Saving Fruit Quality for Tomorrow

www.tomgem.e

TomGEM

Newsletter

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Editorial

Dear Supporters and Followers of the TomGEM project,

After more than four years, the TomGEM project has terminated. This first and, at the same time, final newsletter of our project will give you an overview of what we have achieved within the project – from scientific results to the international conferences we have attended over the years and the papers that were published. Some of our research efforts were even honoured with awards. Our partner Alma Seges received the Agriculture and Innovation Award fostered by Legambiente, an important and popular Italian authority for environmental protection, while our tomato variety “Aleno sartse” (Ruby Heart) won the innovation price at the XXVII International Agricultural Exhibition in 2018.

I hope you will find these insights generated by the TomGEM project and the tireless work of all project members as stimulating as we did and that you will draw inspiration from TomGEM for your own research. After all, this was one of the major goals of the TomGEM project: to kickstart further research into how to advance plant breeding that will increase food quality and productivity in the face of global warming, while also maintaining high crop yield in the face of world demographic growth.

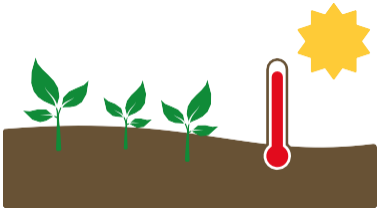
You can keep following our research journey on our project website (www.tomgem.eu) as well as on our Social Media channels.

Thank you for your sustained support and encouragement.

Prof. Mondher Bouzayen - TomGEM Coordinator

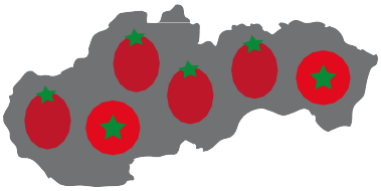
2. Our Research Vision

TomGEM - A Horizon 2020 research project designed to develop heat-tolerant tomato varieties and management practices in the face of climate change.



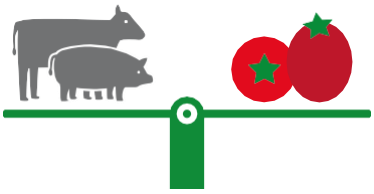
29+ °C

Climate change threatens global crop production



4.8M ha

Area of tomato production is the same size as Slovakia



162 MT

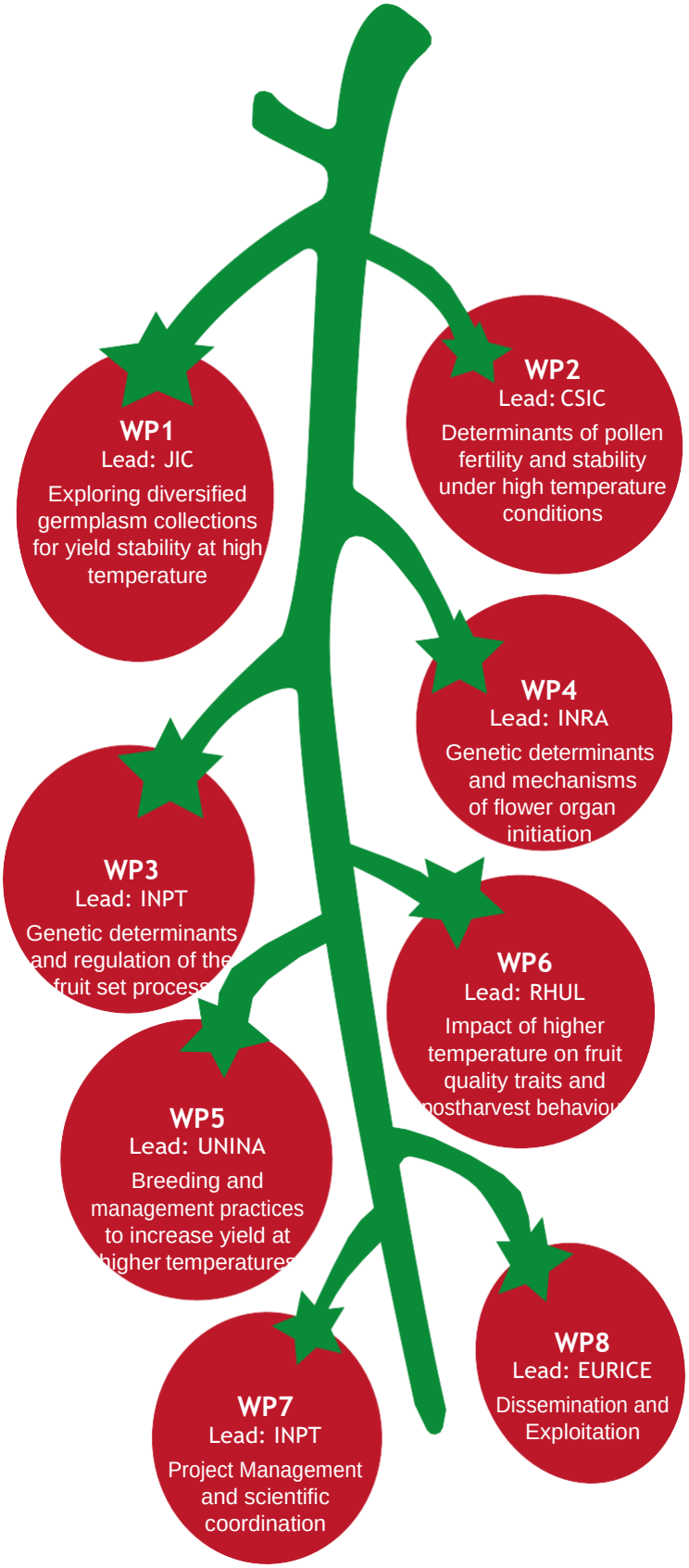
Weight of annual tomato production is roughly equal to that of cattle and swine produce combined

18-29 °C

Ideal growth temperatures for tomatoes

3. Our Partner Network

TomGEM is a global research alliance bringing together 18 partner institutions from three continents comprised of expert academic researchers, private actors and tomato producers.



4. Our Outputs and Results

> "The main outcomes of the project are the superior genotypes in terms of tolerance to heat stress and yield stability, but also new genes and new markers that will help the tomato breeders to create new tomato varieties and cultivars that are better suited to high temperature conditions."
>
> Prof. Mondher Bouzayen, TomGEM coordinator

a) More than 500 Seed Packets: Top Heat Tolerant Genotypes Distributed

TomGEM field trial at the Maritsa Vegetable Crops Research Institute (MVCRI) in Bulgaria

The TomGEM project produced, characterized and disseminated tomato germplasm with good tolerance to elevated temperatures. This part of the project involved 12 collaborating research groups from Europe, South America and Asia. Following the screening of an initial pool of nearly 700 genotypes and three years of field and glasshouse trials in three different countries (Bulgaria, Italy and Spain), a portfolio of 18 genotypes with different growth types (determinate / indeterminate) and fruit types (cherry / domesticated not cherry / wild-breeding material) have been identified for high performance under high temperature. Among these, 7 tomato lines and hybrids exhibited consensus top performance in all countries during the last two years of the project. A centralised database has been set up allowing to relate plant performance to temperature. In addition to heat tolerance, quality parameters, photographic records, molecular markers and metabolite data can also be accessed for the top TomGEM genotypes.

During the course of the TomGEM project, hundreds of seed packets were exchanged between partners to ensure the smooth progress of all activities and enabled the selection of the top heat tolerant genotypes. These were subsequently narrowed down to roughly half a dozen of genotypes exhibiting consistently good performance under elevated temperature across multiple locations, growers and years.

Seeds from top heat tolerant tomato genotypes with different growths and fruit types, as well as a range of genotypes to be used in crosses, were made available and used by project partners. During the first half of the TomGEM project, seed and plant material distribution took place mainly with partners to enable…

Tomato flower and fruit morphology

- …the production of different hybrid combinations between heat sensitive and heat tolerant genotypes as well as for the testing of different management practices including reduced irrigation.
- …fruit post-harvest quality studies (shelf life and fungus susceptibility) of the top 30 genotypes as well as metabolomics studies of the field grown plants. For this latter activity, scientist from the UK and Germany visited and collected material from partners in Bulgaria and Italy, respectively. Seeds were also sent to P13-BTG for analysis of health promoting properties.

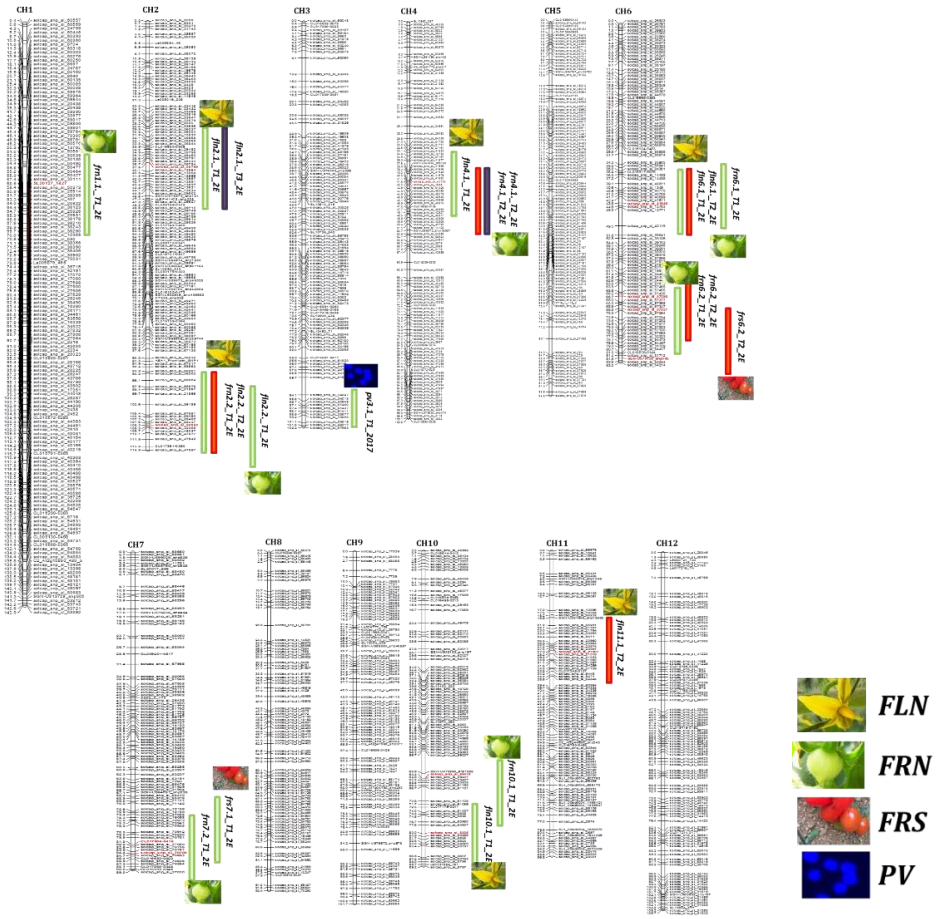
More than 500 seed packets from three large RIL populations from Taiwan were sent to Spain and conversely one RIL from Spain was sent to Taiwan for evaluation and genetic mapping under elevated temperature. Seeds from two RIL populations from Taiwan were also sent to project partner Enza Zaden in Spain. Numerous additional ad-hoc seed exchanges also took place during the TomGEM project.

The genotypes selected, characterised and disseminated by the project have already been involved in further crossing programmes, molecular and physiological analyses. They also have been used to develop additional scientific research projects and have been included in the breeding programmes of companies that are partners of the TomGEM project.

b) 'The Most Powerful Toolkit': Determinants of Pollen Fertility Under High Temperature Conditions Discovered

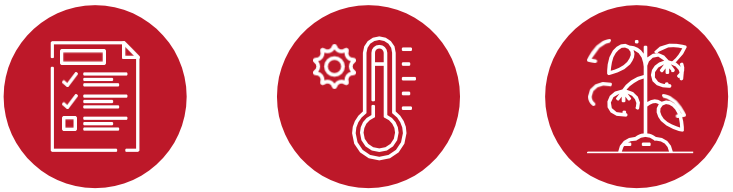
The objective of this part of the project was to find genomic regions and eventually genes that confer the ability to tomato plants to set fruit at high temperature conditions. Three recombinant inbred line (RIL) and one introgression line (IL) populations were evaluated for their capacity of set fruits at high temperature in several replicated assays in a close collaboration between TomGEM's Asian and European research groups. A comprehensive catalogue of Quantitative Trait Loci (QTL) associated with the capacity of set fruit at high temperature was generated. The catalogue includes QTLs with stable effects in several replicated experiments, working on different mapping populations, while others showed specificity for the heat stress level or the type of population. Markers associated to those QTLs have also been identified. Additionally, for one RIL population, the QTL analysis was combined with transcriptional analysis by RNAseq, which allowed defining specific candidate genes involved in pollen viability under high temperature stress.

Remarkably, some of those QTLs are already introduced in a modern tomato cultivar, confirming their interest for applied breeding. The results constitute the most powerful toolkit ever compiled in tomato to develop new heat tolerant tomato varieties. This toolkit could be used to follow single gene (from ILs or candidate genes) or genomic selection (QTL) strategies, as well as to create a platform to identify the genes involved in heat tolerance and to understand the underlying genetic mechanisms.



QTLs detected in the MoneyMaker-x-To -937 (Solanum pimpinellifolium) for reproductive traits number of flowers (FLN), fruit number (FRN), fruit set (FRS) and pollen viability (PV) at high temperature with consistent effects in replicated experiments.

c) TomExpress: A Platform for Storing, Processing and Mining Transcriptomic Data



37 PROJECTS 395 CONDITIONS 1,200 SAMPLES

TomExpress is a major achievement that is becoming widely used by the scientific community worldwide. It allows the search for candidate genes putatively involved in a biological process of interest by in silico search without the need for a setup of wet lab experiments. In this regard, it saves both time and money for all researchers

d) Flower-to-fruit Transition: Genome-wide Profiling of DNA Methylation and Chromatin Status

The process of fruit formation is made up of a series of developmental shifts that include the fruit set and ripening transitions which are essential in determining yield and quality attributes. The epigenetic and transcriptomic reprogramming underlying the flower-to-fruit transition in the tomato was explored using combined genome-wide transcriptomic profiling, ChIP-sequencing and DNA bisulfite sequencing. The data reveals that most of the global changes in gene expression were associated with changes in histone marking, whereas changes in DNA methylation concerned a minor proportion of differentially expressed genes. The expression level of genes essential for the fruit set process strongly correlated with their H3K9ac or H3K4me3 marking status, but not with changes in Cytosine methylation.

Remarkably, this contrasts with prior reports on the prominent role of DNA methylation in reprogramming key genes associated with the transition to ripening, indicating that the transcriptomic programs underlying the two main developmental transitions in fleshy fruit are associated with different modes of epigenetic regulation.

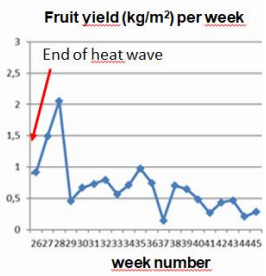
e) 4,000 Tomato Mutants: Heat Tolerance Conferred to other Tomato Cultivars

Recent heat waves during the last summers have affected the production of fruits in tomato plants. The figure below shows some modifications that were observed by the tomato producers and the reduced production of fruits associated. In order to overcome this situation, the scientists of the TomGEM project have explored a large collection of 4,000 tomato mutants and have isolated several mutants exhibiting enhanced tolerance to high ambient temperatures. In addition, researchers have shown that these mutants can confer the tolerance to other tomato cultivars after crossing. The next steps of the research will be focused on the identification of the genes conferring such resistance and the underlying molecular and cellular mechanisms.

4000 Tomato mutant plants cultivated in the TomGEM Partner 9 - INRA for selecting heat wave-tolerant mutants

Producer's tomato truss well-developed in normal conditions. Five fruits for around 800g.

Delayed and abnormal development of tomato truss after a heat wave. Only 4 fruits with desynchronized maturation.



A heat wave affects tomato fruit yield 3 to 4 weeks after its occurrence.

(photos and yield data provided by TomGEM Partner 17-Rougelines)

f) Research on Management Practices: Novel Plant-based Biostimulant Tested

The TomGEM project investigated genotypes, molecular markers and management practices, whose integrated use could improve facing high temperature conditions in tomato, by combining the efforts of eight partners acting in four different countries. Following the screening for yield-related traits of segregating progenies and their genotyping by high-throughput platforms, a group of QTLs and markers was identified that might be useful to aid the selection of genotypes tolerant to high temperatures. The QTLs and markers might serve both the basic and applied future research for the tomato community. Superior F1 hybrids were selected by testing many cross combinations in three countries (Bulgaria, Italy, Spain) under different environmental conditions. The selected hybrids will be valuable genetic materials for breeding companies. Also, among management practices evaluated in the same three countries, the use of a plant-based biostimulant emerged as a potential novel product to be exploited by farmers as a factor contributing to increase the tolerance to high temperatures.

g) Exploitable Cross-Combinations: Production of Superior F1 Hybrids

In Bulgaria, Italy and Spain a lot of hybrid combinations were obtained, grown and evaluated.

One of the important outputs of the TomGEM project is the development of new tomato hybrids with good yield performances under high temperature and with good fruit quality traits. A group of best performing F1 hybrids was identified in each country and under different growing conditions: these are BG Solaris x BG Marti and BG 24/a x BG 1923 in Bulgaria, E103 x E48 and E103 x PDLUC in Italy, E7 x E36 and E7 x E48 in Spain.

These cross-combinations will be exploitable in the future by seed companies, which could evaluate them in additional environmental conditions and for other interesting traits, such as tolerance to pathogens, viruses or insects, and other quality and nutritional traits.

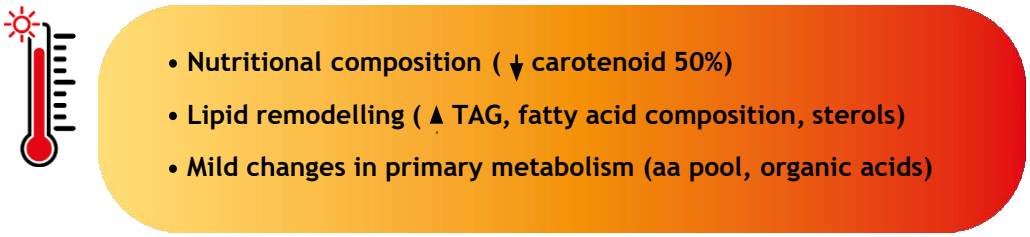
h) Sustainable Cultivation: Best Management Practices Tested under Heat

The use of a 50 % reduced regime, even though it decreased yield in most cases, contemporarily increased the values of some fruit quality traits. In addition, a group of genotypes confirmed the better performances for two consecutive years, such as the determinate BG 11/15, BG Marti and E42, and the indeterminate BG Alia, BG1923/15 and Monterrey. In the immediate future, a reduced water regime of approximately 30 % could be also tested, in order to verify if this sustainable management practice could be successfully used on the best selected genotypes, inducing a commercially acceptable reduction of yield.

As for the management practices based on the use of growing-promoting substances or of foliar protection by whitening or anti-transpirants, the best one was the biostimulant, which evidenced for two consecutive years to produce good performances on some genotypes in respect to their controls.

Finally, it can be concluded that all genotypes showed a better general performance under biocide plant soil management compared with the control. There was a positive influence of biocide plants over production and tomato plant development. Furthermore, no differences among the use of different biofilms were observed for plant development. A positive impact on production was observed under white biofilm, while the highest average weight was achieved in plants grown under transparent biofilm.

i) Evaluating Nutritional Attributes: Marked Changes in Response to Heat Stress



Scheme 1: Metabolic changes occurring upon application of heat stress to ripening tomato fruit.

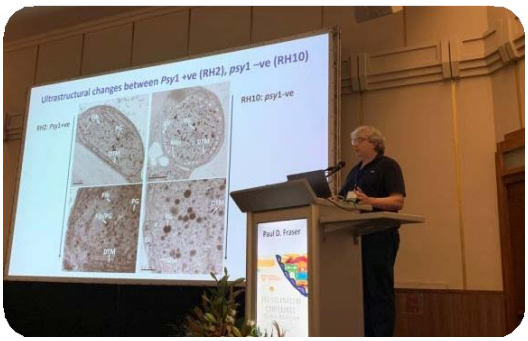
Heat stress in crops like tomato has traditionally been associated with reduced yield, while the effects on fruit quality were largely unknown at the start of the TomGEM project. Results from the project have now indicated that heat stress can have an effect on the metabolism of ripening fruit. The fundamental changes occurring across the transcriptome and metabolome of ripening fruit in response to heat stress have recently been accepted for publication in the journal "Plant Cell Environment". This work performed by Almeida et al. is titled "A transcriptomic, metabolomic and cellular approach to the physiological adaptation of tomato fruit to high temperature". In this study, the changes occurring in wild type tomato fruits after exposure to transient heat stress have been elucidated at the transcriptome, cellular and metabolite level. The data revealed that fruit quality, particularly nutritional attributes, changed in response to heat stress. The formation of carotenoids, which are pigments responsible for fruit colour and can confer essential nutritional attributes to humans and animals, was particularly affected, predominantly at the stage of phytoene formation. The metabolomic analysis showed (scheme 1) limited effects on primary / intermediary metabolism but lipid

remodelling (changes in triacylglycerols, and the degree of membrane lipid unsaturation), was evident. Collectively, this data has provided valuable insights into potential genes and mechanisms that could be exploited to generate future heat tolerant tomato varieties with favourable quality traits.

5. TomGEM around the World – Selected Conferences

Over the entire project span, TomGEM consortium members and partners attended conferences all over the world. One particular highlight was the XVI Solanaceae Conference (SOL 2019) in Jerusalem, Israel, from 15–19 September, 2019. SOL 2019 brought together leading scientists, students and plant breeders in a friendly atmosphere set for sharing knowledge, expertise and a vision of international collaboration.

TomGEM coordinator Mondher Bouzayen presenting at the SOL2019 conference.



Paul Fraser on ultrastructural changes

The meeting explored advances in the breeding and physiology of Solanaceae crops and also looked toward the future: participants aimed to jointly develop a road map for the next International SOL project (SOLII).

Among the leading SOL experts, the TomGEM consortium was represented widely and the project's results thus far were shown to the audience:

- TomGEM coordinator Mondher Bouzayen (Institut National Polytechnique de Toulouse) described the transcriptional and epigenetic regulation of fruit ripening and the effect of environmental perturbation,
- Saleh Alseekh and Alisdair Fernie of the Max-Planck-Institute of Molecular Plant Physiology in Potsdam (Germany) presented the topic "Functional metabolomics in tomato and other species",
- Cathie Martin of the John Innes Centre gave a talk on "Improving our health and well-being with high quality Solanaceous Foods",
- Paul Fraser from the Royal Holloway and Bedford New College spoke about "Carotenoid biosynthesis in Capsicum Annuum; were we right to use tomato as the translatable model" and
- Antonio Granell (Agencia Estatal Consejo Superior de Investigaciones Científicas) presented the topic "Breadth, depth, and elasticity of the tomato health and flavour composition space".

6. TomGem in Writing – Selected Publications

During the TomGEM project, a multitude of papers were published by partners and consortium members on their respective research methods and findings. A selection of publications from the last two years of the project can be found here. For an exhaustive list of all publications arising from the TomGEM project, please visit our website.

2020

- Juliana Almeida and Paul D. Fraser:
  A transcriptomic, metabolomic and cellular approach to the physiological adaptation of tomato fruit to high temperature.
  Plant Cell Environment July 2020, e-pub ahead of print, 10.1111/pce.13854
  Additional link

- Cappetta E., Andolfo G., Di Matteo A., Barone A., Frusciante L., Ercolano M.R.:
  Accelerating tomato breeding by exploiting genomi selection approaches.
  Plants 9, September 18th 2020, 14, https://doi.org/10.3390/plants9091236
  Additional link

- Thole V, Vain P, Yang RY, Almeida Barros da Silva J, Enfissi EMA, Nogueira M, Price EJ, Alseekh S, Fernie AR, Fraser PD, Hanson P, Martin C:
  Analysis of Tomato Post-Harvest Properties: Fruit Colour, Shelf Life, and Fungal Susceptibility
  Current Protocols in Plant Biology Curr Protoc Plant Biol 5(2):e20108, 1-17, doi: 10.1002/cppb.20108
  Additional link

- Arena C, Conti C, Francesca S, Melchionna G, Hájek J , Barták M , Barone A, Rigano MM:
  Eco-physiological screening of different tomato genotypes in response to high temperatures: a combined field-to-laboratory approach
  Plants 9, April 15th 2020, 16, doi:10.3390/plants9040508
  Additional link

- Gonzalo MJ, Lee YC Chen K, Montoro, T, Gil D, Nájera I, Bauxauli C, Granell A, Monforte A.J :
  Genetic control of reproductive traits in tomato at different temperatures
  Frontiers on Plant Science 11, 326, 10.3389/fpls.2020.00326
  Additional link

- Olivieri F., Calafiore R., Francesca S., Schettini C., Chiaiese P., Rigano M.M, Barone A:
  High-throughput genotyping of resilient tomato landraces to detect candidate genes involved in the response to high temperatures Genes
  Additional link

- Scarano, Olivieri, Gerardi, Liso, Chiesa, Chieppa, Frusciante, Barone, Santino, Rigano:
  Selection of tomato landraces with high fruit yield and nutritional quality under elevated temperatures
  Journal of the Science of Food and Agriculture 100, February 29th 2020, 9, DOI 10.1002/jsfa.10312
  Additional link

- Francesca S., Arena C., Hay Mele B.., Schettini C., Ambrosino P., Barone A., Rigano M.M.:
  The Use of a Plant-Based Biostimulant Improves Plant Performances and Fruit Quality in Tomato Plants Grown at Elevated Temperatures
  Agronomy 10, 363, 10.3390/agronomy1003036
  Additional link

- Antonio Jose Monforte:
  Time to exploit phenotypic plasticity
  Journal of experimental botany 71, doi:10.1093/jxb/eraa268
  Additional link

2019

- Ruggieri V., Calafiore R., Schettini C., Rigano M.M., Olivieri F., Frusciante L., Barone A.:
  Exploiting Genetic and Genomic Resources to Enhance Heat-Tolerance in Tomato
  Agronomy 9(1), 22, doi: 10.3390/agronomy9010022

- Nunes-Nesi, A., Alseekh, S., de Oliveira Silva, F.M. et al.:
  Identification and characterization of metabolite quantitative trait loci in tomato leaves and comparison with those reported for fruits and seeds
  Metabolomics (2019) 15:46 , https://doi.org/10.1007/s11306-019-1503-8

- A. Sacco, A. Raiola, R. Calafiore, A. Barone, M.M. Rigano:
  New insights in the control of antioxidants accumulation in tomato by transcriptomic analyses of genotypes exhibiting contrasting levels of fruit metabolites.
  BMC Genomics (2019), 20:43 20:43, doi: 10.1186/s12864-019-5428-4

- Vera Thole, Jean-Etienne Bassard, Ricardo Ramírez-González, Martin Trick, Bijan Ghasemi Afshar, Dario Breitel, Lionel Hill, Alexandre Foito, Louise Shepherd, Sabine Freitag, Cláudia Nunes dos Santos, Regina Menezes, Pilar Bañados, Michael Naesby, Liangsheng Wang, Artem Sorokin, Olga Tikhonova, Tatiana Shelenga, Derek Stewart, Philippe Vain and Cathie Martin :
  RNA-seq, de novo transcriptome assembly and flavonoid gene analysis in 13 wild and cultivated berry fruit species with high content of phenolics
  BMC Genomics 20:995, 1-23, https://doi.org/10.1186/s12864-019-6183-2

- Christophe Rothan, Isidore Diouf and Mathilde Causse:
  Trait discovery and editing in tomato
  The Plant Journal (2019) 97, 73–90, doi: 10.1111/tpj.14152

- M. Carmen González-Mas, José L. Rambla, M. Pilar López-Gresa, M. Amparo Blázquez and Antonio Granell:
  Volatile Compounds in Citrus Essential Oils: A Comprehensive Review
  Front. Plant Sci. (2019) 10:12. doi: 10.3389/fpls.2019.00012

7. Lights, Camera, Action – The Interview Series in TomGEM

Over the course of the project, two video interview series were specifically produced to highlight TomGEM's research approach, overall objectives and, ultimately, results.

The first interview series, produced shortly after the kick-off meeting at the beginning of the project, outlines the general aims and impact of the TomGEM project and gives insights into the approach and targets of the multinational consortium. Three years into the project, the second interview series traces the project's progress from different partners' perspectives.

Samples from our first interview series

https://www.youtube.com/watch?v=Xd0JBvIWtsc&list=PLNhMWKRzktjKsPRMGlE-6m59AbzHsHXni&index=9

https://www.youtube.com/watch?v=hj_inczGHZA&list=PLNhMWKRzktjKsPRMGlE-6m59AbzHsHXni&index=8

Behind the scenes of the second interview series

Dr David Gil (from the breeding company within the consortium, ENZA ZADEN) in action during TomGEM's 3rd annual project meeting in Old Windsor, UK, during which the second interview series was produced.

Dr Antonietta Aliberti from the John Innes Centre explaining how elated she was to have found a particular genotype with a high vitamin C content as well as a good shelf life within the TomGEM project

Find more videos from our TomGEM Interview Series on Youtube

TomGEM Partners

Norfolk Plant Sciences Ltd.