogma of molecular biology). Finally, it discuses traditional Mendelian inheritance and the effect of polyploidy.

2.3 Wheat Genomics

A description of the current status of the wheat genome (Mayer et al. (2014), Chapman et al. (2015)), the different available assemblies and and approaches to sort the scaffolds (Genome Zipper, the various genetic maps).

2.4 Sequencing

The importance of the selection of the library preparation and the sequencing platforms available. A brief summary of RNA-Seq, Exome capture, Whole Genome Shotgun, etc. and on which cases are more suitable for different experiments. Mention the new technologies developed during the years of the PhD (Ren-Seq, PacBio?)

2.5 Sequence analysis

This section discusses the criteria to decide analysis done after sequencing, when to do re-alignments or *de novo* assemblies, how to do SNP calling in diploid and polyploid organisms and the bulk frequency ratios.

2.6 Wheat online resources

A compilation of the currently available resource for whet genetics and genomics. MAS wheat, CeralsDB, Ensembl, etc.

Genetic mapping of Yr15

This section describes in detail than the paper of Ramirez-Gonzalez et al. (2014)

3.1 (Introduction) Yr15

Breeding importance of Yr15 and original source (an introgression of T. diccocoides).

3.2 Segregating population and resistance essays

A description of the starting material and how the population was generated.

3.3 Sequencing and mapping

RNA-Seq and the decision to call SNPs on gene models rather than the whole reference. Details of the mapping against the Wheat UniGenes Pontius et al. (2002) and the UCW. Krasileva et al. (2013) gene models.

3.4 SNP Calling

. Ruby implementation of the methodology described by Trick et al. (2012).

3.5 Bulk Frequency Ratios

Results of the simple SNP calls from the progenitors and how the score of the Bulk Frequency Ratios(BFR) improve the location of the SNPs.

3.6 In silico mapping

Mapping of the gene models to the IWGSC CSS Mayer et al. (2014) reference and the location of the SNPs using the genetic map from Wang et al. (2014).

3.7 Assay selection

. The selection criteria to decide which SNPs where selected to produce the genetic map: BFR>6, in the short arm of chromosome group 1 and from the Yr15 progenitor.

3.8 Genetic map

The three versions of the genetic map: With a subset of the F₂ population

3.9 Assembly of the transcriptome

A comparison between the known unigenes and the transcript from the progenitors. Since Yr15 comes from an introgression with $T.\ diccocoides$, some novel transcripts can be extracted. Analysis of the gels from Mitaly?

3.10 Conclusions

Remarks on how this techinque can be used to do fine-mapping and that if I were to start the project now I would use exome capture or Ren-Seq.

PolyMarker: A fast polyploid primer design pipeline

One of the main challenges of working with polyploid species is the design of genome specific molecular markers. This is particularly true when targeting conserved homoeologue regions, where a primer could bind to a pair,or triplet, of identical sequences. For that reason, designing primers for polyploids require to include bases that are specific to the target, in addition to the physicochemical properties of the primer. The traditional methodology to find primer candidates include a blast search and a local alignment, select the primer candidates manually, and finally, validate the primers with a tool, like Primer3 (Rozen and Skaletsky, 2000). To reduce the time invested in designed primers I have developed PolyMarker (Ramirez-Gonzalez et al., 2015), a pipeline to automate the primer design for polyploid organisms.

4.1 Pipeline

PolyMarker is an automated pipeline that takes as input a list of SNPs and a reference file and produces a list of primer triplets for SNP genotyping. The list of SNPs is first converted to a FASTA file with ambiguity codes(Cornish-Bowden, 1985) The sequences are searched on the genomic reference using exonerate(Slater and Birney, 2005) to find the homoeologue regions to the target sequence. Then, the alignment between homoeologues is refined using MAFFT(Katoh and Standley, 2013). A list of candidate variations is produced and used as input for Primer3(Rozen and Skaletsky, 2000). Finally, the output of Primer3 is parsed to find the best primer pair that contains a the targeted SNP and a base that is specific to the target genome (Figure 4.1). The pipeline is written as a Ruby script, using parsers and wrappers from BioRuby (Goto et al., 2010) and bio-samtools (Etherington et al., 2015; Ramirez-Gonzalez et al., 2012). The software is open source and released as a biogem (Bonnal et al., 2012), bio-polyploid-tools, the source code is available in github: https://github.com/TGAC/bioruby-polyploid-tools.

The PolyMarker input consist on SNP list with: unique name for the marker, the target chromosome and the sequence for the marker. The alternative alleles are surrounded by square brackets within the sequence. PolyMarker can take a list of several markers and design them in batch (Figure 4.2a). A FASTA file is produced with all the template sequences, with the alternative alleles substituted by the IUAPC ambiguity codes (Cornish-Bowden, 1985). The flanking sequence surrounding the SNP is limited by default to 100bp to reduce the search time and avoid missing regions that diverge near the SNP, as when the variation is near an

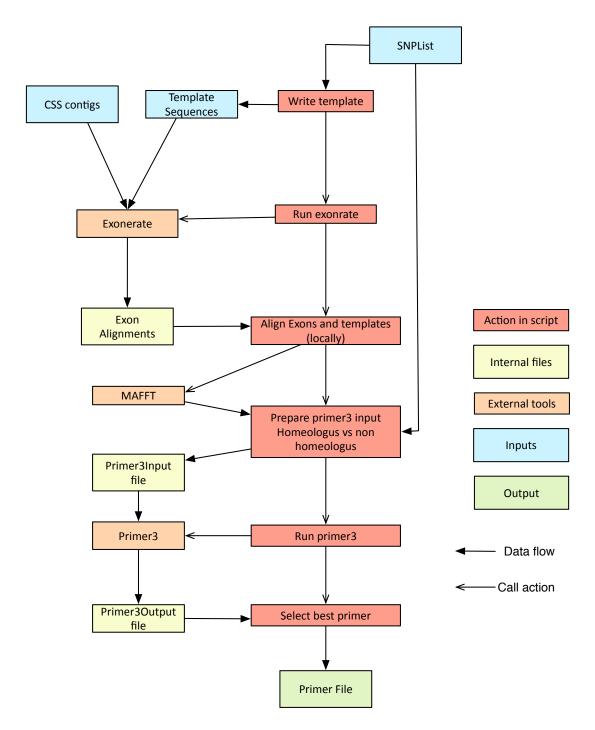


Figure 4.1: Steps and tools called by PolyMarker. The colour of the boxes represent: the step is an action inside the script(red); actions of the script(orange); temporary files(yellow); inputs(blue) and; outpus(green)

intron-exon junction.

The template sequences are searched in the reference sequence using exonerate (Slater and Birney, 2005), figure 4.2b. The alignment is run with the --model est2genome option, to allow the search of sequences coming from transcripts, a common source of SNPs (Allen et al., 2011). The exonerate output is formatted with the --ryo (roll your own format) to get an output easy to parse. All the hits that contain the SNP are extracted from the reference with a flanking sequence that extend out of the hit, by defualt, to 100bp on each side of the SNP (Figure 4.2c). The size of the flanking sequence can be set to different sizes to allow the design of different types of primers. Different homoeologues may contain small indels (Figure 4.2d). To enable a comparasion base-per-base, a local alignment with MAFFT (Katoh and Standley, 2013) is produced (Figure 4.2e.

PolyMarker searches across each base in the local alignment to identify the variations across homoeologues and the target marker. A mask is produced to highlight the bases with a variations (Figure 4.2f) on the following categories:

Specific Homoeologous polymorphism which is only present in the target

genome (upper case).

Semi-specific Homoeologous polymorphism which is found in 2 of the 3 genomes,

hence it discriminates against one of the off-target genomes or when not all the homoeologous sequences were found (lower

case).

Non-specific No variation is found across homoeologues (-).

Homoeologous The target SNP is present across different chromosomes, so can-

didate SNP markers on this category are not expected to be

reliably identify the allele (:).

Non-homoeologous The target SNP is not present across chromosomes, so it can be

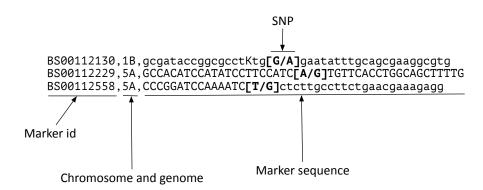
used to identify an allele (&).

PolyMarker was designed to produce SNP assays for KASP genotyping (LGC Genomics, 2013), which requires a common primer and two allele-specific primers. The common primer is selected to start on a position from a: Specific; Semi-specific or; Non-specific, on that priority. This means that the common primer will be as specific as possible in the region. For the allele-specific primers, the starting position of the primer is on the base with the SNP. To ensure that the stability of the candidate primers will be met, the putative starting positions are tested with Primer3 (Rozen and Skaletsky, 2000).

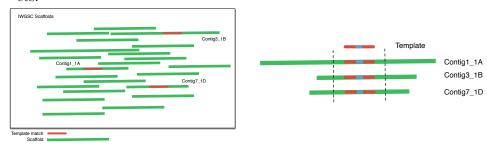
PolyMarker was designed and validated with the markers described in section 3.8. For wheat, PolyMarker uses the contigs from Mayer et al. (2014), as deposited in Ensembl. As new releases of the wheat genome are made available, different parsers to assign the chromosome to each sequence can be added with little effort to PolyMarker.

4.2 PolyMarker public web service

To make PolyMarker accessible to the community, a web server that allow the submission of SNPs was developed. The web interface consists on two virtual machines,



(a) PolyMarker input. The alternative alleles are sorrounded by brackets.



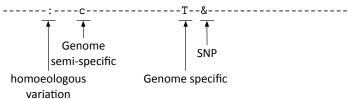
- (b) Global search of templates in the reference contigs.
- SNP-1 A cgcatttGcgcgYgcgataccggcgcctKtgGgaatatttgcagcgaaggcgtg
 SNP-1 B cgcatttAcgcgYgcgataccggcgcctKtgAgaatatttgcagcgaaggcgtg
 TWGSC-1A cgcatttgcgcgcgataccggcgctttgggaatatttgcagcgaaggcgtg
 TWGSC-1B cgcatttacgcgcgcgataccggcgctttgggaatatttgcaaggcgtg
 TWGSC-1D catttgcgcgTgcgataccggcgctttggggaatatttgcagcgaaggcgtg
- (c) Selected regions around the SNP on every chromosome.
- SNP-1 A
 cgcatttGcgcgYgcgataccggcgctKtgGgaatatttgcagcagaggcgtg

 SNP-1 B
 cgcatttAcgcgYgcgataccggcgctKtgAgaatatttgcagcagaaggcgtg

 TWGSC-1A
 cgcatttGcgcgcgctataccggcgcttGtgGgaatatttgcagcagaggcgtg

 TWGSC-1B
 cgcatttAcgcgcgcgataccggcgctTtgGgaatatttgc---gaaggcgtg

 TWGSC-1D
 c--atttGcgcgTgcgataccggcgctCtGtgGgaatatttgcagcagaggcgtg
- (d) Sequence of found regions around the SNP.
- (e) Local alignment on regions around the SNP detects indels.
- SNP-1 A cgcattt**G**cgcgYgcgataccggcgcctKtg**G**gaatatttgcagcgaaggcgtg
 SNP-1 B cgcattt**A**cgcgYgcgataccggcgcctKtg**A**gaatatttgcagcgaaggcgtg
 IWGSC-1A cgcatttGcgcgcgcgataccggcgcctGtgGgaatatttgcagcgaaggcgtg
 IWGSC-1B cgcatttAcgcgcg<mark>cgataccggcgcctT</mark>tgGgaatatttgc---gaaggcgtg
 IWGSC-1D c--atttGcgcgTgcgataccggcgcctGtgGgaatatttgcagcgaaggcgtg



(f) Alignment with mask and primer candidates.

Figure 4.2: Alignments done by PolyMarker.

Table 4.1: Count of KASP assays designed for the 40,267 SNP markers located in the genetic map from Wang et al. (2014). 4,228 assays did not align to the target chromosome. Not designed: Primer3 could not find viable primers flanking the SNP.

	Homoeologous variant	Varietal SNP	Percentage
Non-specific Semi-specific Specific Not designed	1,765 7,942 6,813 242	5,857 6,907 5,957 556	21.15% 41.20% 35.43% 2.21%
Total	16,762	19,277	36,039

one with a web facing interface that stores the queries, and a dedicated node to submit jobs to an HPC cluster. The on-line interface further simplifies the design of KASP assays, a process that used to take a couple of weeks now is done in a couple of hours. Since the release of the public service in July 2014 until August 2016, 1,739 requests to PolyMarker have been done.

4.3 Applications of PolyMarker

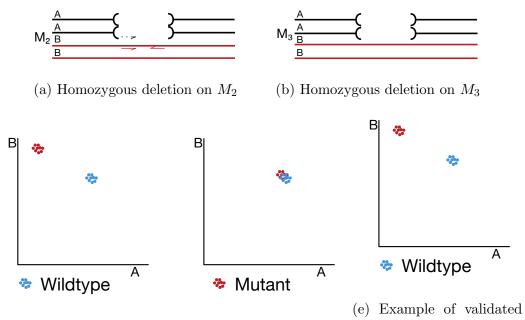
PolyMarker is not restricted to wheat or to KASP assays, the source code is flexible and can be extended for other types of analysis. On each of the following projects, PolyMarker has been adapted to design primers in species where KASP hasn't been used before, the primers are used for regular PCR amplification, or the use of KASP is not the conventional SNP calling.

4.3.1 KASP assays for public sets of SNPs

PolyMarker was used to design KASP assays for the 81,587 markers from (Wang et al., 2014), available on the PolyMarker website and in CeralsDB (Wilkinson et al., 2012). Of those markers, 40,267 where designed using the target chromosome using the genetic map published by the genetic map. Genes without a genetic position were aligned to scaffolds sorted by chromosome from the International Wheat Genome Sequencing Consortium (Mayer et al., 2014) with BLAT (Kent, 2002) and the best hit was selected as putative location. 97.5% of the assays where designed and 76% of them are semi-specific or specific, thereby improving their expected performance with respect to randomly designed primers (Table 4.1). A set of the designed assay was used to genotype a mapping population to find resistance to Fusarium head blight (Burt et al., 2015).

4.3.2 Genotyping of *Puccinia striiformis f. sp. tritici* isolates.

In Hubbard et al. (2015), *Puccinia striiformis* f. sp. *tritici* (PST) isolates were sequenced and assigned to clusters, according to their genotype. The clusters are useful to monitor the changes in the pathogen population, which can be used to predict if certain wheat lines will be resistant to the isolates in the field. PolyMarker was used to design primers for PST, using the assembly PST-130 Cantu et al. (2011).



- (c) KASP amplification for (d) KASP amp a real deletion false positive
- (d) KASP amplification on deletion on mutant poulafalse positive tion

Figure 4.3: PolyMarker used to find primers to detect long deletions in tetraploid wheat.

Out of 15 assays 11 can be used to identify to which cluster of isolates a sample is likely to belong (Supplemental Table A.1).

4.3.3 Validation of SNPs in a mutant population

(Krasileva et al., submitted 2016)

4.3.4 Validation of deletions on a mutant population

Primers

4.4 Conclusions

Remarks on the importance of getting the primers right, and the time saved by automating the primer selection. Also mention other primer design tools that have been inspired by polymarker: Ma et al. (2015), Wang et al. (2016)

PolyMarker has been used successfully to design genome-specific primers in several projects.

Gene expression (expVIP)

5.1 Expression experiments (Introduction)

Describe the list of previously published expression experiments and how they can potentially be used as a framework for new experiments.

5.2 Database design

Description of how the database was designed and the flexibility given by having the factors and units as variables

5.3 Analysis pipeline

Implementation of the pipeline, from running kallisto to load the data in the database

5.4 Graphical interface

How the expression can be displayed filtered, and sorted

5.5 Conclusions

The use of previously published studies is a valuable resource. Also, mention that despite the fact that there are several expression/gene browsers, none of them allow comparisons between species and don't consider polyploids.

Conclusions and final remarks

This section wraps up by showing the relationship and importance of a comprehensive approach to data analysis, from the field, genetics, molecular biology and genomics. I will also remark how the technology and the resources have changed in the last 4 years. As at the references used at beginning where superseded during the PhD.

Appendix A Supplemental tables.

Table A.1: PolyMarker used to genotype PST $\,$

					Cluster	I isolates	Cluste	r II isolates	Clu	ster III is	olates	Cluster	IV isolates
Assay	Contig	Position	X	Y	13/26	13/123	CL1	T-13/3	13/09	13/23	13/182	13/36	13/40
1	PST130_14470	268	C	Т	X:Y	X:Y	X:X	X:X	X:X	X:X	X:X	X:X	X:X
2	PST130_8160	11876	$^{\rm C}$	\mathbf{T}	Y:Y	Y:Y	X:Y	X:Y	X:Y	X:Y	X:Y	X:Y	X:Y
3	PST130_14628	1712	A	$^{\rm C}$	X:Y	_	X:X	X:X	X:X	X:X	X:X	X:X	X:X
4	PST130_14898	503	G	A	X:X	X:X	X:Y	X:Y	X:Y	X:Y	-	X:Y	X:Y
5	PST130_28344	2372	A	\mathbf{G}	Y:Y	Y:Y	X:Y	X:Y	Y:Y	Y:Y	Y:Y	Y:Y	Y:Y
6	PST130_7634	3463	A	$^{\rm C}$	Y:Y	Y:Y	X:Y	X:Y	Y:Y	Y:Y	Y:Y	Y:Y	Y:Y
7	PST130_7629	11699	\mathbf{G}	A	Y:Y	Y:Y	X:Y	X:Y	Y:Y	Y:Y	Y:Y	Y:Y	Y:Y
8	PST130_10943	2979	$^{\rm C}$	T	X:Y	X:Y	X:Y	X:Y	X:X	X:X	X:X	X:Y	X:Y
9	PST130_10126	6216	G	T	Y:Y	Y:Y	X:X	X:X	X:X	X:X	-	Y:Y	Y:Y
10	PST130_22010	172	$^{\rm C}$	T	Y:Y	Y:Y	Y:Y	Y:Y	X:Y	X:Y	-	X:Y	X:Y
11	PST130_16961	1098	$^{\rm C}$	T	X:X	X:X	X:Y	X:Y	Y:Y	Y:Y	Y:Y	X:Y	X:Y
12	PST130_6915	2710	A	T	Y:Y	Y:Y	Y:Y	Y:Y	Y:Y	X:Y	X:Y	Y:Y	Y:Y
13	PST130_12479	1428	$^{\rm C}$	T	X:X	X:X	Y:Y	Y:Y	X:X	X:X	X:X	Y:Y	X:X
14	PST130_7634	3883	$^{\rm C}$	\mathbf{G}	X:X	X:X	X:Y	X:Y	X:X	X:X	X:Y	X:Y	X:X
15	PST130_14470	456	\mathbf{T}	$^{\rm C}$	Y:Y	Y:Y	X:Y	X:Y	Y:Y	Y:Y	X:Y	Y:Y	Y:Y

A.1 Validation of mutations on M_4 on Kronos

IWGSC contig	Line	Pos	WT	Mut	Predicted	Called on M_4	Primer 1 (Kronos)	Primer 2 (mutant)	Common Primer
IWGSC_CSS_1AS_scaff_3284790	Kronos3085	7449	ŭ	A	Het	Het	ccacaccttgagcctcgC	ccacaccttgagcctcgT	gtgattttgccaggggagA
IWGSC_CSS_1BL_scaff_3897513	Kronos3085	1515	U (E E	Het	Het	gettecactGggteetgC	gettecaetGggteetgT	acAaggactgcttcagaGaC
IWGSC_CSS_ZAL_SCSH_0454/45	Kronos3085	735) כ	- E	нет	net Hot	ccicdittigcaaatitctatgC	ccic_gittigcaaatitctatg_I	gGCaalggcataacaacagatA
IWGSC CSS-3AS-Scall-3406993	Kronos3085	2675	ט כי	-	Het	Het	aggecatticgaaticege	aggecatticgaatieeg 1	gg i gua i ccagnaccigag i G
IWGSC_CSS_4AL_scaff_7132733	Kronos3085	1799	ט	: [-	Hom	Hom	caccegtgagtgaccetC	caccetgagtgaccetT	aCcGcctaGaaagaaagcttC
IWGSC_CSS_5AS_scaff_1534693	Kronos3085	4605	C	L	Het	Het	cagcttcctggccctcAtC	cagcttcctggccctcAtT	gtaCctcacgAgtcaTgagAG
IWGSC_CSS_6AS_scaff_4361911	Kronos3085	8857	r.	Ą	Het	Het	tcacgaaagacgacttcaacctcC	tcacgaaagacgac t tcaacc t c T	catgaggtgctgcatctccatcA
IWGSC_CSS_6BS_scaff_3008326	Kronos3085	1528	<u>ن</u> ن	∢ :	Het	Het	ccatgttgtactggtggtgC	ccatgttgtactggtggtgT	ggaagcatggCaagtgcA
IWGSC_CSS_(AS_scal_4214385) IWGSC_CSS_1A1_scal_3020064	Kronos3085	1336	ט כ	H E	Hom Het	Hom Het	cgtaccttcgttgggaaagG +++camcca+acctmaca+C	cgtaccttcgttgggaaagA +++caacca+acc+aaca+T	ctcttggtcagctgtataagacT
IWGSC_CSS_1BL_scaff_3899789	Kronos3191	7925) U	· [-	Het	Het	acteteacTegeage	acteteaeTegeageagT	caaceteetecccatcGtA
IWGSC_CSS_2AL_scaff_6426728	Kronos3191	1481) U	4	Hom	Hom	gaaActeccecaectCeC	gaaActeccecaectCeT	ccaGcaGctcgtgagaaA
IWGSC_CSS_2BL_scaff_7960273	Kronos3191	069	Ö	H	Hom	Hom	gccattcatccttaggcgC	gccattcatccttaggcgT	acatgcaattgctgatgactG
IWGSC_CSS_3AS_scaff_3286603	Kronos3191	2975	Ü	A	Het*	Hom	ccgtgtggtttgttgtggG	ccgtgtggtttgttgtggA	${\tt gaaaggaacgtgTcaTgcaG}$
IWGSC_CSS_5AL_scaff_2694249	Kronos3191	2399	0	H	Het	Het	gccttccagatagagccGC	gccttccagatagagccGT	cgccacatcgacattcctG
IWGSC_CSS_5BL_scaff_10923577	Kronos3191	3713	U ([- E	Het	Het	gtggattgcctgagcttgC	gtggattgcctgagcttgT	tggtggccttcttgggaC
IWGSC_CSS_6AL_scaff_5823017	Kronos3191	13225) C	⊢ E	Hom	Hom	ccettcgagcctctggaG	cctttcgagcctctggaA	ttcgagaaggcccatcgA
IWGSC_CSS_0DS_SCall_2955594	Kronos 191	19961	ט כ	⊣ ∇	Нот	нош	gragagargaaggreragead	gragagargaaggrerageaaA	gatacteg 1 geaatgggtg 1
IWGSC CSS 1AS seaff 3276389	Kronos3288	9720	ט כ	¢ [−	Hom	Hom	gagacaagentgaantgenee a Cca Gcaggacc Aatotet	gagacaagettigaatigeter a.Cca.GcagaaccAatetetT	Sagigacci i catricco
IWGSC_CSS_2AL_scaff_6367515	Kronos3288	9269) U	4	Het	Het	cagetceaeTeteteceG	caertceae Tetetece A	gegeteatCtegaageeC
IWGSC_CSS_2AL_scaff_6422019	Kronos3288	4523	Ü	A	Het	Het	cgctaggtccctgcatagG	cgctaggtccctgcatagA	acgcAcgctaagccgtaC
IWGSC_CSS_3AL_scaff_4284850	Kronos3288	7901	C	H	Hom	Hom	tggctttggacaacatcgG	tggctttggacaacatcgA	tgtcAgcatcgacagccaG
IWGSC_CSS_4AS_scaff_5962359	Kronos3288	13049	Ü	Α	Het	Hom	ccatcaagaagtacgagttcgaC	ccatcaagaagtacgagttcgaT	accatgcccagcttgtcA
IWGSC_CSS_6AL_scaff_5778773	Kronos3288	6853	r o	Ą	Het	Het	gagtgaccttcccgtctttC	gagtgaccttcccgtctttT	ggagaacagctactcggcT
IWGSC_CSS_6AS_scaff_4392100	Kronos3288	3434	U ([-	Het	Het	atggaagcacaggtgaccG	atggaagcacaggtgaccA	ggAagcgaaagtgaacaaacA
IWGSC_CSS_/BL_scan_6/44240	Kronos3288	9772	י ל	∢ E	Het	Het	agetgttetteteetaetteage	agetgttetteteetaetteaA	caggicgitcitgagcic
IWGSC_CSS_IAL_SCAIL_SOS 1103	Kronos3413	8708) כ	- E	Hot*	нош	gcacgcctttatcgaggtaaaG	gcacgcctttatcgaggtaaaA	AgaaacagcagagcgcaA + a A maa++ c+ macCcaaaaaa
IWGSC_CSS_3AS_scaff_3296605	Kronos3413	6154) Ü	- ₹	Het	Het	ctertcacerectctaeC	ctertcacerectctaeT	carcacteararacateraC
IWGSC_CSS_3B_scaff_10693516	Kronos3413	12632	Ö	L	Het	Het	ctaggettggacaaacaggC	ctaggettggacaaacaggT	agettgeatetatgggeatT
IWGSC_CSS_5AS_scaff_1547699	Kronos3413	2686	Ü	А	Het	Het	gCtacaaccttcaccaatcgC	gCtacaaccttcaccaatcgT	gacggctttgaagtgtcatC
IWGSC_CSS_5BL_scaff_10856077	Kronos3413	5853	Ü	Ą	Het	Het	agagetteacceatgetC	agagcttcacccatgctT	${\it acgCacatttAatagctgaagC}$
IWGSC_CSS_6AL_scaff_5750718	Kronos3413	11046	Ü	A	Hom	Hom	cacgcTtcccgacttcttataG	cacgcTtcccgacttcttataA	AgacgatgtgatcaggattcaG
IWGSC_CSS_7AL_scaff_4433177	Kronos3413	3511	Ö	H	Het	Het	GaTgctccGtcaggctgG	GaTgctccGtcaggctgA	cactactggacaagctcttgG
IWGSC_CSS_7BL_scaff_6742567	Kronos3413	299	Ö	<u> </u>	Het	Het	gttgcttgcgtggcagaC	gttgcttgcgtggcagaT	cattttgcaccgtgtgtcTG
IWGSC_CSS_1AL_scaff_3976389	Kronos3935	10941	ت د د	<u>.</u>	Hom	Hom	ggtgaggagatcggCgatG	ggtgaggagatcggCgatA	cagtcatctacatgagaggtcaG
IWGSC_CSS_IBL_scall_3873362	Kronos3935	1392	ۍ ر	∢ [Het	Het Ust	cagatotgaagcotaGcacatG	cagatetgaageetaGeacatA	actaccagaatcagcacaaaaAC
TW/GSC_CSS_ZBL_SCall_1082302	Kronos3935	2710	ט כ	- E	нег На	пет Наt	gcaagctaagatgtaccgtagC	gcaagctaagatgtaccgtag1	gccacagtaggagaagact1
IWGSC_CSS_3B_scaff_10485067	Kronos3935	3349) U	- [-	Hom	Hom	ectteaccaactactccaactG	ectreaceactactccaactA	gcastttcctttaTccgcagT
IWGSC_CSS_4AS_scaff_5984153	Kronos3935	9009	Ü	A	Het	Het	agCaggtctggccaagttG	agCaggtctggccaagttA	cgaatGtatgaGtaggcgcT
IWGSC_CSS_4BL_scaff_7019402	Kronos3935	9081	Ö	H	Het	Het	tgcaatcatgtagtgagctgG	tgcaatcatgtagtgagctgA	agcatgatccctagaaCcataC
IWGSC_CSS_5BL_scaff_10842786	Kronos3935	3304	Ü	Α	Het	Het	tggttcccGaagcctgaaC	tggttcccGaagcctgaaT	$\operatorname{cgcatacttgaaacaTGagcAC}$
IWGSC_CSS_6BS_scaff_3045205	Kronos3935	2293	U (∢ E	Het	Het	aaggaccaagcccaaactctcG	aaggaccaagcccaaactctcA	agtgatcaagcccaatgtcgcA
IWGSC_CSS_/AL_Scan_4555249	Kronos3935	4487) כ	- -	Het Ust	Het Het	cAgigcicgagaiggcgC	cAgtgctcgagatggcg I	cCttgcaacctcctgat I
IWGSC CSS-1BL-scall-3910498	Kronos4240	2000	י ל	ζ ⊲	нег Н	ner Het	tigcatigccccaagaagad	tigcatgccccaagaagaA	reggedadergeradigied
IWGSC_CSS_5AL_scaff_2769540	Kronos4240	9626) ()	: [-	Het	Het	teCaetetegeaaaceeaG	teCaeteteesaaceeaA	cateaetGaeatcttcctecT
IWGSC_CSS_5BL_scaff_10871091	Kronos4240	7062	Ü	A	Het	Het	gccaaggAaccataacctgC	gccaaggAaccataacctgT	GgactcttggcAaccggA
IWGSC_CSS_6AL_scaff_5800333	Kronos4240	2360	Ü	A	Het	Het	cgacaggattgtgagCgC	cgacaggattgtgagCgT	tcagatgctgcaagattcatcT
IWGSC_CSS_7BL_scaff_6716931	Kronos4240	2613	r.	A	Het	Het	gGtgGgtattTgcttggtgaG	gGtgGgtattTgcttggtgaA	tgGtggactcgacaGtGtA
IWGSC_CSS_2BL_scaff_8029221	Kronos4346	2860	ن ن	∢ [Het	Het	tgcttccgctcttgctcC	tgcttccgctcttgctcT	$\operatorname{atTtgcatTCgAtcgggcC}$
IWGSC_CSS_3B_scatt_10460714	Kronos4346	14359) C	<u> </u>	Hom	Hom	ctaccttgccatgcgacatG	ctaccttgccatgcgacatA	agcaccccagtctttgacG
IWGSC_CSS_5BL_scaff_7648030	Kronos4346	6893	טט	t [-	Het	Het	taccettectactercarG	taccettectactercarA	ttttcagagagacacaggtatcA
IWGSC_CSS_6AL_scaff_5755840	Kronos4346	778	Ö	Ĺ	Het	Het	atcgagtaagctgtcacCgC	atcgagtaagctgtcacCgT	acctgcatgtcaCatccaC
IWGSC_CSS_6BS_scaff_2972151	Kronos4346	7876	Ü	Ą	Hom	Hom	gcagcaatgtcActgtttgG	gcagcaatgtcActgtttgA	gcttggactgggcatttatG
IWGSC_CSS_7AL_scaff_4542983	Kronos4346	18700	<u>ن</u> ن	∢ 6	Het	Het	gcagggctAccggatacC	gcagggctAccggatacT	catctgccGgttaaacatgC
TWGSC_CSS_/BS_scall_3098098	Kronos4346	210	ט כ	- -	Het Hot	Het Hot	gCgatatggtacttgcaatgaG	gCgatatggtacttgcaatgaA	ttacattgcttataG I ttgCcgG
IWGSC CSS-1A3-8call-3239804	Kronos4485	10490	ט כי	-	Hom	Hom	greggeacaaceerige	greggeacaaceerigg	gcircuitaaggagggcgA
IWGSC_CSS_2BS_scaff_5181092	Kronos4485	3742	ט ט	. ∢	Het	Het	TerccaracacatecaG	TercaracacateaA	teraceateaeTreaterAaaT
IWGSC_CSS_3B_scaff_10425015	Kronos4485	2372	Ö	H	Het	Het	gctactgaagttggCtcGG	gctactgaagttggCtcGA	cttcacatccttggggggTtC
IWGSC_CSS_3B_scaff_10775915	Kronos4485	4701	0	Ή.	Het	Het	ccaagggctgcagagagG	ccaagggctgcagagagA	agacctcacgatGtcctcC
IWGSC_CSS_5AL_scan_2754304	Kronos4485	1867	ט כ	∢ [-	Het	Het Hom	taaccc I gccatcgcccG	taaccc I gccatcgcccA	cattgGccagccaTgacT
IWGSC_CSS_7AS_scaff_4245431	Kronos4485	3402	<u>ت</u> د	4 4	Hom	Hom	aaggegeetggtgttteC	aaggegeetggtgttteT	agtaagtggaAcagctaagatcaT
IWGSC_CSS_7BL_scaff_6667357	Kronos4485	641	Ö	L	Het	Het	gatcAgctgctcattcgagG	gatcAgctgctcattcgagA	ttccctgtcaattgatgccC

A.2 Validation of mutations on M_4 on Cadenza

IWGSC contig	Line	Pos	ΤM	Mut	Predicted	Called on M_4	Primer 1 (Cadenza)	Primer 2 (mutant)	Common Primer
IWGSC_CSS_3B_scaff_10445294	Cadenza1772	6019	Ö	H	het	het	caggatAgtGggactgtcaaaG	caggatAgtGggactgtcaaaA	ggagacGGctGtggacatT
IWGSC_CSS_3DL_scaff_6955403	Cadenza1772	2418	Ö	L	het^*	hom	tcagCggattgtcgggatG	tcagCggattgtcgggatA	tgtcCatgaaTcttgtccacG
IWGSC_CSS_4AL_scaff_7106846	Cadenza1772	11277	Ü	Α	hom	hom	tgggatccatgcctacactG	tgggatccatgcctacactA	${\tt gatggtGgatttgccgctA}$
IWGSC_CSS_4AS_scaff_5991335	Cadenza1772	15710	Ü	Ą	hom	hom	ctggccctgcgctac	ctggccctgcgctgctaT	gtggaaGttcagaaggaccaG
IWGSC_CSS_4BS_scaff_4956646	Cadenza1772	252	Ü	A	$^{ m het}^{*}$	hom	gcaggttgacttcccggaG	gcaggttgacttcccggaA	${f tGaggtacgaGcTaaagAaagC}$
IWGSC_CSS_4DS_scaff_1715962	Cadenza1772	1225	r U	Ą.	hom	hom	cagctgtggTatctcaactgG	cagctgtggTatctcaactgA	CcCtGaaACACcGtttggaT
IWGSC_CSS_5AL_scaff_2763407	Cadenza1772	2119	ڻ ا	۷ I	hom	hom	gcgacGaacctcgagatctG	gcgacGaacctcgagatctA	gaTggcaAtcgtCgtgcA
IWGSC_CSS_5AS_scaff_1548786	Cadenzal772	12625) C	<u></u> ⊢ [het	het	AtaggcacattgctagactgaG	AtaggcacattgctagactgaA	ggattgggtgttgcacgC
IWGSC_CSS_5BL_scall_10849226	Cadenzal772	6877	ט כ	-	het*	nom	cctgacatcattgttcacgatC	cctgacatcattgttcacgatT	cactccgaggtgtccatgaT
IWGSC-CSS-SBS-Scan_2270737	Cadenzal / / 2	7077	י ל	⊄ E	nom		attc I grgrtgrgg Caaarga G	attc I gigtigigg aaatgaA	taaGcacaaAccctccagctgG
IWGSC_CSS_IAL_SCAH_3022915	Cadenzalobi	881) כ	⊢ E	nom	nom	ccacagtgagactcctattgaCG	ccacagtgagactcctattgaCA	atgretgaticGreated
IWGSC-CSS-IAS-SCall-329/240	Cadenzaloo1	1970) כ		net	net	catcccgccctttcctcC	carcegee Gitteete 1	gctcgccgatgaagagc 1
IWGSC_CSS_IBL_scall_3828996	Cadenzalbb1	1340	י ל	∢ •	hom	nom	agccggatgttagtgttaacC	agccggatgttagtgttaacl	agcagcttg regegttaac
IWGSC_CSS_IDS_scall_1884529	Cadenza1661	10575	ۍ د	⊄ E	hom	hom	aCagatacaAttgtcatgcaggC	aCagatacaAttgtcatgcaggT	acctgggTTgtccaatacttC
IWGSC_CSS_ZAL_scaff_6318370	Cadenzalbb1	19142	י כ	-	het	-	cgtggcCgaatCtcGacG	cgtggcCgaatCtcGacA	ttcttgtgggagccgggC
IWGSC_CSS_ZAS_scaff_5213460	Cadenza1661	1358	י ל	۷.	mou.	nom	gtcacgaaCccgctcagG	gtcacgaaCccgctcagA	aggaaagagaaaagaGcG
IWGSC_CSS_2BS_scaff_5179331	Cadenza1661	5604	J (₹.	het	het	actetegteaagaactgatacaG	actctcgtcaagaactgatacaA	gcaGagaatgttcttgcaac'I'
IWGSC_CSS_2DS_scaff_5341235	Cadenza1661	4673	J (۸.	het	het	ggtgaggatctcggagctG	ggtgaggatctcggagctA	gcgcggtcgtacgagttG
IWGSC_CSS_3AL_scaff_4250995	Cadenza1661	7046	Ü	Ą	hom	hom	cCaagaaacgggtggtccaG	cCaagaaacgggtggtccaA	${ m ctgcagctgtcccatcatcgT}$
IWGSC_CSS_3B_scaff_10404421	Cadenza1661	4303	r.	A	het	het	ccttcgtcgaCaggacctG	ccttcgtcgaCaggacctA	GCcagtactCacAtgctctC
IWGSC_CSS_5DL_scaff_2390496	Cadenza1538	2125	Ö	⊣	hom	het	gcagttttatcctcagtagtcttgG	gcagttttatcctcagtagtcttgA	ttctgagaaTgtaatgtgcGatG
IWGSC_CSS_6AL_scaff_5753680	Cadenza1538	3920	Ö	⊣	hom	hom	tgctccaaatttgagcacaaTaaC	${ m tgctccaaatttgagcacaaTaaT}$	aaatgcaaggggtaagtttttgT
IWGSC_CSS_6AS_scaff_4425792	Cadenza1538	4307	Ü	A	hom	het	agatgcttgtCggGccaG	agatgcttgtCggGccaA	gctgaagcaacgcgatcaaT
IWGSC_CSS_6BS_scaff_3003630	Cadenza1538	6933	Ö	H	het	het	ggcagtaatgtggtgctgagC	ggcagtaatgtggtgctgagT	tTgaCttctggtttggtggcA
IWGSC_CSS_6DL_scaff_3246988	Cadenza1538	9186	Ü	Ą	het	het	gctaaagaagcttgagagaattC	gctaaagaagcttgagagaattT	aatttctgaagagaggtgttgtatG
IWGSC_CSS_7AL_scaff_4480114	Cadenza1538	3446	Ö	H	het		gatateteceacaegeegG	gatateteceacaegeegA	tgagccactcttgcagtttT
IWGSC_CSS_7AS_scaff_4193541	Cadenza1538	8359	Ö	Η	hom	het	agcaattetttggetateaattagC	agcaattetttggetateattagT	tcatctGtcttaactctactgctG
IWGSC CSS 7BL scaff 6721572	Cadenza1538	9223	C	F	het	het	ectCasesaseaseaseas	ectCaereageageagagaA	tectateaaeaattcceacctC
IWGSC CSS 7BS scaff 3152545	Cadenza 1538	3960	7	. ∢	hom		tcascasatcacctscCsC	tcascasatcacctscCsT	gCtgcccatcatcgtttaT
IWGSC CSS 7DS seaf 3963838	Cadenza 1538	2013	י כי	; ⊲	het	hot	+CattersageCttTtateC	+CattacaaacCt+TtataT	ses Ctts Tesser Tacter A
IWDSC OSS 1AT 555# 3003380	Cadenza 1460	6103	י כ	ζ <	hom	hem	0+0++0 A m m+ m m m	C+C++CAAABCCCCT TESTS T	40C+Coso+6C+6S++CH+
TATO CO COST A COST COST COST COST COST COST COST COST	Cauchiza1409	0100	י ל	¢ E	HOIII	HOIL	Ciciic Agaigaacgeg G	Ciciic AgagaigaacgegA	CGCGGGGGGGGGGGGTCG
IWGSC_CSS_IAS_scan_3287728	Cadenza1469	3817) C	<u>.</u>	hetr	nom,	ccgaccaAttcactaaccgG	ccgaccaAttcactaaccgA	accetetteccAgacatga I
IWGSC_CSS_IBL_scaff_3815304	Cadenza1469	513	י ל	∢	mou.	hom	aacatttgcct LaCcaaaacGC	aacatttgcctTaCcaaaacGT	acacagcaagttataatgCAAgC
IWGSC_CSS_1DL_scaff_2266648	Cadenza1469	5926) i	<u>-</u>	het	het	caacatgagacacaacaccttC	caacatgagacacaacaccttT	gtcaacgcgtgaggattgtC
IWGSC_CSS_1DS_scaff_1906671	Cadenza1469	3697)	Ή.	hom	hom	tggTGtagacacttggcgaG	tggTGtagacacttggcgaA	catggcgaccaccAcctG
IWGSC_CSS_2AL_scaff_6337088	Cadenza1469	7334	Ü	A	$_{ m het}^*$	hom	acaatgccAagttgacaggttG	acaatgccAagttgacaggttA	${\tt gggagtgttggttCagaacaT}$
IWGSC_CSS_2BL_scaff_7972799	Cadenza1469	8995	Ö	⊣	het	hom	gTgCtcctcGgcatccttC	${ m gTgCtcctcGgcatccttT}$	${ m gatccgGgcaaactacgTG}$
IWGSC_CSS_2DL_scaff_9832343	Cadenza1469	3262	Ü	A	het	het	TtgtctaAcagcacCGcagG	TtgtctaAcagcacCGcagA	agateteggteageettteT
IWGSC_CSS_2DS_scaff_5327939	Cadenza1469	3889	Ü	Ą	het	het	ttttTgccttatgtgactctagtaC	ttttTgccttatgtgactctagtaT	gaggccatcacagatagcG
IWGSC_CSS_3B_scaff_10395219	Cadenza1469	1292	Ü	Ą	hom		aggtgcttgtgcttgctgG	aggtgcttgtgcttgctgA	cctcttctgggggctttataC
IWGSC_CSS_3B_scaff_10592217	Cadenza0580	2994	Ö	H	het		acagcagtatcaagcccctC	acagcagtatcaagcccctT	tgatactgttgTggCggagG
IWGSC_CSS_3DS_scaff_2596771	Cadenza0580	1037	Ü	Ą	het	het	tggttatgCAcaggataatCagG	tggttatgCAcaggataatCagA	${\tt tggcaaatgtgatgtcattaggT}$
IWGSC_CSS_4AL_scaff_7093953	Cadenza0580	9881	Ö	⊢	hom	hom	GacaggaagccggtaacaC	GacaggaagccggtaacaT	${ m ctcc} A { m gcaggcatgggaT}$
IWGSC_CSS_4BL_scaff_7037448	Cadenza0580	1837	Ö	⊣	hom	hom	CgttgaaaaGctgcaagaacttaaC	CgttgaaaaGctgcaagaacttaaT	cagttcttccTtCaGagcagataT
IWGSC_CSS_4BS_scaff_4929479	Cadenza0580	10668	Ü	Ą	hom		tggattttcccgcactgttC	tggatttcccgcactgttT	${f gtaaacaaggcatttcaagagtcA}$
IWGSC_CSS_4DL_scaff_14359838	Cadenza0580	1408	r U	Ą	hom	1.	gCtcAttcagggatTGTcCtaTatG	gCtcAttcagggatTGTcCtaTatA	tgaCagaacagttggtcatacT
IWGSC_CSS_4DS_scaff_2276484	Cadenza0580	8034	Ü	A	hom	hom	gccgtggttgatggAgaG	gccgtggttgatggAgaA	cgtccagattactgatacttgcA
IWGSC_CSS_5AL_scaff_2756579	Cadenza0580	5278	U	Ą	het	het	tgaatggatttttcgtccgttC	tgaatggattttcgtccgttT	ggAAtCCTATgCAgaAgAaaCTG
IWGSC_CSS_5BL_scaff_10787208	Cadenza0580	10627	Ü	A	het		gcctctcacatgcggagaC	gcctctcacatgcggagaT	${ m acgatgtcAggtggGcgT}$
IWGSC_CSS_5BS_scaff_2282179	Cadenza0580	5267	Ü	A	het		tgatgggctacgacgtgC	${ m tgatgggctacgacgtgT}$	tcggcgcccttgaaAtcC
IWGSC_CSS_5DL_scaff_4498073	Cadenza0423	4937	Ö	H	hom	hom	gcaccctctggttggtcatC	gcaccctctggttggtcatT	tgagcagcaAagcagccG
IWGSC_CSS_5DS_scaff_2738970	Cadenza0423	2319	0	Ε4.	het	Ι.	cgtgaggtgggtgatttgC	cgtgaggtgggtgatttgT	tggaactagttacactgcagtTC
IWGSC_CSS_6AL_scaff_5757109	Cadenza0423	2788	r o	Ą	hom	hom	caggaGcctggcaaataaaGG	caggaGcctggcaaataaaGA	ctttcGcagtctcttagtttcG
IWGSC_CSS_6AS_scaff_4387871	Cadenza0423	2543	Ů,	Ą	hom	hom	gcatgctaacaggcgaaaagG	gcat g ctaaca g g c gaaaa g A	ctcatgctcctgatcttaaggtT
IWGSC_CSS_6BL_scaff_4271391	Cadenza0423	4660) (μ.	hom	hom	tacgtgcatgatgtggtagtcgtaC	tacgtgcatgatgtggtagtcgtaT	${ m gtttgaagtgcatcagatgTaccA}$
IWGSC_CSS_6DS_scaff_1880206	Cadenza0423	9159	J (۸.	het	het	ctgCgaaggctccacaaG	ctgCgaaggctccacaaA	ggatgagaagtttgcattgctC
IWGSC_CSS_7AS_scaff_4227506	Cadenza0423	952	J (∢ (het	۱.	ccatgtgtttccaatgttagagC	ccatgtgtttccaatgttagag I	tgccctagctggtatgc1
IWGSC_CSS_7BL_scaff_6681782	Cadenza0423	1486) C	.⊣ E	hom	hom	agtaagUGtgacagcaatggG	agtaagCGtgacagcaatggA	AtgtctItgGtggaagtacatcA
IWGSC_CSS_7BS_scaff_3160328	Cadenza0423	1801) C	<u>.</u>	het	het	tgttaaatGatacagCctgcagC	tgttaaatGatacagCctgcagT	tggaatggtgCgttgtttT
IWGSC_CSS_7DS_scall_407428	Cadenza0423	2051	י ל	∢ E	het	net 1 4	gtcGCgccatcctgacaG	gtcGCgccatcctgacaA	actcatcAggtcagcccaA
IWGSC_CSS_5AL_Scan_442479	Cadenzau304	5198) (net	net 1	gagrea I taagriggtaagarigg	gagica i taagiiggtaagaiigg i	GCaGaTaaCaaggatcacG
IWGSC_CSS_3AL_scat_4447942	Cadenza0364	11917	ڻ د	∢ [het	het Let	gtcataaagattgctcctgtgaaG	gtcataaagattgctcctgtgaaA	ctcGgatgtgggaggaagA
TWGSC_CSS_3AS_SCAH_155/463	Cadenzau304	7507) כ	- -	net bet	net bet	aaagtcacatcatgcttaccataac	aaagtcacatcatgcttaccataaA	CgaaatccaacgcctcatcA
1WG3C_C33_3A3_SC3H_2046/4/	Cadenza0364	1017	י ל	< <	net bet	net hot	tggAagcAcaaggggccC	tggAagcAcaaggggcc1	GccgccgatggagactcG
1117707 700 9 A C 222H 2304930	Cadenza0364	101/	י ל	≮ E	net het	net bet	giccingcacacageing	giccingcacacageintA	cogcoggactacaacticaal
IWGSC_CSS_3AS_SCAH_3321091	Cadenzau304	4000 000 000) כ	- -	net bet	net bet	caagaatgAl gctgatgttggaG	caagaatgA I gctgatgttggaA	acatgetgaategeegaate
1WGSC_CSS_SAS_SCALL_SS_1555	Cadenza0364	1061	י כ	∢ E	net	ner	BBBaaa CBABACBaBCBG	gggaaa CgAgAcgagcgA	o A++sacco++satas++cC
IWGSC_CSS_3AS_scaff_3440912	Cadenza0364	4498) U	. ₹	het	het	ccetaaaactttctetectteC	cetaaaactttctetectteT	at ActeacaactacateateteC
IWGSC_CSS_3B_scaff_10343586	Cadenza0364	2242	Ü	A	het	Ī	ggttcTgTcctcttccactG	ggttcTgTcctcttccactA	tgtgttgaacccgcaagcA
							000		0

IWGSC.CSS.3AL.scaff.4447942 IWGSC.CSS.3AL.scaff.157483 IWGSC.CSS.3AS.scaff.1557483 IWGSC.CSS.3AS.scaff.3304956 IWGSC.CSS.3AS.scaff.3321091 IWGSC.CSS.3AS.scaff.3321091	Cadenza0364	3198	C	E	het	het	gagteagttggtaagattggC	gagteagttggtaagttggT	GCaGaTaaCaacaacatcacG
WGSC_CSS_3AL_scaff_4447942 WGSC_CSS_3AS_scaff_1557483 WGSC_CSS_3AS_scaff_2648747 WGSC_CSS_3AS_scaff_3304956 WGSC_CSS_3AS_scaff_3321091 WGSC_CSS_3AS_scaff_3371333	Cadenza0364	11917		4					
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Cadenzal551 4779 G A hom hom ggcaaggcaaggcaaggcaagaacGgtC Cadenzal551 589 C T het ctcttcactgtgaggC Cadenzal551 589 C T het het ctcttcactgtaggC Cadenzal551 1908 G A hom hom agcatctcactgcaacaata Cadenzal551 1908 G A hom hom agcatctcactgcaacaaca Cadenzal551 1908 G A hom hom agcatctcactgcaacaaca Cadenzal551 1908 G A hom hom ccttttcactgcaacaacaacaacaacaacaacaacaacaacaacaacaa	IWGSC_CSS_3AS_scaff_3441108	Cadenza2092	541	Ü	Ą	het	het	GtgatgaccttgagacGgaG	GtgatgaccttgagacGgaA	aggcaTgacaaCgcgcaA
Cadenzal551 3550 C T het het tectricactigitggggC Cadenzal551 358 C T hom hom agaatcacetgaadaatC Cadenzal551 3698 C T hom hom agaatcacetgaadaatC Cadenzal551 19080 G A hom hom agaatcacetgaadaatC Cadenzal551 19080 G A hom hom agaatcacetgaadaacaaaC Cadenzal551 2530 G A hom — cutttcggacaacaaaaC Cadenza2088 8059 G A hom — cttttcggacaacaaaaC Cadenza2088 16815 G A hom — cttttcggacaacaaaaG Cadenza2088 16815 G A hom hom cttttcggacaacaacaaa Cadenza2088 1362 G A hom hom ctttttcgacatcacaaagagagacactcacaaagagagacacaacaacaacaacaacaacaacaaca	IWGSC_CSS_3B_scaff_10449827	Cadenza1551	4779	Ü	Ą	hom	hom	ggcaaggtcaagaaacGgtC	ggcaaggtcaagaaacGgtT	aCagaGtgggttagaggcaG
Cadenza1551 589 C T hem hem pagacatcacactgaadcaataC Cadenza1551 3508 C T het het tgtagaatcacattaactttcctG Cadenza1551 11092 C T het het gccttgattcggaacaataG Cadenza1551 2589 C T het het gccttgattcggaacaaaaC Cadenza2088 8059 G A hom — cttttccgtccgtaagcaatgG Cadenza2088 6697 G A hom hom cttttccgtccgtaagcaataG Cadenza2088 3627 G A hom hom cttttccgtcctctcacgatC Cadenza2088 3885 G A hot hot	IWGSC_CSS_3B_scaff_10550638	Cadenza1551	3250	Ö	Η	het	het	ctccttcacttgttgcggC	ctccttcacttgttgcggT	gcaacAtTttgatactgcaaagG
Cadenza1551 3508 C A het tet gagactacactacactacactaccd Cadenza1551 19080 G A hom hom aga/AcCogatagcaatgG Cadenza1551 11092 T het het cggtgattatfTttagacttcgacacacaca Cadenza1551 5559 C T het het cggtgatatfTttagacttcgacgC Cadenza2088 8059 G A hom — cttttccgtccgtaagcaacacacaa Cadenza2088 16515 G A het het cgttgattatfTttagacttcgacgC Cadenza2088 16517 G A het het cttttccgtccgtaagcaacacaa Cadenza2088 16597 G A het het cttttcgtccgtcagctcgCg Cadenza2088 10234 G A het het cttttcgtcggacacacaga Cadenza2088 11034 G A het het cttttgattgatgattgat Cadenza2088 11035 G A het het ctttga	IWGSC_CSS_3DL_scaff_6945816	Cadenza1551	589	Ö	H	hom	hom	agcatctcacctgcaaCaataC	agcatctcacctgcaaCaataT	TgtgcccTctgaAtattttcaTG
Cadenza1551 19980 G A hom hom agAcCccgAtcgccatgG Cadenza1551 19980 G T het het gcttgattatfTttagattcggacaacaaC Cadenza1551 2530 G A hom — cggtgatatfTttagattcggacacaaC Cadenza2088 8059 G A hom — ctttcgcgctcgtaagcattcg Cadenza2088 16815 G A hom — cttttcgcgctcgtaagcattcg Cadenza2088 16815 G A hom hom pgcgttaattgatgcattcg Cadenza2088 16815 G A hom hom cttttggatgatgatggggg Cadenza2088 1362 G A hom hom pgcgttactcgatgatggggg Cadenza2088 1362 G A hom hom pgcgttaccgatgggggggggggggggggggggggggggg	IWGSC_CSS_3DL_scaff_6954177	Cadenza1551	3508	Ö	Η	het	het	tgtagcatcacattaactttcctG	tgtagcatcacattaactttcctA	gcttggtataaaccCttacgacA
Cadenza1551 11992 C T het pet eggtgatatfTtggaacaaaaaa Cadenza1551 2539 C T het het eggtgatatfTtgaacttgagC Cadenza2088 8059 G A hom — ctttccgtcagtaggag Cadenza2088 16815 G A hot het petsagagtatfTtgagcttagC Cadenza2088 3627 G A hot hot ctttccgtccgtaagcaatgC Cadenza2088 3627 G A hot hot gtcaacaaacaagcgctctfc Cadenza2088 3827 G A hot hot gtcaacaagcacccgcd Cadenza2088 3885 G A hot hot cttccaccaaatggcctaftC Cadenza2088 3885 G A hot hot ctttcgaccatctCtcacgC Cadenza1409 4555 G A hot hot ctttgagacaagcactCtCa Cadenza1409 3561 G A hot hot cttcgac	IWGSC_CSS_4AS_scaff_5938272	Cadenza1551	19080	Ü	Α	hom	hom	agAcCccgAtcgccatgG	agAcCccgAtcgccatgA	GggAgatAcaggtaaaActcTtcG
Cadenza1551 5559 C A het eggggatattTfttagacttcgacgC 0 dednza1551 2559 G A hom — eqttgtgatattTfttagacttcgacgC 0 cadenza2088 8059 G A het het etttfccgtccgtaagcaataG Cadenza2088 16697 G A het het agcaagcttaccGgtctgC Cadenza2088 1697 G A het het agcaagcttaccGgtctgC Cadenza2088 1362 G A het — agraatcaggatcagctctCCG Cadenza2088 13162 G A het — agraatcagggatcagctCtCCG Cadenza108 13162 G A het — ctttgattgatactcgatttgC Cadenza1409 2203 G A hom hom ctttgatgatctcaggctctTC Cadenza1409 13073 G A hom hom ctttgatgatctaggctctTC Cadenza1409 2203 G A het hom ctttgatgatc	IWGSC_CSS_4AS_scaff_5977594	Cadenza1551	11092	Ö	H	het	het	gccttgattcggaacaacaaaC	gccttgattcggaacaacaaaT	gcgtctctcagtcctgcA
0 Cadenzal551 2530 G A hom hom egacttaactcgcagatggaG Cadenza2088 8059 G A hom — cattrcgctcgtcgagcatadG Cadenza2088 6697 G A het het cattrcgctcagtcagcatcgtcg Cadenza2088 3627 G A het het cattrcgctcatcacacacacacacacacacacacacacacacac	IWGSC_CSS_5AL_scaff_2671035	Cadenza1551	5859	Ö	Η	het	het	cggtgatattTttagacttcgacgC	$\operatorname{cggtgatattTttagacttcgacgT}$	ggcagttcagcGacccatT
Cadenza2088 8559 G A hom — cttttccgtccgtaagcaataG Cadenza2088 16815 G A het het pgcagtctactcgtraccgtrag Cadenza2088 3627 G A hom hom gtcaaaaacaagtggctatg Cadenza2088 13624 G A hom hom gtcaaaaacaagtggctAattC Cadenza2088 13162 G A het het agraagctatctcagcgctAttC Cadenza2088 13162 G A het het ctraafggatgagggtgattCtC Cadenza1089 3885 G A het het ctraafggatcagggctAttC Cadenza1409 4555 G T het het ctraaggacaagcatCtCaG Cadenza1409 4555 G T het het pccaccacaatgggccactCTG Cadenza1409 13073 G A het het pccaccacatgggccActCG Cadenza1409 3561 G A het het	IWGSC_CSS_5BL_scaff_10889480	Cadenza1551	2530	Ü	Ą	hom	hom	gagcttaactcgcagatggaG	gagcttaactcgcagatggaA	tccatgCAacGccttggT
Cadema2088 16815 G A het het gagaagcttaccGgtctgC Cadema2088 3637 G A het het gtccaanacaagtggtAattgC Cadema2088 3637 G A het — aggatcaggatggtCAattgC Cadema2088 13162 G A het — aggatcacagggtGgtAattgC Cadema2088 13162 G A het — aggatcacagggtGgtAattGC Cadema2088 13162 G A het het cTcaaccacaatgggtCAattGC Cadema2088 13113 C T hom hom cttgatcacaccaatgggCAAttCaG Cadema1409 2203 G A het hom cttgatggaaagcactCtTG Cadema1409 13073 C T hom hom pcdCgaacaccaatggCctctCG Cadema1409 13073 C T hom hom pcdCgaacaccataggGCctCtCGCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC	IWGSC_CSS_3B_scaff_10528396	Cadenza2088	8059	Ü	A	hom		cttttccgtccgtaagcaataG	cttttccgtccgtaagcaataA	gtgcactgttcaggcctgA
Cadenza2088 6697 G A het het pectagratesacgeG Cadenza2088 3627 G A hom hom tcaatgatgatgatgatgattchatttgC Cadenza2088 13162 G A het — agtattcaggacaagcatCttaCG Cadenza2088 13162 G A het — agtattcaggacaagcatCttaCG Cadenza2088 11113 C T hom hom ctttgatgatcctaggacaagcatCttaCG Cadenza1409 2203 G A het het ctttgatgatcctaggcacAtCTTC Cadenza1409 2203 G A het het ctttgatgatcctaggcacAtCTTC Cadenza1409 13673 C T hom hom agCtatcaggacaagcatCtTCG Cadenza1409 13673 C T hom hom tccgacgtcacttcTCG Cadenza1409 2010 G A het het tccgacgacatctaccatggcaccttcTCAgg Cadenza1409 1367 G A het	IWGSC_CSS_3B_scaff_10637573	Cadenza2088	16815	Ü	Ą	het	het	agcaagcttaccGgtctgC	agcaagcttaccGgtctgT	cgagcAactacgagcagctT
Cadenza2088 3527 G A hom hom gttcaaaaacaaggggtAatttgC Cadenza2088 13624 G A hom hom tcaatggaggggggggggggggggggggggggggggggg	IWGSC_CSS_4AL_scaff_7086469	Cadenza2088	2699	Ü	Ą	het	het	gccgtctacttcaacgcG	gccgtctacttcaacgcA	ccaGaggcttgtTGcattttT
Cadenza2088 10334 G A hom toatgatteagggggggggggggggggggggggggggggg	IWGSC_CSS_4AL_scaff_7126302	Cadenza2088	3627	Ü	A	hom	hom	gttcaaaaacaagtggctAatttgC	gttcaaaaacaagtggctAatttgT	cacaaggatatgaagcTcttctagA
Cadenza2088 13162 G A het — agtattcaggacaagcatCttCaG 2 debnza2088 3885 G A het het rCracaccaalaggacatAatC Cadenza1409 2203 G A hom hom agCgaacaagaGctcaaacG Cadenza1409 2203 G A hom hom actragrectctTG Cadenza1409 2010 G A het het tccgacactaggcctctGG Cadenza1409 2010 G A het het tccgacactaggcctctGG Cadenza1409 2010 G A het het tccgacactaggcctctGG Cadenza1409 2010 G A het het tccgacacttagG Cadenza1409 3561 G A het het tccgacagacttaccdcctGGG Cadenza1409 3561 G A hom hom ccaaatgacttaccgcacgGG Cadenza1599 19073 G A hom hom ccCaggaaatgcactC </td <td>IWGSC_CSS_4BL_scaff_7041808</td> <td>Cadenza2088</td> <td>10234</td> <td>Ü</td> <td>A</td> <td>hom</td> <td>hom</td> <td>tcaatggatgagggtgcttC</td> <td>tcaatggatgaggggtgcttT</td> <td>ccatagcagcatcagccacA</td>	IWGSC_CSS_4BL_scaff_7041808	Cadenza2088	10234	Ü	A	hom	hom	tcaatggatgagggtgcttC	tcaatggatgaggggtgcttT	ccatagcagcatcagccacA
2 Cadenza2088 3885 G A het c'TeaacacaatgggcacAAtC Cadenza2088 11113 C T hom hom ctttgatgatcctaggcacAAtC Cadenza1409 4555 C T het het gcttcagtgatactcaggcactcTG Cadenza1409 13073 C T het het gcttcagtgcatgcatgcatcaGG Cadenza1409 2010 A het het tccgaccgAtcaacttgG Cadenza1409 7606 G A het het tccgacggtacGcacGaG Cadenza1409 3561 G A het het tccgacagaaatgtgCcaGaG Cadenza1409 19073 G A het het tccgacagaacgcacCaGaG Cadenza1599 15074 G A hom hom ccaaatgacatgcaacagagcacCC Cadenza1599 1286 G A hot hot ccdagaaatgaccaccacatGaC Cadenza1599 1286 G T hot hot ccdagaaatg	IWGSC_CSS_5AL_scaff_2794167	Cadenza2088	13162	Ü	A	het		agtattcaggacaagcatCttCaG	agtattcaggacaagcatCttCaA	caatgaaacctctcgaagaaGaG
Cadema2088 11113 C T hom hom ctttgatgatcatgatcatagacctctTG Cadema21409 2203 G A hom hom agCgaacaagagGtcaaacG Cadema1409 13673 C T hom hom pgctgaggcctctTG Cadema1409 13073 C T hom hom pgcgacacagagGtcaaacG Cadema1409 13073 C T hom hom pcgacacccccccCcCCAGG Cadema1409 3561 G A het het tccgaccgAtcaacctgG Cadema1409 3561 G A hom het tccgacactctcccccCcCCAGG Cadema1409 13073 G A hom hom ccaaatgacatcacccccctcCaGG Cadema1599 5504 G A hom hom ccaaatgacatgacatgac Cadema1599 7566 G A hom hom ccaagaagacccc Cadema1599 7566 G A hom hom ccGagaaatgacacc	IWGSC_CSS_5BL_scaff_10889232	Cadenza2088	3885	Ü	Ą	het	het	cTcaaccacaatgggca A at C	cTcaaccacaatgggcaAatT	tccttcatcaatcatcaattgttgG
Cadema1499 2203 G A hom hom agCgaacagagGtcaaaCG Cadenza1409 4555 C T het het pettragtgcatgcctcaCG Cadenza1409 2010 G A het hom pettragtgcatgcctcaCG Cadenza1409 2010 G A het het tccgaccgAtcaaccttgG Cadenza1409 3561 G A het het tccgacatcttccgtgaG Cadenza1409 3561 G A hom — gtgatctcaccgcaGgC Cadenza1599 5204 C T hom hom ccdagaaatgactcacgaGGC Cadenza1599 5204 C T hom hom ccCagaaatgacgaccaCGGC Cadenza1599 12856 C T hom hom ccCagaaatgacgcccacgaC Cadenza1599 1766 G A het pet petgagacaagcaccacaagcaC Cadenza1599 1766 G A het pet petgagaacgaccac	IWGSC_CSS_5BS_scaff_2267405	Cadenza2088	111113	Ö	H	hom	hom	ctttgatgatcctaggcctctTG	ctttgatgatcctaggcctctTA	${\it tgatttggtCtggttAgagtttGA}$
Cadema1499 4555 C T het gettragtgeatgeatgecttead 6 Cadema1499 13073 C T hom tccgacqqcatgcattcad 6 Cadema1409 2010 G A het hom ptagtgcccctcctCAggG Cadema1409 7606 G A het tccgacagacatttcccgtgad Cadema1409 8054 G A hom hom caaatgacattcacgcadgaC Cadema1599 1286 G T hom hom ccCaggaaatgagcactC Cadema1599 1286 G T hom hom GgtagaaatgagcactC Cadema1599 1766 G A het tccagagaaatgagcactC Cadema1599 1766 G A het het gGagaatgagcactC Cadema1599 1766 G A het het gGagaatgacacgacG Cadema1599 1766 G A het het gCagaatgacagcactC Cadema1599	IWGSC_CSS_3B_scaff_10475354	Cadenza1409	2203	Ü	A	hom	hom	agCgaacaagagGtcaaacG	agCgaacaagagGtcaaacA	ctgaaacacaCtagaCAattAccG
Cademai 1499 13073 C	IWGSC_CSS_3B_scaff_10674115	Cadenza1409	4555	Ö	L	het	het	gcttcagtgcatgccttcaG	gcttcagtgcatgccttcaA	cttcacacccGagataatGtattG
6 Cadema1499 2010 G A het hom glaggtccctcctCAggG Cadema1499 7606 G A het het tGcatgaaatgtgCaGaG Cadema1409 3561 G A hom — ggtgatctaccgcaGgaC Cadema1409 8054 G A hom hom caaatgacatgcaaagtgC Cadema1599 6534 C T hom hom cCAggaaatgagcactC Cadema1599 12856 C T hom hom GgtagaaatgagcactC Cadema1599 7566 G A het gctagaaatgcaCcaaCaGG Cadema1599 19249 G A het gctagaaatgcaCcacacaatgc Cadema1599 19249 G A het het gctgtagatgcatgcacg Cadema1599 19249 G A het het gctgtagatgcatgcacg Cadema1599 19249 G A het het gctgtagatgctgcacg Cad	IWGSC_CSS_4AL_scaff_7153568	Cadenza1409	13073	Ö	Η	hom	hom	tccgaccgAtcaaccttgG	tccgaccgAtcaaccttgA	gaccggaactcctcggcC
Cadema1499 7606 G A het het tGeatgaaaatgtgGcaGaG Cadema1499 3561 G A het tctcgacattctccgtgtaC Cadema1409 3561 G A hom — gttgatctaccgccaggaC Cadema1409 19073 G A hom hom caaatgacatcaccagaCgaC Cadema1599 5204 C T hom hom ccCaggaaatgaccacaC Cadema1599 12856 C T hom hom GgtagaatgcacctC Cadema1599 7566 G A het gCagaatgcaCACtActCC Cadema1599 9736 G A het gCagaatgcaCACtActCCC Cadema1599 19249 G A het gCtgtagatttatagctgctatgC Cadema1599 19249 G A hom cgTcctCcttagcacgaC Cadema1599 1627 C T het tttggtgctTgattgcttactC	IWGSC_CSS_4DL_scaff_14314966	Cadenza1409	2010	Ü	Ą	het	hom	gtaggtcccttctCAggG	gtaggtccctcctCAggA	cggcgTcacaAgttgCcT
Cademal499 3561 G A het tctcgacatcttcccgtgfaC Cademal499 8054 G A hom — ggtgatctaccgccagaC Cademal499 19073 G A hom hom caaatgacatgacatgacatgaC Cademal599 5204 C T hot hot tgatgccaaccacaatGaC Cademal599 6634 C T hom hom cCagagacaagagatgC Cademal599 7566 G A het gGgaaatgacaagcacC Cademal599 7566 G A het gCgaaatgacaagcacgC Cademal599 1949 G A het het gCgaaatgcacgaC Cademal599 19249 G A het het cgCractCctcatagcacgaC Cademal599 5627 C T het cttggtgcTgatgcttactC	IWGSC_CSS_4DS_scaff_2324074	Cadenza1409	2006	Ü	Ą	het	het	tGcatgaaaatgtgtGcaGaG	tGcatgaaaatgtgtGcaGaA	${\tt gggtaAgttcAaaactGaagtgaaG}$
Cadenzal499 8054 G A hom — ggtgatctaccgcadgaC Cadenzal409 19073 G A hom hom cadangagagttgC Cadenzal599 5504 C T hom hom ccCaggaaatgagcacctC Cadenzal599 12856 C T hom hom CgtagaacagtcgcagG Cadenzal599 7566 G A het het gctgtagattatagctgctatgC Cadenzal599 19249 G A hom hom cgTcctCctctagatttatagctgctatgC Cadenzal599 5627 C T het tttggtgctTgattgcttactC	IWGSC_CSS_5AS_scaff_1517889	Cadenza1409	3561	Ü	A	het	het	tctcgacatcttcccgtgtaC	tctcgacatcttcccgtgtaT	gtgcctggaacattgcttatttA
5 Cadenza1499 19073 G A hom hom caaatgacatgcaaagaagttgC Cadenza1599 5204 C T het tytatgcaaacacaaattgC Cadenza1599 6634 C T hom hom ccCaggaaatggacactC Cadenza1599 12856 C T hom hom GgtagaaagtggacactC Cadenza1599 7566 G A het het gGagaatgcaCAgtAacTtctgG Cadenza1599 9736 G A het pet gCtgtagattgttatgcttatgC Cadenza1599 19249 G A hom pet pet Cadenza1599 5627 C T het cttggtgctTgattgcttactC	IWGSC_CSS_5AS_scaff_1523866	Cadenza1409	8054	Ü	Ą	hom		ggtgatctaccgccaGgaC	ggtgatctaccgccaGgaT	tcctgcagCcTctcctcA
Cadenza1599 5204 C T het tgatgccaaccaaccaatGcC Cadenza1599 6634 C T hom hom cCagagacaagtgacactC Cadenza1599 7566 G A het het gCgagaaatgacgcacGG Cadenza1599 7566 G A het het gCgagaatgcaCAgtAacTtctg Cadenza1599 19749 G A het het gCgtgagatttataggcagg Cadenza1599 5627 C T het tetggtgctTgattgcttactC	IWGSC_CSS_5BL_scaff_10917655	Cadenza1409	19073	Ü	A	hom	hom	caaatgacatgcaaaagaagttgC	caaatgacatgcaaaagaagttgT	cgcttcatcactacaAaatatgtcT
Cadenzal599 6634 C T hom ccCaggaaatgagcacctC Cadenzal599 12856 C T hom GgtagacaagtcgcgaG Cadenzal599 7566 G A het het gCagaaatgcaCAgtAaCTtctgG Cadenzal599 9736 G A het het gctgtagatttatagctgctatgG Cadenzal599 19249 G A hom hom cgTcctCctctagcacgaC Cadenzal599 5627 C T het cttggtgctTgattgcttactC	IWGSC_CSS_1AL_scaff_3886649	Cadenza1599	5204	Ö	H	het	het	tgatgccaaccacaatGcC	tgatgccaaccacaatGcT	ggactgactgctgaccatatttaG
Cadenzal599 12856 C T hom GatagacaagtcgccgaG Cadenzal599 7566 G A het het gGagaagcaCAgtAacTtctgG Cadenzal599 9736 A het pet gCtgtagatttatagctgctatgC Cadenzal599 19249 G A hom hom cgTcctCctcgcacgaC Cadenzal599 5627 C T het cttggtgctTgattgcttactC	IWGSC_CSS_1BL_scaff_3810267	Cadenza1599	6634	Ö	H	hom	hom	ccCaggaaatgagcacctC	ccCaggaaatgagcacctT	cgcaggcgaagatgtgaTtG
Cadenzal599 7566 G A het het gGagaatgeaCAgtAacTtctgG CAGenzal599 9736 G A het het ggtgtgatttatagetgetatgC CAdenzal599 19249 G A hom hom cgTcctCctagacagaC CAdenzal599 5627 C T het het cttggtgctTgattgcttactC CAGenzal599 6627 C T het het cttggtgctTgattgcttactC	IWGSC_CSS_1DL_scaff_2291677	Cadenza1599	12856	Ö	⊣	hom	hom	GgtagacaagtcgccgaG	GgtagacaagtcgccgaA	cetectecateaacGCcG
Cadenzal599 9736 G A het het getgtagatttatagetgetatgC Cadenzal599 19249 G A hom hom cgTccctCctagcacgaC Cadenzal599 5227 C T het het cttggtgctTgattgcttactC	IWGSC_CSS_2AL_scaff_6354492	Cadenza1599	7566	Ü	Ą	het	het	gGagaatgcaCAgtAacTtctgG	gGagaatgcaCAgtAacTtctgA	ttccgaagaaccacaTccTG
Cadenza1599 19249 G A hom hom cgTccctCcctagcacgaC Cadenza1599 5227 C T het het cttggtgctTgattgcttactC	IWGSC_CSS_2AS_scaff_5282937	Cadenza1599	9736	Ü	Ą	het	het	gctgtagattttatagctgctatgC	gctgtagattttatagctgctatgT	cacCagaattgttCactgatttTC
Cadenza1599 5627 C T het het cttggtgctTgattgcttactC	IWGSC_CSS_2BL_scaff_7952427	Cadenza1599	19249	Ü	Ą	hom	hom	cgTccctCcctagcacgaC	cgTccctCcctagcacgaT	aTcactccattagcgcgAG
Q	IWGSC_CSS_2DL_scaff_9897981	Cadenza1599	5627	Ö	Η	het	het	cttggtgctTgattgcttactC	${ m cttggtgctTgattgcttactT}$	gTttgctCtctctgatctTtgtG
Cadenzal599 1765 G A hom — aaatgctttcctaCcgctagtG	IWGSC_CSS_3AL_scaff_4446105	Cadenza1599	1765	Ü	A	hom		aaatgctttcctaCcgctagtG	aaatgctttcctaCcgctagtA	${ m ttctAgaggcaatagctTatatgcT}$

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