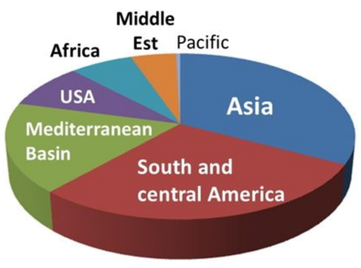
Citrus genomic, genetics and breeding for sustainable citrus industry in Mediterranean and Tropical areas

cirad LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT — agap APMV — INRA SCIENCE & IMPACT

▪ Innovative cultivars and rootstock are key components to promote sustainable citrus industry



The citrus industry is threatened by increasing biotic and abiotic constraints that are and is particularly affected by climate change.

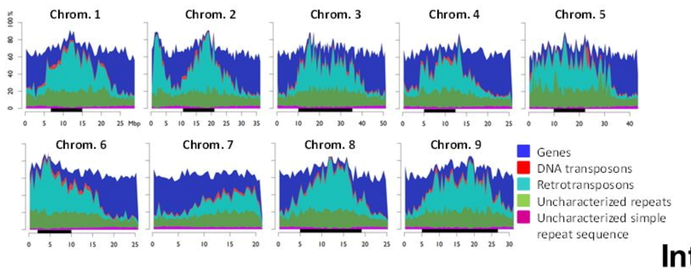
- Citrus are cultivated worldwilde between 40° north and south latitude
- First world fruit crop production (125MT)

1: Phytophtora; 2: Cercosporiosis; 3: citrus tristeza virus; 4: Diaprepes; 5: Huanglongbing 6: Iron chlorosis; 7: chloride leaf burning

▪ Implementation of a high quality reference genome sequence and genetic maps

Haploid Clementine sequence
International Citrus Genome Consortium

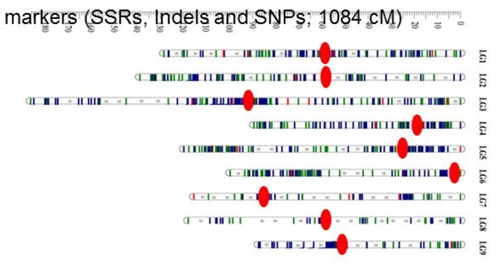
Sanger 6x + Illumina 30x
Pseudomolecules assembly
286 Mb for the 9 main scaffolds
gene annotation: 24533 genes
(http://www.phytozome.net/cgi-bin/gbrowse/clementine/)



Wu et al. 2014. Nature Biotechnology, 32, 656–662.

Clementine genetic map and centromere mapping from half tetrad analysis
ICGC and AGAP/IVIA collaboration

961 markers (SSRs, Indels and SNPs; 1084 cM)

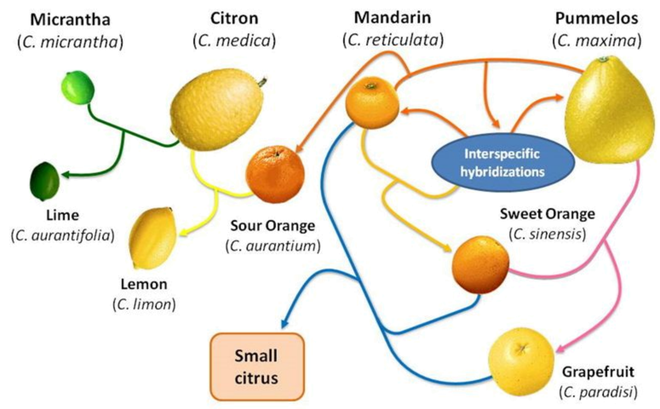


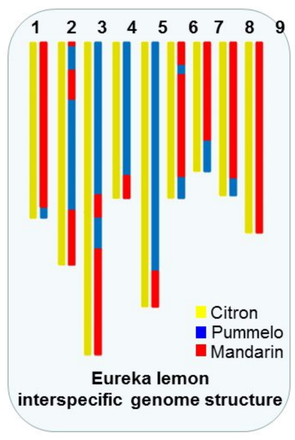
Ollitrault et al. 2012. BMC Genomics, 13.593.
Aleza et al. 2015. BMC Plant Biology. 15 (80)

Inter-specific comparative mapping

Ollitrault et al. 2012. BMC Genomics, 13.593.
Ollitrault et al. 201. 5Acta Hort. (ISHS) 1065:561-573

▪ Deciphering the origin and interspecific mosaic genomes of modern citrus varieties





Froelicher et al. 2011. Tree Genetics and Genomes, 7 (1): 49-61.
Ollitrault et al. 2012. BMC Genomics, 13.13
Garcia Lor et al.2013. Annals of Botany. 111 (1): 1-19
Curk.et al. 2015. Plos 10 (5) : e0125628
Ollitrault et al., 2015. Acta Hort. (ISHS) 1065:457-466
Curk et al., 2016. Annals of Botany. 117(4):565-83. DOI: 10.1093/aob/mcw005

AGAP/IVIA/CITRUSEQ collaboration

Curk et al. 2014. BMC Genetics. 15:152
Curk F. 2014. PHD. Ecole Doctoral SIBAGHE, Un. Mtp 2
Wu et al. 2014. Nature Biotechnology, 32, 656–662

▪ Analysis of meiotic behaviors, sexual recombination, ploidy effect and phenotypic traits inheritance in diploids and polyploids

Mechanisms of sexual polyploidization and genetic structure of polyploid progenies

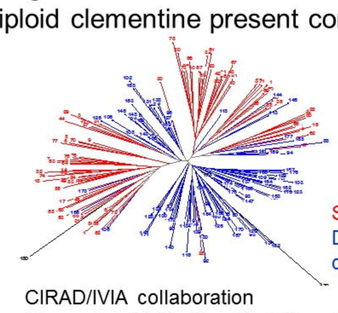
Second Division Restitution (SDR) is the predominant mechanism of sexual polyploidization in citrus

CIRAD/IVIA collaboration
Cuenca et al. 2011. Heredity. 107, 462–470.
Cuenca et al. 2015 Scientific reports. 5 (9897) : 11 p.

Intermediate inheritance with respectively preferential tetrasomic and disomic tendencies are found in interspecific and intergeneric tetraploid citrus

Kamiri et al. 2011. Plant Cell Rep 30:1415-1425
Kamiri et al. 2012. ISC congress. Valencia, Spain

2n gametes from SDR and diploid gametes from doubled diploid clementine present complementary polymorphisms

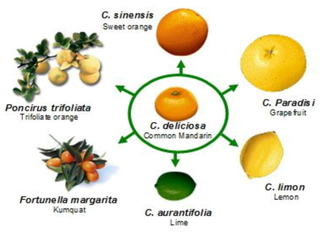


SDR 2n gametes
Diploid gamete from tetraploid clementine

CIRAD/IVIA collaboration
Aleza el al. 2016. Plant Cell Reports. DOI: 10.1007/s00299-016-1972-4

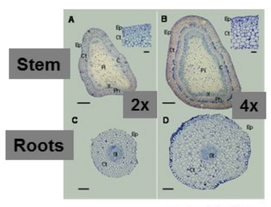
Impact of polyploidy and interspecificity in transcriptome, proteome and phenome (quality an adaptation)

Dominance of *C. deliciosa* in somatic allotetraploid hybrids

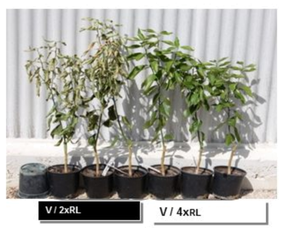


- Transcriptome level
Bassene et al. 2010. Heredity, 105 (3): 299-308
- Proteome level
Gancel et al. 2006. J. Agric. Food Chem., 54 , 6212 - 6218
- Aromatic counpounds level
Gancel et al. 2003. J. Agric. Food Chem., 51, 6006-6013

Polyploidy modifies anatomy and physiology; tetraploid rootstocks confer an enhanced adaptation to abiotic stresses



Allario et al., 2011

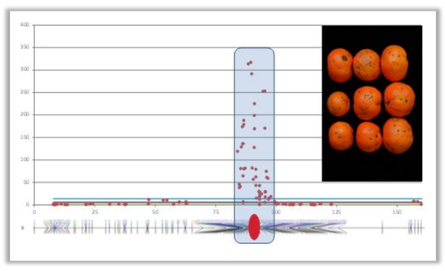


Better water deficit tolerance of sweet orange grafted onto tetraploid rootstocks (right) than onto diploid ones (left)

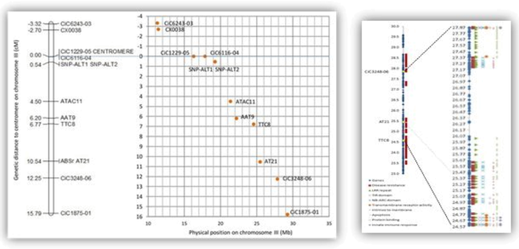
Saleh et al. 2008. Comptes Rendus Biologies, 331 (9): 703-710.
Allario et al. 2011.. Journal of Experimental Botany, 62 (8): 2507-2519
Allario et al. 2013 . Plant, Cell & Environment, 36 (4): 856-868.

Genetic determinism and search of genes implied in useful phenotypic diversity

Resistance to *Alternaria alternata* in mandarins is a recessive trait controlled by a single region of chromosome III that include a cluster of resistance genes



BSA in triploid progenies reveals a single region for *A. alternata* resistance close to Chromosome III centromere



Using genetic mapping a 5 cM flanking area was located where a cluster of 33 resistance genes is identified by gene ontology analysis

IVIA/CIRAD collaboration
Cuenca et al. 2013. PLoS One, 8 (10), e76755.

▪ Optimized breeding strategies and methods

- Ploidy manipulation
- Somatic hybridization for additions of dominant traits
- Seedless triploid breeding
- Reconstruction of the genomes of the main modern species from ancestral taxa germplasm
- Marker assisted selection

High quality seedless triploid cultivars

Tetraploid rootstock adapted to biotic and abiotic stresses

Ollitrault et al. 2007. In Citrus Genetics, Breeding and Biotechnology. I. Khan Edit. CABI publishing. 235-260.
Ollitrault et al. 2008. Plant breeding review. 30: 323-352.
Dambier et al. 2011. Plant Cell Reports, 30 (5): 883-900.
Ollitrault and Navarro. 2012. Citrus. In: Fruit breeding. Badenes Edit New-York, USA: Springer. 623-662
Dambier et al. 2015. Acta Hort. (ISHS) 1065:501-510

Contact : Patrick Ollitrault - Equipe APMV – UMR AGAP - CIRAD - Station de Roujol - 97170 Petit-Bourg, Guadeloupe