# Contents

# Chapter 1

# 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.

# Chapter 2

# 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 organisims 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.

# Chapter 3

# 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 $F_2$ population

## 3.9 Assembly of the transcriptome

A comparison between thef 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.

# Chapter 4

# 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

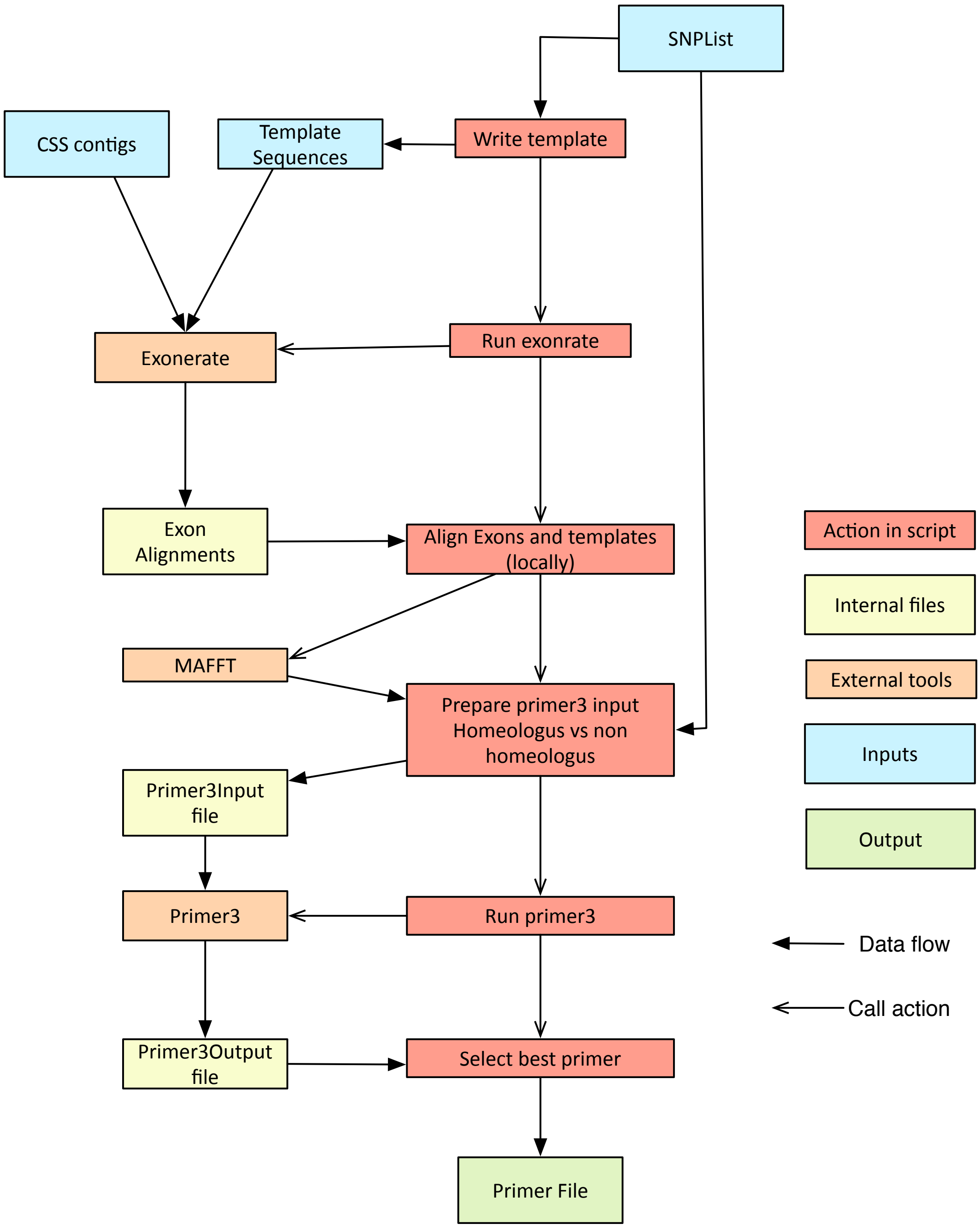



Figure 4.1: Steps and tools called by PolyMarker. The colour of the boxes represent: the step is an action inside the script(red); actions of the script(orange); temporary files(yellow); inputs(blue) and; outpus(green)

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 candidate SNP markers on this category are not expected to be reliably identify the allele (`:`).

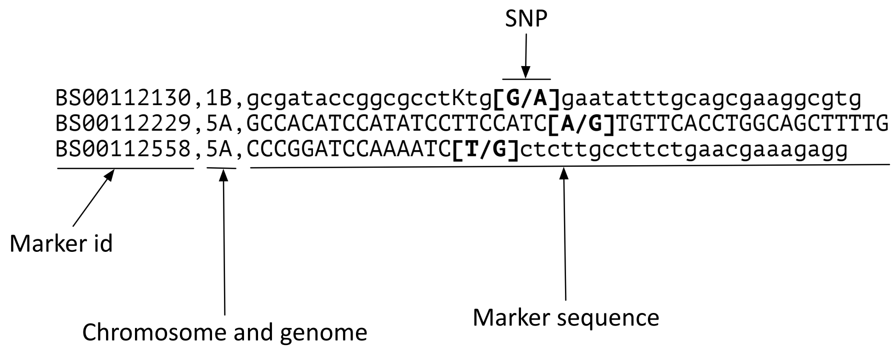
Non-homoeologous
: The target SNP is not present across chromosomes, so it can be used to identify an allele (`&`).

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).

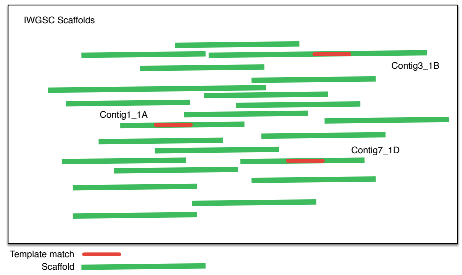
PolyMarker was designed and validated with the markers described in section 3.8. For wheat, PolyMarker uses the contigs from Mayer et al. (2014), as deposited in Ensembl. As new releases of the wheat genome are made available, different parsers to assign the chromosome to each sequence can be added with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

## 4.2 PolyMarker public web service

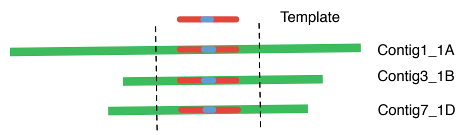
To make PolyMarker accessible to the community, a web server that allow the submission of SNPs was developed. The web interface consists on two virtual machines,




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




(b) Global search of templates in the reference contigs.



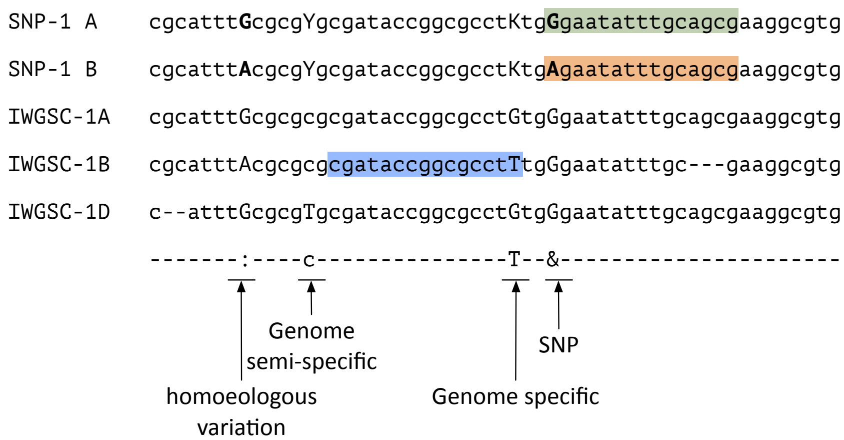

(c) Selected regions around the SNP on every chromosome.

```
SNP-1 A     cgcatttGcgcgYgcgataccggcgcctKtgGgaatatttgcagcgaaggcgtg
SNP-1 B     cgcatttAcgcgYgcgataccggcgcctKtgAgaatatttgcagcgaaggcgtg
IWGSC-1A    cgcatttgcgcgcgcgataccggcgcctgtgggaatatttgcagcgaaggcgtg
IWGSC-1B    cgcatttacgcgcgcgataccggcgcctttgggaatatttgcgaaggcgtg
IWGSC-1D    catttgcgcgTgcgataccggcgcctgtgggaatatttgcagcgaaggcgtg
```

(d) Sequence of found regions around the SNP.

```
SNP-1 A     cgcatttGcgcgYgcgataccggcgcctKtgGgaatatttgcagcgaaggcgtg
SNP-1 B     cgcatttAcgcgYgcgataccggcgcctKtgAgaatatttgcagcgaaggcgtg
IWGSC-1A    cgcatttGcgcgcgcgataccggcgcctGtgGgaatatttgcagcgaaggcgtg
IWGSC-1B    cgcatttAcgcgcgcgataccggcgcctTtgGgaatatttgc---gaaggcgtg
IWGSC-1D    c--atttGcgcgTgcgataccggcgcctGtgGgaatatttgcagcgaaggcgtg
```

(e) Local alignment on regions around the SNP detects indels.




(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 | 1,765 | 5,857 | 21.15% |
| Semi-specific | 7,942 | 6,907 | 41.20% |
| Specific | 6,813 | 5,957 | 35.43% |
| Not designed | 242 | 556 | 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.

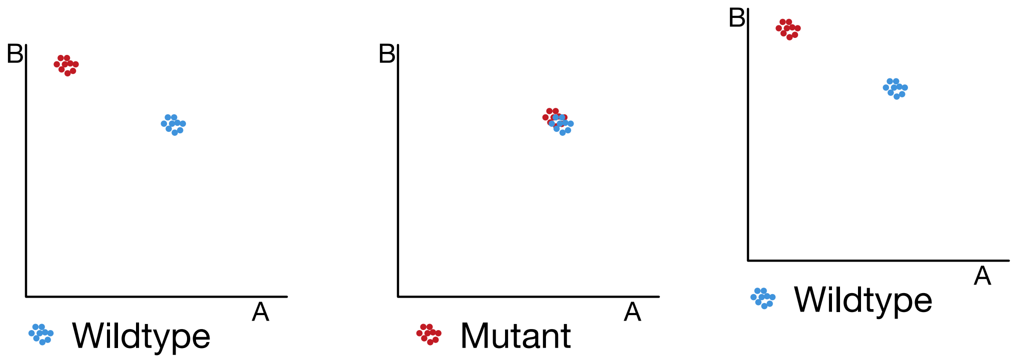
### 4.3.1 KASP assays for public sets of SNPs

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).


(a) Homozygous deletion on $M_2$ (b) Homozygous deletion on $M_3$




(c) KASP amplification for a real deletion (d) KASP amplification on false positive (e) Example of validated deletion on mutant poulation

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 succesfully to design genome-specific primers in several projects.

# Chapter 5

# 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.

# Chapter 6

# 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 | | Cluster II isolates | | Cluster III isolates | | | 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 | T | X:Y | X:Y | X:X | X:X | X:X | X:X | X:X | X:X | X:X |
| 2 | PST130_8160 | 11876 | C | T | Y:Y | Y:Y | X:Y | X:Y | X:Y | X:Y | X:Y | X:Y | X:Y |
| 3 | PST130_14628 | 1712 | A | 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 | G | Y:Y | Y:Y | X:Y | X:Y | Y:Y | Y:Y | Y:Y | Y:Y | Y:Y |
| 6 | PST130_7634 | 3463 | A | C | Y:Y | Y:Y | X:Y | X:Y | Y:Y | Y:Y | Y:Y | Y:Y | Y:Y |
| 7 | PST130_7629 | 11699 | G | A | Y:Y | Y:Y | X:Y | X:Y | Y:Y | Y:Y | Y:Y | Y:Y | Y:Y |
| 8 | PST130_10943 | 2979 | 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 | C | T | Y:Y | Y:Y | Y:Y | Y:Y | X:Y | X:Y | - | X:Y | X:Y |
| 11 | PST130_16961 | 1098 | 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 | C | T | X:X | X:X | Y:Y | Y:Y | X:X | X:X | X:X | Y:Y | X:X |
| 14 | PST130_7634 | 3883 | C | G | X:X | X:X | X:Y | X:Y | X:X | X:X | X:Y | X:Y | X:X |
| 15 | PST130_14470 | 456 | T | 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 | G | A | Het | Het | ccacaccttgagcctcgC | ccacaccttgagcctcgT | gtgattttgccaggggagA |
| IWGSC_CSS_1BL_scaff_3897513 | Kronos3085 | 1515 | C | T | Het | Het | gcttccactGggtcctgC | gcttccactGggtcctgT | acAaggactgcttcagaGaC |
| IWGSC_CSS_2AL_scaff_6434745 | Kronos3085 | 3424 | C | T | Het | Het | cctcGgttttgcaaatttctatgC | cctcGgttttgcaaatttctatgT | gGCaaTggcataacaacagatA |
| IWGSC_CSS_3AS_scaff_3408995 | Kronos3085 | 732 | C | T | Het | Het | aggccatttcgaattccgC | aggccatttcgaattccgT | ggTgttaTccagAacctgagTG |
| IWGSC_CSS_3B_scaff_10708748 | Kronos3085 | 2675 | G | A | Het | Het | gttgcatgcttcacccagG | gttgcatgcttcacccagA | gtaacaatctgagttcgtagcaC |
| IWGSC_CSS_4AL_scaff_7132733 | Kronos3085 | 1799 | C | T | Hom | Hom | cacccgtgagtgaccctC | cacccgtgagtgaccctT | aCcGcctaGaaagaaagcttC |
| IWGSC_CSS_5AS_scaff_1534693 | Kronos3085 | 4605 | C | T | Het | Het | cagcttcctggccctcAtC | cagcttcctggccctcAtT | gtaCctcacgAgtcaTgagAG |
| IWGSC_CSS_6AS_scaff_4361911 | Kronos3085 | 8857 | G | A | Het | Het | tcacgaaagacgacttcaacctcC | tcacgaaagacgacttcaacctcT | catgaggtgctgcatctccatcA |
| IWGSC_CSS_6BS_scaff_3008326 | Kronos3085 | 1528 | G | A | Het | Het | ccatgttgtactggtggtgC | ccatgttgtactggtggtgT | ggaagcatggCaagtgcA |
| IWGSC_CSS_7AS_scaff_4214385 | Kronos3085 | 27835 | C | T | Hom | Hom | cgtaccttcgttgggaaagG | cgtaccttcgttgggaaagA | ctcttggtcagctgtataagacT |
| IWGSC_CSS_1AL_scaff_3929964 | Kronos3191 | 1336 | C | T | Het | Het | tttcggccatacctgacatC | tttcggccatacctgacatT | attgcctccagttcttgcaG |
| IWGSC_CSS_1BL_scaff_3899789 | Kronos3191 | 7925 | C | T | Het | Het | actctcacTggcagcagC | actctcacTggcagcagT | caacgtggtgcccatcGtA |
| IWGSC_CSS_2AL_scaff_6426728 | Kronos3191 | 1481 | G | A | Hom | Hom | gaaActgccgcagctCgC | gaaActgccgcagctCgT | ccaGcaGctcgtgagaaA |
| IWGSC_CSS_2BL_scaff_7960273 | Kronos3191 | 690 | C | T | Hom | Hom | gccattcatccttaggcgC | gccattcatccttaggcgT | acatgcaattgctgatgactG |
| IWGSC_CSS_3AS_scaff_3286603 | Kronos3191 | 2975 | G | A | Het* | Hom | ccgtgtggtttgttgtggG | ccgtgtggtttgttgtggA | gaaaggaacgtgTcaTgcaG |
| IWGSC_CSS_5AL_scaff_2694249 | Kronos3191 | 2399 | C | T | Het | Het | gccttccagatagagccGC | gccttccagatagagccGT | cgccacatcgacattcctG |
| IWGSC_CSS_5BL_scaff_10923577 | Kronos3191 | 3713 | C | T | Het | Het | gtggattgcctgagcttgC | gtggattgcctgagcttgT | tggtggccttcttgggaC |
| IWGSC_CSS_6AL_scaff_5823017 | Kronos3191 | 13225 | C | T | Hom | Hom | ccctttcgagcctctggaG | ccctttcgagcctctggaA | ttcgagaaggcccatcgA |
| IWGSC_CSS_6BS_scaff_2955394 | Kronos3191 | 1622 | C | T | Het* | Hom | gtggagatgaaggtctagcaaG | gtggagatgaaggtctagcaaA | gatactcgTgcaatgggtgT |
| IWGSC_CSS_7BL_scaff_6739382 | Kronos3191 | 12261 | G | A | Hom | Hom | gagacaagctttgaattgctcC | gagacaagctttgaattgctcT | CgagtgacctTcatttcccG |
| IWGSC_CSS_1AS_scaff_3276389 | Kronos3288 | 9720 | C | T | Hom | Hom | aCcaGcaggaccAatgtctC | aCcaGcaggaccAatgtctT | atgatgcaacctcagccaT |
| IWGSC_CSS_2AL_scaff_6367515 | Kronos3288 | 6976 | G | A | Het | Het | caggtcgagTgtctccgG | caggtcgagTgtctccgA | ggggtgatCtggaagggC |
| IWGSC_CSS_2AL_scaff_6422019 | Kronos3288 | 4523 | G | A | Het | Het | cgctaggtccctgcatagG | cgctaggtccctgcatagA | acgcAcgctaagccgtaC |
| IWGSC_CSS_3AL_scaff_4284850 | Kronos3288 | 7901 | C | T | Hom | Hom | tggctttggacaacatcgG | tggctttggacaacatcgA | tgtcAgcatcgacagccaG |
| IWGSC_CSS_4AS_scaff_5962359 | Kronos3288 | 13049 | G | A | Het | Hom | ccatcaagaagtacgagttcgaC | ccatcaagaagtacgagttcgaT | accatgcccagcttgtcA |
| IWGSC_CSS_6AL_scaff_5778773 | Kronos3288 | 6853 | G | A | Het | Het | gagtgaccttcccgtctttC | gagtgaccttcccgtctttT | ggagaacagctactcggcT |
| IWGSC_CSS_6AS_scaff_4392100 | Kronos3288 | 3434 | C | T | Het | Het | atggaagcacaggtgaccG | atggaagcacaggtgaccA | ggAagcgaaagtgaacaaacA |
| IWGSC_CSS_7BL_scaff_6744240 | Kronos3288 | 9772 | G | A | Het | Het | agctgttcttctcctacttcaaG | agctgttcttctcctacttcaaA | caggtcgttcttgagctcC |
| IWGSC_CSS_1AL_scaff_3887185 | Kronos3413 | 9708 | C | T | Hom | Hom | gcacgcctttatcgaggtaaaG | gcacgcctttatcgaggtaaaA | AgaaacagcagagcgcaA |
| IWGSC_CSS_2BS_scaff_3381362 | Kronos3413 | 5160 | C | T | Het* | Hom | caacttctgggctgtagtgtG | caacttctgggctgtagtgtA | tgAgaattctgacGcaaaagaC |
| IWGSC_CSS_3AS_scaff_3296605 | Kronos3413 | 6154 | G | A | Het | Het | ctggtcacgggctctagC | ctggtcacgggctctagT | cagcactgagagacatggaC |
| IWGSC_CSS_3B_scaff_10693516 | Kronos3413 | 12632 | C | T | Het | Het | ctaggcttggacaaacaggC | ctaggcttggacaaacaggT | agcttgcatctatgggcatT |
| IWGSC_CSS_5AS_scaff_1547699 | Kronos3413 | 2686 | G | A | Het | Het | gCtacaaccttcaccaatcgC | gCtacaaccttcaccaatcgT | gacggctttgaagtgtcatC |
| IWGSC_CSS_5BL_scaff_10856077 | Kronos3413 | 5853 | G | A | Het | Het | agagcttcaccccatgctC | agagcttcaccccatgctT | acgCacatttAatagctgaagC |
| IWGSC_CSS_6AL_scaff_5750718 | Kronos3413 | 11046 | G | A | Hom | Hom | cacgcTtcccgacttcttataG | cacgcTtcccgacttcttataA | AgacgatgtgatcaggattcaG |
| IWGSC_CSS_7AL_scaff_4433177 | Kronos3413 | 3511 | C | T | Het | Het | GaTgctccGtcaggctgG | GaTgctccGtcaggctgA | cactactggacaagctcttgG |
| IWGSC_CSS_7BL_scaff_6742567 | Kronos3413 | 667 | C | T | Het | Het | gttgcttgcgtggcagaC | gttgcttgcgtggcagaT | cattttgcaccgtgtgtcTG |
| IWGSC_CSS_1AL_scaff_3976389 | Kronos3935 | 10941 | C | T | Hom | Hom | ggtgaggagatcggCgatG | ggtgaggagatcggCgatA | cagtcatctacatgagaggtcaG |
| IWGSC_CSS_1BL_scaff_3873362 | Kronos3935 | 1392 | G | A | Het | Het | cagatctgaagcctaGcacatG | cagatctgaagcctaGcacatA | actaccagaatcagcacaaaaAC |
| IWGSC_CSS_2BL_scaff_7882382 | Kronos3935 | 2721 | C | T | Het | Het | gcaagctaagatgtaccgtagC | gcaagctaagatgtaccgtagT | gccacagtaggagaaagactT |
| IWGSC_CSS_3AL_scaff_4242376 | Kronos3935 | 2410 | C | T | Het | Het | agaacccaaaacccgTacttaG | agaacccaaaacccgTacttaA | gtagGgtCcatcCtaaagcttG |
| IWGSC_CSS_3B_scaff_10485067 | Kronos3935 | 3349 | C | T | Hom | Hom | gcttgagcaactactccaactG | gcttgagcaactactccaactA | gcaatttcctttaTccgcagT |
| IWGSC_CSS_4AS_scaff_5984153 | Kronos3935 | 6006 | G | A | Het | Het | agCaggtctggccaagttG | agCaggtctggccaagttA | cgaatGtatgaGtaggcgcT |
| IWGSC_CSS_4BL_scaff_7019402 | Kronos3935 | 9081 | C | T | Het | Het | tgcaatcatgtagtgagctgG | tgcaatcatgtagtgagctgA | agcatgatccctagaaCcataC |
| IWGSC_CSS_5BL_scaff_10842786 | Kronos3935 | 3304 | G | A | Het | Het | tggttcccGaagcctgaaC | tggttcccGaagcctgaaT | cgcatacttgaaacaTGagcAC |
| IWGSC_CSS_6BS_scaff_3045205 | Kronos3935 | 2293 | G | A | Het | Het | aaggaccaagcccaaactctcG | aaggaccaagcccaaactctcA | agtgatcaagcccaatgtcgcA |
| IWGSC_CSS_7AL_scaff_4555249 | Kronos3935 | 4487 | C | T | Het | Het | cAgtgctcgagatggcgC | cAgtgctcgagatggcgT | cCttgcaaccctcctgatT |
| IWGSC_CSS_1BL_scaff_3918498 | Kronos4240 | 6096 | G | A | Het | Het | ttgcatgccccaagaagaG | ttgcatgccccaagaagaA | tgggcgaactggtaatgtgG |
| IWGSC_CSS_2BS_scaff_5131713 | Kronos4240 | 5900 | G | A | Het | Het | cctttatcgaggaaagagacacC | cctttatcgaggaaagagacacT | caccattgtagggttcctttTttC |
| IWGSC_CSS_5AL_scaff_2769540 | Kronos4240 | 9626 | C | T | Het | Het | tgCagtgtgggaaacggaG | tgCagtgtgggaaacggaA | catgagtGagatcttcctgcT |
| IWGSC_CSS_5BL_scaff_10871091 | Kronos4240 | 7062 | G | A | Het | Het | gccaaggAaccataacctgC | gccaaggAaccataacctgT | GgactcttggcAaccggA |
| IWGSC_CSS_6AL_scaff_5800333 | Kronos4240 | 2360 | G | A | Het | Het | cgacaggattgtgagCgC | cgacaggattgtgagCgT | tcagatgctgcaagattcatcT |
| IWGSC_CSS_7BL_scaff_6716931 | Kronos4240 | 2613 | G | A | Het | Het | gGtgGgtattTgcttggtgaG | gGtgGgtattTgcttggtgaA | tgGtggactcgacaGtGtA |
| IWGSC_CSS_2BL_scaff_8029221 | Kronos4346 | 2860 | G | A | Het | Het | tgcttccgctcttgctcC | tgcttccgctcttgctcT | atTtgcatTCgAtcgggcC |
| IWGSC_CSS_3B_scaff_10460714 | Kronos4346 | 14359 | C | T | Hom | Hom | ctaccttgccatgcgacatG | ctaccttgccatgcgacatA | agcaccccagtctttgacG |
| IWGSC_CSS_4AS_scaff_5989735 | Kronos4346 | 6404 | G | A | Hom | Hom | acgcatgctaacatcagcC | acgcatgctaacatcagcT | actcaagataccaCcgcacG |
| IWGSC_CSS_5BL_scaff_7648030 | Kronos4346 | 6893 | C | T | Het | Het | taccctttcctactggcagG | taccctttcctactggcagA | ttttcagaggaacacaggtatcA |
| IWGSC_CSS_6AL_scaff_5755840 | Kronos4346 | 778 | C | T | Het | Het | atcgagtaagctgtcacCgC | atcgagtaagctgtcacCgT | acctgcatgtcaCatccaC |
| IWGSC_CSS_6BS_scaff_2972151 | Kronos4346 | 7876 | G | A | Hom | Hom | gcagcaatgtcActgtttgG | gcagcaatgtcActgtttgA | gcttggactgggcatttatG |
| IWGSC_CSS_7AL_scaff_4542983 | Kronos4346 | 18700 | G | A | Het | Het | gcagggctAccggatacC | gcagggctAccggatacT | catctgccGgttaaacatgC |
| IWGSC_CSS_7BS_scaff_3098098 | Kronos4346 | 5183 | C | T | Het | Het | gCgatatggtacttgcaatgaG | gCgatatggtacttgcaatgaA | ttacattgcttataGTttgCcgG |
| IWGSC_CSS_1AS_scaff_3259804 | Kronos4485 | 219 | C | T | Het | Het | gtcggcacaaccccttgC | gtcggcacaaccccttgT | gcttctttaaggagggcgA |
| IWGSC_CSS_2AL_scaff_6315418 | Kronos4485 | 10490 | G | A | Hom | Hom | gcccctctcaaCcttctcagC | gcccctctcaaCcttctcagT | ttcagacgctCgaggaatttccC |
| IWGSC_CSS_2BS_scaff_5181092 | Kronos4485 | 3742 | G | A | Het | Het | TggccagcacacctgcaG | TggccagcacacctgcaA | tggacgatgagTgatggAaaT |
| IWGSC_CSS_3B_scaff_10425015 | Kronos4485 | 2372 | C | T | Het | Het | gctactgaagttggCtcGG | gctactgaagttggCtcGA | cttcacatccttgggggTtC |
| IWGSC_CSS_3B_scaff_10775915 | Kronos4485 | 4701 | C | T | Het | Het | ccaagggctgcagagagG | ccaagggctgcagagagA | agacctcacgatGtcctcC |
| IWGSC_CSS_5AL_scaff_2754304 | Kronos4485 | 2301 | G | A | Het | Het | taacccTgccatcgcccG | taacccTgccatcgcccA | cattgGccagccaTgacT |
| IWGSC_CSS_5BL_scaff_10919959 | Kronos4485 | 1867 | C | T | Hom | Hom | gatgccctttgtggagaagG | gatgccctttgtggagaagA | tcttgttcccgaaacatgtcA |
| IWGSC_CSS_7AS_scaff_4245431 | Kronos4485 | 3402 | G | A | Hom | Hom | aaggcgcctggtgtttcC | aaggcgcctggtgtttcT | agtaagtggaAcagctaagatcaT |
| IWGSC_CSS_7BL_scaff_6667357 | Kronos4485 | 641 | C | T | Het | Het | gatcAgctgctcattcgagG | gatcAgctgctcattcgagA | ttccctgtcaattgatgccC |

## A.2 Validation of mutations on $M_4$ on Cadenza

| IWGSC contig | Line | Pos | WT | Mut | Predicted | Called on $M_4$ | Primer 1 (Cadenza) | Primer 2 (mutant) | Common Primer |
|---|---|---|---|---|---|---|---|---|---|
| IWGSC_CSS_3B_scaff_10445294 | Cadenza1772 | 6019 | C | T | het | het | caggatAgtGggactgtcaaaG | caggatAgtGggactgtcaaaA | ggagacGGctGtggacatT |
| IWGSC_CSS_3DL_scaff_6955403 | Cadenza1772 | 2418 | C | T | het* | hom | tcagCggattgtcgggatG | tcagCggattgtcgggatA | tgtcCatgaaTcttgtccacG |
| IWGSC_CSS_4AL_scaff_7106846 | Cadenza1772 | 11277 | G | A | hom | hom | tgggatccatgcctacactG | tgggatccatgcctacactA | gatggtGgatttgccgctA |
| IWGSC_CSS_4AS_scaff_5991335 | Cadenza1772 | 15710 | G | A | hom | hom | ctggccctgcgctgctaC | ctggccctgcgctgctaT | gtggaaGttcagaaggaccaG |
| IWGSC_CSS_4BS_scaff_4956646 | Cadenza1772 | 252 | G | A | het* | hom | gcaggttgacttcccggaG | gcaggttgacttcccggaA | tGaggtacgaGcTaaagAaagC |
| IWGSC_CSS_4DS_scaff_1715962 | Cadenza1772 | 1225 | G | A | hom | hom | cagctgtggTatctcaactgG | cagctgtggTatctcaactgA | CcCtGaaACACcGtttggaT |
| IWGSC_CSS_5AL_scaff_2763407 | Cadenza1772 | 2119 | G | A | hom | hom | gcgacGaacctcgagatctG | gcgacGaacctcgagatctA | gaTggcaAtcgtCgtgcA |
| IWGSC_CSS_5AS_scaff_1548786 | Cadenza1772 | 12625 | C | T | het | het | AtaggcacattgctagactgaG | AtaggcacattgctagactgaA | ggattgggtgttgcacgC |
| IWGSC_CSS_5BL_scaff_10849226 | Cadenza1772 | 2289 | C | T | het* | hom | cctgacatcattgttcacgatC | cctgacatcattgttcacgatT | cactccgaggtgtccatgaT |
| IWGSC_CSS_5BS_scaff_2270737 | Cadenza1772 | 2262 | G | A | hom | — | attcCTgtgttgtggCaaatgaG | attcCTgtgttgtggCaaatgaA | taaGcacaaAccctccagctgG |
| IWGSC_CSS_1AL_scaff_3022915 | Cadenza1661 | 891 | C | T | hom | hom | ccacagtgagactcctattgaCG | ccacagtgagactcctattgaCA | atgtctgattcGtcGtagtcC |
| IWGSC_CSS_1AS_scaff_3297240 | Cadenza1661 | 1970 | C | T | het | het | catcccgccGtttcctcC | catcccgccGtttcctcT | gctcgccgatgaagagcT |
| IWGSC_CSS_1BL_scaff_3828996 | Cadenza1661 | 1340 | G | A | hom | hom | agccggatgttagtgttaacC | agccggatgttagtgttaacT | agcagcttgTcgcgttaaC |
| IWGSC_CSS_1DS_scaff_1884529 | Cadenza1661 | 10575 | G | A | hom | hom | aCagatacaAttgtcatgcaggC | aCagatacaAttgtcatgcaggT | acctgggTTgtccaatacttC |
| IWGSC_CSS_2AL_scaff_6318370 | Cadenza1661 | 19142 | C | T | het | — | cgtggcCgaatCtcGacG | cgtggcCgaatCtcGacA | ttcttgtgggagccgggC |
| IWGSC_CSS_2AS_scaff_5213460 | Cadenza1661 | 1358 | G | A | hom | hom | gtcacgaaCccgctcagG | gtcacgaaCccgctcagA | aggaaagagaggaaaagaGcG |
| IWGSC_CSS_2BS_scaff_5179331 | Cadenza1661 | 5604 | G | A | het | het | actctcgtcaagaactgatacaG | actctcgtcaagaactgatacaA | gcaGagaatgttcttgcaacT |
| IWGSC_CSS_2DS_scaff_5341235 | Cadenza1661 | 4673 | G | A | het | het | ggtgaggatctcggagctG | ggtgaggatctcggagctA | gcgcggtcgtacgagttG |
| IWGSC_CSS_3AL_scaff_4250995 | Cadenza1661 | 7046 | G | A | hom | hom | cCaagaaacgggtggtccaG | cCaagaaacgggtggtccaA | ctgcagctgtcccatcatcgT |
| IWGSC_CSS_3B_scaff_10404421 | Cadenza1661 | 4303 | G | A | het | het | ccttcgtcgaCaggacctG | ccttcgtcgaCaggacctA | GCcagtactCacAtgctctC |
| IWGSC_CSS_5DL_scaff_2390496 | Cadenza1538 | 2125 | C | T | hom | het | gcagttttatcctcagtagtcttgG | gcagttttatcctcagtagtcttgA | ttctgagaaTgtaatgtgcGatG |
| IWGSC_CSS_6AL_scaff_5753680 | Cadenza1538 | 3920 | C | T | hom | hom | tgctccaaatttgagcacaaTaaC | tgctccaaatttgagcacaaTaaT | aaatgcaaggggtaagtttttgT |
| IWGSC_CSS_6AS_scaff_4425792 | Cadenza1538 | 4307 | G | A | hom | het | agatgcttgtCggGccaG | agatgcttgtCggGccaA | gctgaagcaacgcgatcaaT |
| IWGSC_CSS_6BS_scaff_3003630 | Cadenza1538 | 6933 | C | T | het | het | ggcagtaatgtggtgctgagC | ggcagtaatgtggtgctgagT | tTgaCttctggtttggtggcA |
| IWGSC_CSS_6DL_scaff_3246988 | Cadenza1538 | 9186 | G | A | het | het | gctaaagaagagcttgagagaattC | gctaaagaagagcttgagagaattT | aatttctgaagagaggtgttgtatG |
| IWGSC_CSS_7AL_scaff_4480114 | Cadenza1538 | 3446 | C | T | het | — | gatatctcccacacggcgG | gatatctcccacacggcgA | tgagccactcttgcagtttT |
| IWGSC_CSS_7AS_scaff_4193541 | Cadenza1538 | 8359 | C | T | hom | het | agcaattctttggctatcaattagC | agcaattctttggctatcaattagT | tcatctGtcttaactctactgctG |
| IWGSC_CSS_7BL_scaff_6721572 | Cadenza1538 | 9223 | C | T | het | het | gctCagggaggaagacaagaaG | gctCagggaggaagacaagaaA | tgctatgaagaattccgacctC |
| IWGSC_CSS_7BS_scaff_3152545 | Cadenza1538 | 3960 | G | A | hom | — | tcagcaaaatcacctgcCgC | tcagcaaaatcacctgcCgT | gCtgccccatcatcgtttaT |
| IWGSC_CSS_7DS_scaff_3963838 | Cadenza1538 | 2913 | G | A | het | het | tCgttgcaagcCttTtgtgC | tCgttgcaagcCttTtgtgT | agaGttaTcaagcTactgtcacA |
| IWGSC_CSS_1AL_scaff_3903380 | Cadenza1469 | 6193 | G | A | hom | hom | ctcttcAgagatgaacgcgG | ctcttcAgagatgaacgcgA | tcGtGagatgGtggtttGTtA |
| IWGSC_CSS_1AS_scaff_3287728 | Cadenza1469 | 3817 | C | T | het* | hom | ccgaccaAttcactaaccgG | ccgaccaAttcactaaccgA | accctctttcccAgacatgaT |
| IWGSC_CSS_1BL_scaff_3815304 | Cadenza1469 | 513 | G | A | hom | hom | aacatttgcctTaCcaaaacGC | aacatttgcctTaCcaaaacGT | acacagcaagttataatgCAAgC |
| IWGSC_CSS_1DL_scaff_2266648 | Cadenza1469 | 5926 | C | T | het | het | caacatgagacacaacaccttC | caacatgagacacaacaccttT | gtcaacgcgtgaggattgtC |
| IWGSC_CSS_1DS_scaff_1906671 | Cadenza1469 | 3697 | C | T | hom | hom | tggTGtagacacttggcgaG | tggTGtagacacttggcgaA | catggcgaccaccAcctG |
| IWGSC_CSS_2AL_scaff_6337088 | Cadenza1469 | 7334 | G | A | het* | hom | acaatgccAagttgacaggttG | acaatgccAagttgacaggttA | gggagtgttggttCagaacaT |
| IWGSC_CSS_2BL_scaff_7972799 | Cadenza1469 | 8995 | C | T | het | hom | gTgCtcctcGgcatccttC | gTgCtcctcGgcatccttT | gatccgGgcaaactacgTG |
| IWGSC_CSS_2DL_scaff_9832343 | Cadenza1469 | 3262 | G | A | het | het | TtgtctaAcagcacCGcagG | TtgtctaAcagcacCGcagA | agatctcggtcagcctttcT |
| IWGSC_CSS_2DS_scaff_5327939 | Cadenza1469 | 3889 | G | A | het | het | ttttTgccttatgtgactctagtaC | ttttTgccttatgtgactctagtaT | gaggccatcacagatagcG |
| IWGSC_CSS_3B_scaff_10395219 | Cadenza1469 | 1292 | G | A | hom | — | aggtgcttgtgcttgctgG | aggtgcttgtgcttgctgA | cctcttctgggggctttataC |
| IWGSC_CSS_3B_scaff_10592217 | Cadenza0580 | 2994 | C | T | het | — | acagcagtatcaagcccctC | acagcagtatcaagcccctT | tgatactgttgTggCggagG |
| IWGSC_CSS_3DS_scaff_2596771 | Cadenza0580 | 1037 | G | A | het | het | tggttatgCAcaggataatCagG | tggttatgCAcaggataatCagA | tggcaaatgtgatgtcattaggT |
| IWGSC_CSS_4AL_scaff_7093953 | Cadenza0580 | 9881 | C | T | hom | hom | GacaggaagccggtaacaC | GacaggaagccggtaacaT | ctccAgcaggcatgggaT |
| IWGSC_CSS_4BL_scaff_7037448 | Cadenza0580 | 1837 | C | T | hom | hom | CgttgaaaaGctgcaagaacttaaC | CgttgaaaaGctgcaagaacttaaT | cagttcttccTtCaGagcagataT |
| IWGSC_CSS_4BS_scaff_4929479 | Cadenza0580 | 10668 | G | A | hom | — | tggattttcccgcactgttC | tggattttcccgcactgttT | gtaaacaaggcatttcaagagtcA |
| IWGSC_CSS_4DL_scaff_14359838 | Cadenza0580 | 1408 | G | A | hom | — | gCtcAttcagggatTGTcCtaTatG | gCtcAttcagggatTGTcCtaTatA | tgaCagaacagttggtcatacT |
| IWGSC_CSS_4DS_scaff_2276484 | Cadenza0580 | 8034 | G | A | hom | hom | gccgtggttgatggAgaG | gccgtggttgatggAgaA | cgtccagattactgatacttgcA |
| IWGSC_CSS_5AL_scaff_2756579 | Cadenza0580 | 5278 | G | A | het | het | tgaatggatttttcgtcccgttC | tgaatggatttttcgtcccgttT | ggAAtCCTATgCAgaAgAaaCTG |
| IWGSC_CSS_5BL_scaff_10787208 | Cadenza0580 | 10627 | G | A | het | — | gcctctcacatgcggagaC | gcctctcacatgcggagaT | acgatgtcAggtggGcgT |
| IWGSC_CSS_5BS_scaff_2282179 | Cadenza0580 | 5267 | G | A | het | — | tgatgggctacgacgtgC | tgatgggctacgacgtgT | tcggcgcccttgaaAtcC |
| IWGSC_CSS_5DL_scaff_4498073 | Cadenza0423 | 4937 | C | T | hom | hom | gcaccctctggttggtcatC | gcaccctctggttggtcatT | tgagcagcaAagcagccG |
| IWGSC_CSS_5DS_scaff_2738970 | Cadenza0423 | 2319 | C | T | het | — | cgtgaggtgggtgatttgC | cgtgaggtgggtgatttgT | tggaactagttacactgcagtTC |
| IWGSC_CSS_6AL_scaff_5757109 | Cadenza0423 | 2788 | G | A | hom | hom | caggaGcctggcaaataaaGG | caggaGcctggcaaataaaGA | ctttcGcagtctcttagtttcG |
| IWGSC_CSS_6AS_scaff_4387871 | Cadenza0423 | 2543 | G | A | hom | hom | gcatgctaacaggcgaaaagG | gcatgctaacaggcgaaaagA | ctcatgctcctgatcttaaggtT |
| IWGSC_CSS_6BL_scaff_4271391 | Cadenza0423 | 4660 | C | T | hom | hom | tacgtgcatgatgtggtagtcgtaC | tacgtgcatgatgtggtagtcgtaT | gtttgaagtgcatcagatgTaccA |
| IWGSC_CSS_6DS_scaff_1880206 | Cadenza0423 | 9159 | G | A | het | het | ctgCgaaggctccacaaG | ctgCgaaggctccacaaA | ggatgagaagtttgcattgctC |
| IWGSC_CSS_7AS_scaff_4227506 | Cadenza0423 | 952 | G | A | het | — | ccatgtgtttccaatgttagagC | ccatgtgtttccaatgttagagT | tgccctagctggtatgcT |
| IWGSC_CSS_7BL_scaff_6681782 | Cadenza0423 | 1486 | C | T | hom | hom | agtaagCGtgacagcaatggG | agtaagCGtgacagcaatggA | AtgtctTtgGtggaagtacatcA |
| IWGSC_CSS_7BS_scaff_3160328 | Cadenza0423 | 7801 | C | T | het | het | tgttaaatGatacagCctgcagC | tgttaaatGatacagCctgcagT | tggaatggtgCgttgttttT |
| IWGSC_CSS_7DS_scaff_407428 | Cadenza0423 | 2051 | G | A | het | het | gtcGCgccatcctgacaG | gtcGCgccatcctgacaA | actcatcAggtcagcccaA |
| IWGSC_CSS_3AL_scaff_442479 | Cadenza0364 | 3198 | C | T | het | het | gagtcaTtaagttggtaagattggC | gagtcaTtaagttggtaagattggT | GCaGaTaaCaacaggatcacG |
| IWGSC_CSS_3AL_scaff_4447942 | Cadenza0364 | 11917 | G | A | het | het | gtcataaagattgctcctgtgaaG | gtcataaagattgctcctgtgaaA | ctcGgatgtgggaggaagA |
| IWGSC_CSS_3AS_scaff_1557483 | Cadenza0364 | 2547 | C | T | het | het | aaagtcacatcatgcttaccataaG | aaagtcacatcatgcttaccataaA | cgaaatccaacgcctcatcA |
| IWGSC_CSS_3AS_scaff_2648747 | Cadenza0364 | 2688 | G | A | het | het | tggAagcAcaaggggccC | tggAagcAcaaggggccT | GccgccgatggagactcG |
| IWGSC_CSS_3AS_scaff_3304956 | Cadenza0364 | 1017 | G | A | het | het | gtcccttgcacacagctttG | gtcccttgcacacagctttA | cctgctggactacaacttcaaT |
| IWGSC_CSS_3AS_scaff_3321091 | Cadenza0364 | 4585 | C | T | het | het | caagaatgATgctgatgttggaG | caagaatgATgctgatgttggaA | acatgctgaatcgccgaatC |
| IWGSC_CSS_3AS_scaff_3371333 | Cadenza0364 | 538 | G | A | het | het | gggaaaCgAgAcgagcgG | gggaaaCgAgAcgagcgA | ccgtgccttcctcacccT |
| IWGSC_CSS_3AS_scaff_3371815 | Cadenza0364 | 1061 | C | T | het | het | atccccacggcacagagG | atccccacggcacagagA | aAttggcccttggtgattcC |
| IWGSC_CSS_3AS_scaff_3440912 | Cadenza0364 | 4498 | G | A | het | het | ccgtaaaactttctgtgcttgC | ccgtaaaactttctgtgcttgT | atActgacaaactacatgatgtgC |
| IWGSC_CSS_3B_scaff_10343586 | Cadenza0364 | 2242 | G | A | het | — | ggttcTgTcctctcttccactG | ggttcTgTcctctcttccactA | tgtgttgaacccgcaagcA |

| IWGSC contig | Line | Pos | WT | Mut | Predicted | Called on $M_4$ | Primer 1 (Cadenza) | Primer 2 (mutant) | Common Primer |
|---|---|---|---|---|---|---|---|---|---|
| IWGSC_CSS_3AL_scaff_442479 | Cadenza0364 | 3198 | C | T | het | het | gagtcaTtaagttggtaagattggC | gagtcaTtaagttggtaagattggT | GCaGaTaaCaacaggatcacG |
| IWGSC_CSS_3AL_scaff_4447942 | Cadenza0364 | 11917 | G | A | het | het | gtcataaagattgctcctgtgaaG | gtcataaagattgctcctgtgaaA | ctcGgatgtgggaggaagA |
| IWGSC_CSS_3AS_scaff_1557483 | Cadenza0364 | 2547 | C | T | het | het | aaagtcacatcatgcttaccataaG | aaagtcacatcatgcttaccataaA | cgaaatccaacgcctcatcA |
| IWGSC_CSS_3AS_scaff_2648747 | Cadenza0364 | 2688 | G | A | het | het | tggAagcAcaaggggccC | tggAagcAcaaggggccT | GccgccgatggagactcG |
| IWGSC_CSS_3AS_scaff_3304956 | Cadenza0364 | 1017 | G | A | het | het | gtcccttgcacacagctttG | gtcccttgcacacagctttA | cctgctggactacaacttcaaT |
| IWGSC_CSS_3AS_scaff_3321091 | Cadenza0364 | 4585 | C | T | het | het | caagaatgATgctgatgttggaG | caagaatgATgctgatgttggaA | acatgctgaatcgccgaatC |
| IWGSC_CSS_3AS_scaff_3371333 | Cadenza0364 | 538 | G | A | het | het | gggaaaCgAgAcgagcgG | gggaaaCgAgAcgagcgA | ccgtgccttcctcaccc T |
| IWGSC_CSS_3AS_scaff_3371815 | Cadenza0364 | 1061 | C | T | het | het | atccccacggcacagagG | atccccacggcacagagA | aAttggcccttggtgattcC |
| IWGSC_CSS_3AS_scaff_3440912 | Cadenza0364 | 4498 | G | A | het | het | ccgtaaaactttctgtgcttgC | ccgtaaaactttctgtgcttgT | atActgacaaactacatgatgtgC |
| IWGSC_CSS_3B_scaff_10343586 | Cadenza0364 | 2242 | G | A | het | — | ggttcTgTcctctcttccactG | ggttcTgTcctctcttccactA | tgtgttgaacccgcaagcA |
| IWGSC_CSS_5DL_scaff_242342 | Cadenza0281 | 2433 | C | T | hom | hom | catggCgacggtGtcctG | catggCgacggtGtcctA | aAccctcatTTggCTACTtCT |
| IWGSC_CSS_5DL_scaff_4538822 | Cadenza0281 | 1208 | G | A | hom | — | acgtcagaacaaccgtttgaC | acgtcagaacaaccgtttgaT | ttaaattggttggcgccacC |
| IWGSC_CSS_6AL_scaff_5813297 | Cadenza0281 | 4532 | C | T | hom | — | gggagagggacgtctcgG | gggagagggacgtctcgA | ttcttctgccaacgattccG |
| IWGSC_CSS_6AS_scaff_4378990 | Cadenza0281 | 6748 | C | T | hom | hom | cccaggttctgcttcttttcC | cccaggttctgcttcttttcT | caagtatcaagaaaatgaagggTgT |
| IWGSC_CSS_6BL_scaff_4360781 | Cadenza0281 | 5426 | C | T | het | het | aCtactcaaatggcttGgtgtaG | aCtactcaaatggcttGgtgtaA | tcagtccaacatgTcaagagatT |
| IWGSC_CSS_7AL_scaff_4488310 | Cadenza0281 | 3808 | G | A | hom | hom | gttctcttgtagtagcagccG | gttctcttgtagtagcagccA | ggcgctttcttcggcctA |
| IWGSC_CSS_7BL_scaff_6696509 | Cadenza0281 | 9232 | G | A | het | het | gctctaggGgtggcaaAagG | gctctaggGgtggcaaAagA | ggcttGaGgtcGcagtgT |
| IWGSC_CSS_7BS_scaff_3143575 | Cadenza0281 | 1866 | C | T | het | het | agatgttgagagggcgcttC | agatgttgagagggcgcttT | gcttggAtggtggcaagtT |
| IWGSC_CSS_7DL_scaff_3346250 | Cadenza0281 | 1663 | G | A | het | het | acgtgcagcaacatcctaaC | acgtgcagcaacatcctaaT | TttcccaccaggcccaagA |
| IWGSC_CSS_7DS_scaff_3933917 | Cadenza0281 | 1243 | C | T | het | het | tgCtgagcCttTcaccttgC | tgCtgagcCttTcaccttgT | agaggtttggttccatcGG |
| IWGSC_CSS_3B_scaff_10626860 | Cadenza0148 | 7847 | G | A | het | het | gcagctctgggaaggagG | gcagctctgggaaggagA | gttaatgtacCTcctagcctcG |
| IWGSC_CSS_3DL_scaff_6915683 | Cadenza0148 | 6904 | C | T | het | het | cgtcaaCctgtgggcaattG | cgtcaaCctgtgggcaattA | tcatgctcataatgTcatagggT |
| IWGSC_CSS_4AS_scaff_5929057 | Cadenza0148 | 4238 | G | A | hom | hom | gcgcaacgtagCacctacC | gcgcaacgtagCacctacT | ttatctggtgaagtgacaggttCA |
| IWGSC_CSS_4AS_scaff_5950625 | Cadenza0148 | 10590 | C | T | het | het | agaTattCaaaTcggtggAttggC | agaTattCaaaTcggtggAttggT | cctgCtcccctcacgtcC |
| IWGSC_CSS_4AS_scaff_5967119 | Cadenza0148 | 11626 | C | T | hom | hom | cgtGgacaccccgagctG | cgtGgacaccccgagctA | gacgacgcactgcacgaC |
| IWGSC_CSS_4DL_scaff_14455742 | Cadenza0148 | 1946 | C | T | hom | hom | gCctgagggagatcgcgC | gCctgagggagatcgcgT | aaccgGtAaCTGtGgGcA |
| IWGSC_CSS_4DS_scaff_2318993 | Cadenza0148 | 4000 | C | T | hom | hom | tccagtttgacacagattgaatggG | tccagtttgacacagattgaatggA | tgagaTtctgtttcctttcacAttG |
| IWGSC_CSS_5AL_scaff_2750707 | Cadenza0148 | 4603 | G | A | het | het | ccttggtgctagccatttcaagTaG | ccttggtgctagccatttcaagTaA | ccaggaTgcAgtgcaatatttcaaG |
| IWGSC_CSS_5BL_scaff_10794137 | Cadenza0148 | 9235 | C | T | hom | hom | gaagctgcttctgcgttG | gaagctgcttctgcgttA | agtatcccttccatataagcagtG |
| IWGSC_CSS_5BS_scaff_1646558 | Cadenza0148 | 2916 | C | T | het | het | gccGtacactcacctAtcctttG | gccGtacactcacctAtcctttA | gcaaTgtccacttAtcatccc T |
| IWGSC_CSS_1AL_scaff_3883106 | Cadenza0110 | 27536 | C | T | het | het | accttccatcactggctgG | accttccatcactggctgA | gtgaagaacaacaggttgaagC |
| IWGSC_CSS_1BL_scaff_3812829 | Cadenza0110 | 10770 | G | A | het* | hom | cccccactccattccagG | cccccactccattccagA | gGatgttgttctgtgctggaA |
| IWGSC_CSS_1DL_scaff_2266648 | Cadenza0110 | 6156 | G | A | het | het | actgcgtggttatgggacC | actgcgtggttatgggacT | ccccatcactgaacacaacA |
| IWGSC_CSS_1DS_scaff_1889435 | Cadenza0110 | 8826 | C | T | hom | hom | aaccatgaattactcggacagG | aaccatgaattactcggacagA | gccctgaagaattgtatcaaaacaG |
| IWGSC_CSS_2AS_scaff_5268634 | Cadenza0110 | 4636 | G | A | het | het | gatccatgtgattggcatgtttG | gatccatgtgattggcatgtttA | TgctgtTggatatgcagttacT |
| IWGSC_CSS_2BL_scaff_7965110 | Cadenza0110 | 15801 | C | T | hom | hom | cattgaagcAtacacAattgcAtaC | cattgaagcAtacacAattgcAtaT | gccagagtatccagataaggTttA |
| IWGSC_CSS_2DL_scaff_9852812 | Cadenza0110 | 13788 | G | A | hom | hom | atttttgtatggtctcaatcttcgC | atttttgtatggtctcaatcttcgT | gaacgtTcattcttgtacttgcT |
| IWGSC_CSS_2DS_scaff_5371379 | Cadenza0110 | 2166 | C | T | hom | hom | agacacaaaactagtGatgcgC | agacacaaaactagtGatgcgT | gctgctgagaatgttTtgtatttG |
| IWGSC_CSS_3AL_scaff_4384278 | Cadenza0110 | 1276 | C | T | het | het | agcTgaactgccccTgtaG | agcTgaactgccccTgtaA | agggacctCgGtggatgaA |
| IWGSC_CSS_3AS_scaff_3340122 | Cadenza0110 | 1467 | C | T | hom | hom | attcctAgtgttgtcggaacatG | attcctAgtgttgtcggaacatA | gagaagactagaaagttttcAgcaT |
| IWGSC_CSS_5DL_scaff_4554222 | Cadenza2103 | 6528 | C | T | het* | hom | gctgccctacaaagaaacaaaattG | gctgccctacaaagaaacaaaattA | aTcccaactatCGaTtttgtcataC |
| IWGSC_CSS_6AL_scaff_5833640 | Cadenza2103 | 7346 | C | T | hom | hom | aagaaaagccacaatggtttctC | aagaaaagccacaatggtttctT | aCTctgTcagtgtttcccagC |
| IWGSC_CSS_6AS_scaff_4429974 | Cadenza2103 | 3867 | G | A | hom | hom | GagatgaAtttattgagcatgtggC | GagatgaAtttattgagcatgtggT | ggttccggctgcataagT |
| IWGSC_CSS_6DL_scaff_3307626 | Cadenza2103 | 4970 | C | T | hom | hom | tgcagatgttgtcctgtgtaG | tgcagatgttgtcctgtgtaA | ctaggaaggtgattttgtactGtC |
| IWGSC_CSS_6DS_scaff_2059604 | Cadenza2103 | 5224 | G | A | het | — | gctcaatgcatgcTgagtgG | gctcaatgcatgcTgagtgA | tgtcaagtattattttcctgctctG |
| IWGSC_CSS_7AL_scaff_4552322 | Cadenza2103 | 1412 | C | T | het | het | gcaaaggcTgatactccaacaG | gcaaaggcTgatactccaacaA | ggcAAGccAgtataaaagtaaGC |
| IWGSC_CSS_7BS_scaff_3147455 | Cadenza2103 | 4607 | G | A | het | — | gcaccttaggatgtgagTtatgC | gcaccttaggatgtgagTtatgT | gcatgtagggtttatttgactgttA |
| IWGSC_CSS_7DL_scaff_3382467 | Cadenza2103 | 3473 | C | T | hom | — | GGTtctgCaGTTCATAActcatC | GGTtctgCaGTTCATAActcatT | attgaatcaactgatacGaaGactC |
| IWGSC_CSS_3B_scaff_10457010 | Cadenza0277 | 10599 | G | A | het | het | aaccttggccgcagaacaC | aaccttggccgcagaacaT | actggctgcacgagaggG |
| IWGSC_CSS_3B_scaff_10593852 | Cadenza0277 | 10124 | C | T | het | het | tgacaggggacgctatacaG | tgacaggggacgctatacaA | gtctaaCTtACattAcccatcagC |
| IWGSC_CSS_3DS_scaff_2583390 | Cadenza0277 | 663 | G | A | hom | hom | actgcactcatacaatActtCtgC | actgcactcatacaatActtCtgT | tcCacctggacagcaagtG |
| IWGSC_CSS_4AL_scaff_7093953 | Cadenza0277 | 10004 | C | T | hom | hom | ccttgtattcaatggaTtgTtttgG | ccttgtattcaatggaTtgTtttgA | ttccccaaaTaaaaaggaagagC |
| IWGSC_CSS_4AL_scaff_7176064 | Cadenza0277 | 6220 | C | T | het | het | gtgccgtaTtcCgcctgG | gtgccgtaTtcCgcctgA | atgttcgaggggatgggG |
| IWGSC_CSS_4DL_scaff_14122349 | Cadenza0277 | 1010 | C | T | hom | hom | gtcgctgctgCttgtgaG | gtcgctgctgCttgtgaA | ggaacaggcccaaggagG |
| IWGSC_CSS_5AL_scaff_2736916 | Cadenza0277 | 4296 | G | A | het | het | aagaactATgAaaGtaacacacgaC | aagaactATgAaaGtaacacacgaT | ttcGcTttTaagGcAttCtcG |
| IWGSC_CSS_5BL_scaff_10883744 | Cadenza0277 | 2080 | C | T | hom | hom | gcctctttCtgttTagcctcaG | gcctctttCtgttTagcctcaA | cgacaaggttcgtgatTgcA |
| IWGSC_CSS_1AL_scaff_3932013 | Cadenza0548 | 11765 | C | T | hom | hom | accgccaaCccaagacaG | accgccaaCccaagacaA | cccattaGccgTgcAacG |
| IWGSC_CSS_1BS_scaff_3417505 | Cadenza0548 | 373 | C | T | het | het | gtggtgaggaGGgtgGaG | gtggtgaggaGGgtgGaA | tggtcgGccagttgttgA |
| IWGSC_CSS_2AS_scaff_5305619 | Cadenza0548 | 2786 | C | T | hom | hom | atacagatgccctAAgtggTtC | atacagatgccctAAgtggTtT | ggaagacaAtGctccaggtaC |
| IWGSC_CSS_2AS_scaff_5306489 | Cadenza0548 | 46953 | T | G | het | wt | aggttccatgtccatagaagGT | aggttccatgtccatagaagGG | aggctaTAgactcctgtACAgT |
| IWGSC_CSS_2BL_scaff_7984123 | Cadenza0548 | 11660 | G | A | het | het | cattgtggcatagtaatcagtacaG | cattgtggcatagtaatcagtacaA | aatacattgaggaatcaaagcccC |
| IWGSC_CSS_2DL_scaff_9907477 | Cadenza0548 | 1363 | C | T | hom | hom | tgcctccctttgccagaaC | tgcctccctttgccagaaT | ggcaaacctgatgtggcatC |
| IWGSC_CSS_2DS_scaff_5330886 | Cadenza0548 | 5449 | G | A | hom | hom | gcatgtccatttatactgaaCgtG | gcatgtccatttatactgaaCgtA | catgctgcttcttctggacC |
| IWGSC_CSS_3AL_scaff_4449951 | Cadenza0548 | 633 | C | T | het | het | tccaaacctaacagtctaacactaG | tccaaacctaacagtctaacactaA | gtctgcagTGCaatgtgC |
| IWGSC_CSS_3B_scaff_10479889 | Cadenza0097 | 3339 | C | T | hom | — | ttgTttctGgagaagatgcCG | ttgTttctGgagaagatgcCA | ggtgctcattcaAcGgcA |
| IWGSC_CSS_3B_scaff_10562262 | Cadenza0097 | 7819 | C | T | het | het | agaggggtgctatccatAttgG | agaggggtgctatccatAttgA | agcgatgccaaggcttcC |
| IWGSC_CSS_4AL_scaff_7040796 | Cadenza0097 | 10772 | G | A | hom | hom | acacaacattgccaccagaG | acacaacattgccaccagaA | CAatCgattgcttgctTctcC |
| IWGSC_CSS_4AL_scaff_7063488 | Cadenza0097 | 6360 | C | T | het | het | gcctctcacCttAatttgaagctgC | gcctctcacCttAatttgaagctgT | aggcagtggagtatgtgaagttT |
| IWGSC_CSS_4AL_scaff_7091701 | Cadenza0097 | 5050 | G | A | het | het | catgagcatctgggaggaaaatG | catgagcatctgggaggaaaatA | agcaagggaAtaatgaacggaaA |
| IWGSC_CSS_4DS_scaff_1845841 | Cadenza0097 | 7110 | G | A | hom | hom | aatgTAgctccccatacCgG | aatgTAgctccccatacCgA | actgaaacTgcaatcgtTtatggA |
| IWGSC_CSS_5AL_scaff_2767581 | Cadenza0097 | 3737 | G | A | het | het | gagaggtcctcactAtcggC | gagaggtcctcactAtcggT | cgTcatcacaaatattgctggG |
| IWGSC_CSS_5BL_scaff_10784643 | Cadenza0097 | 1568 | C | T | hom | hom | agaaaTAcatggatggatggaCG | agaaaTAcatggatggatggaCA | catctcCCttccaCgGaaaG |

| IWGSC contig | Line | Pos | WT | Mut | Predicted | Called on $M_4$ | Primer 1 (Cadenza) | Primer 2 (mutant) | Common Primer |
|---|---|---|---|---|---|---|---|---|---|
| IWGSC_CSS_1AL_scaff_3952258 | Cadenza2092 | 8107 | C | T | het | — | tgagtagagaaattgacagtgtgG | tgagtagagaaattgacagtgtgA | tgccaccattgacatgagaG |
| IWGSC_CSS_1BL_scaff_3858008 | Cadenza2092 | 10278 | G | A | hom | hom | tttgagcaggcaggatcgC | tttgagcaggcaggatcgT | actcacggcctatatcActattC |
| IWGSC_CSS_1DL_scaff_2265172 | Cadenza2092 | 9094 | C | T | hom | hom | tgcaTGTcatttgttcttatcagC | tgcaTGTcatttgttcttatcagT | agtgtccaacttccGttcatC |
| IWGSC_CSS_2AL_scaff_6435867 | Cadenza2092 | 16201 | G | A | hom | hom | tttctgTaccttaacgtcaattgaC | tttctgTaccttaacgtcaattgaT | gtgaggatgatgaggtaagacC |
| IWGSC_CSS_2AL_scaff_6439430 | Cadenza2092 | 25101 | C | T | het | — | caagaaagggCagCtCagC | caagaaagggCagCtCagT | tcGttAcTctttcActggtgaA |
| IWGSC_CSS_2DL_scaff_9760848 | Cadenza2092 | 4733 | C | T | het | het | gcaccatgggtctcaggtaC | gcaccatgggtctcaggtaT | tcagtcagtttGCTCtgTCTG |
| IWGSC_CSS_3AL_scaff_4407012 | Cadenza2092 | 2785 | C | T | hom | hom | acatatAgtgttctcatccaccatC | acatatAgtgttctcatccaccatT | acctctctcatgttaataggtttgT |
| IWGSC_CSS_3AS_scaff_3441108 | Cadenza2092 | 541 | G | A | het | het | GtgatgaccttgagacGgaG | GtgatgaccttgagacGgaA | aggcaTgacaaCgcgcaA |
| IWGSC_CSS_3B_scaff_10449827 | Cadenza1551 | 4779 | G | A | hom | hom | ggcaaggtcaagaaacGgtC | ggcaaggtcaagaaacGgtT | aCagaGtgggttagaggcaG |
| IWGSC_CSS_3B_scaff_10550638 | Cadenza1551 | 3250 | C | T | het | het | ctccttcacttgttgcggC | ctccttcacttgttgcggT | gcaacAtTttgatactgcaaagG |
| IWGSC_CSS_3DL_scaff_6945816 | Cadenza1551 | 589 | C | T | hom | hom | agcatctcacctgcaaCaataC | agcatctcacctgcaaCaataT | TgtgcccTctgaAtattttcaTG |
| IWGSC_CSS_3DL_scaff_6954177 | Cadenza1551 | 3508 | C | T | het | het | tgtagcatcacattaactttcctG | tgtagcatcacattaactttcctA | gcttggtataaaccCttacgacA |
| IWGSC_CSS_4AS_scaff_5938272 | Cadenza1551 | 19080 | G | A | hom | hom | agAcCccgAtcgccatgG | agAcCccgAtcgccatgA | GggAgatAcaggtaaaActcTtcG |
| IWGSC_CSS_4AS_scaff_5977594 | Cadenza1551 | 11092 | C | T | het | het | gccttgattcggaacaacaaaC | gccttgattcggaacaacaaaT | gcgtctctcagtcctgcA |
| IWGSC_CSS_5AL_scaff_2671035 | Cadenza1551 | 5859 | C | T | het | het | cggtgatattTttagacttcgacgC | cggtgatattTttagacttcgacgT | ggcagttcagcGacccatT |
| IWGSC_CSS_5BL_scaff_10889480 | Cadenza1551 | 2530 | G | A | hom | hom | gagcttaactcgcagatggaG | gagcttaactcgcagatggaA | tccatgCAacGccttggT |
| IWGSC_CSS_3B_scaff_10528396 | Cadenza2088 | 8059 | G | A | hom | — | cttttccgtccgtaagcaataG | cttttccgtccgtaagcaataA | gtgcactgttcaggcctgA |
| IWGSC_CSS_3B_scaff_10637573 | Cadenza2088 | 16815 | G | A | het | het | agcaagcttaccGgtctgC | agcaagcttaccGgtctgT | cgagcAactacgagcagctT |
| IWGSC_CSS_4AL_scaff_7086469 | Cadenza2088 | 6697 | G | A | het | het | gccgtctacttcaacgcG | gccgtctacttcaacgcA | ccaGaggcttgtTGcattttT |
| IWGSC_CSS_4AL_scaff_7126302 | Cadenza2088 | 3627 | G | A | hom | hom | gttcaaaaacaagtggctAatttgC | gttcaaaaacaagtggctAatttgT | cacaaggatatgaagcTcttctagA |
| IWGSC_CSS_4BL_scaff_7041808 | Cadenza2088 | 10234 | G | A | hom | hom | tcaatggatgagggtgcttC | tcaatggatgagggtgcttT | ccatagcagcatcagccacA |
| IWGSC_CSS_5AL_scaff_2794167 | Cadenza2088 | 13162 | G | A | het | — | agtattcaggacaagcatCttCaG | agtattcaggacaagcatCttCaA | caatgaaacctctcgaagaaGaG |
| IWGSC_CSS_5BL_scaff_10889232 | Cadenza2088 | 3885 | G | A | het | het | cTcaaccacaatgggcaAatC | cTcaaccacaatgggcaAatT | tccttcatcaatcatcaattgttgG |
| IWGSC_CSS_5BS_scaff_2267405 | Cadenza2088 | 11113 | C | T | hom | hom | ctttgatgatcctaggcctctTG | ctttgatgatcctaggcctctTA | tgatttggtCtggttAgagtttGA |
| IWGSC_CSS_3B_scaff_10475354 | Cadenza1409 | 2203 | G | A | hom | hom | agCgaacaagagGtcaaacG | agCgaacaagagGtcaaacA | ctgaaacacaCtagaCAattAccG |
| IWGSC_CSS_3B_scaff_10674115 | Cadenza1409 | 4555 | C | T | het | het | gcttcagtgcatgccttcaG | gcttcagtgcatgccttcaA | cttcacacccGagataatGtattG |
| IWGSC_CSS_4AL_scaff_7153568 | Cadenza1409 | 13073 | C | T | hom | hom | tccgaccgAtcaaccttgG | tccgaccgAtcaaccttgA | gaccggaactcctcggcC |
| IWGSC_CSS_4DL_scaff_14314966 | Cadenza1409 | 2010 | G | A | het | hom | gtaggtcccctcctCAggG | gtaggtcccctcctCAggA | cggcgTcacaAgttgCcT |
| IWGSC_CSS_4DS_scaff_2324074 | Cadenza1409 | 7606 | G | A | het | het | tGcatgaaaatgtgtGcaGaG | tGcatgaaaatgtgtGcaGaA | gggtaAgttcAaaactGaagtgaaG |
| IWGSC_CSS_5AS_scaff_1517889 | Cadenza1409 | 3561 | G | A | het | het | tctcgacatcttcccgtgtaC | tctcgacatcttcccgtgtaT | gtgcctggaacattgcttatttA |
| IWGSC_CSS_5AS_scaff_1523866 | Cadenza1409 | 8054 | G | A | hom | — | ggtgatctaccgccaGgaC | ggtgatctaccgccaGgaT | tcctgcagCcTctcctcA |
| IWGSC_CSS_5BL_scaff_10917655 | Cadenza1409 | 19073 | G | A | hom | hom | caaatgacatgcaaaagaagttgC | caaatgacatgcaaaagaagttgT | cgcttcatcactacaAaatatgtcT |
| IWGSC_CSS_1AL_scaff_3886649 | Cadenza1599 | 5204 | C | T | het | het | tgatgccaaccacaatGcC | tgatgccaaccacaatGcT | ggactgactgctgaccatatttaG |
| IWGSC_CSS_1BL_scaff_3810267 | Cadenza1599 | 6634 | C | T | hom | hom | ccCaggaaatgagcacctC | ccCaggaaatgagcacctT | cgcaggcgaagatgtgaTtG |
| IWGSC_CSS_1DL_scaff_2291677 | Cadenza1599 | 12856 | C | T | hom | hom | GgtagacaagtcgccgaG | GgtagacaagtcgccgaA | cctcctccttcaacGCcG |
| IWGSC_CSS_2AL_scaff_6354492 | Cadenza1599 | 7566 | G | A | het | het | gGagaatgcaCAgtAacTtctgG | gGagaatgcaCAgtAacTtctgA | ttccgaagaaccacaTccTG |
| IWGSC_CSS_2AS_scaff_5282937 | Cadenza1599 | 9736 | G | A | het | het | gctgtagattttatagctgctatgC | gctgtagattttatagctgctatgT | cacCagaattgttCactgatttTC |
| IWGSC_CSS_2BL_scaff_7952427 | Cadenza1599 | 19249 | G | A | hom | hom | cgTccctCcctagcacgaC | cgTccctCcctagcacgaT | aTcactccattagcgcgAG |
| IWGSC_CSS_2DL_scaff_9897981 | Cadenza1599 | 5627 | C | T | het | het | cttggtgctTgattgcttactC | cttggtgctTgattgcttactT | gTttgctCtctctgatctTtgtG |
| IWGSC_CSS_3AL_scaff_4446105 | Cadenza1599 | 1765 | G | A | hom | — | aaatgctttcctaCcgctagtG | aaatgctttcctaCcgctagtA | ttctAgaggcaatagctTatatgcT |

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