DEVELOPMENT OF YELLOW LEAF CURL DISEASE RESISTANT AND HIGH YIELDING TOMATO (*Solanum lycopersicum* L.) HYBRID THROUGH MARKER-ASSISTED SELECTION AND DIALLEL CROSSES

By

HITIHAMY MUDIYANSELAGE VISHAKA THARANGANI WELEGAMA

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

August 2022

IPTPH 2022 11

DEDICATION

I dedicate this thesis to all my beloved family members for their continuous support, sacrifices and patience**.**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of
the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF YELLOW LEAF CURL DISEASE RESISTANT AND HIGH YIELDING TOMATO (*Solanum lycopersicum* L.) HYBRID THROUGH MARKER-ASSISTED SELECTION AND DIALLEL CROSSES

By

HITIHAMY MUDIYANSELAGE VISHAKA THARANGANI WELEGAMA

August 2022

Supervisor : Professor Mohd Rafii Yusop, PhD
Institute : Tropical Agriculture and Food Security

Tomato Yellow Leaf Curl Disease (TYLCD) is a highly destructive disease in the most tomato cultivated areas globally, while becoming uncontrollable in tropical and subtropical regions. TYLCD is triggered by several Begomovirus species and it is transmitted by whitefly (*Bemisia tabaci*). TYLCD is controlled mainly by vector targeted pesticides, which leads to evolve pesticide resistant vector biotypes. Thus, resistant tomato varieties are the most sustainable way to control TYLCD. This study aimed to develop tomato F_1 hybrids with TYLCD resistance/ tolerance and higher yield. TYLCD causative Begomovirus in the study was confirmed as Pepper yellow leaf curl virus which has close homology with tomato yellow leaf curl virus. Forty tomato accessions were evaluated and characterized based on 15 traits of yield and yield components, morphological, physiochemical and TYLCD symptom severity in a randomized complete block design (RCBD) with 3 replications at Field 15, Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia and the best 9 accessions were selected as parental lines to produce F_1 crosses. The selected 9 accessions out of initial 40 were used to produce F_1 hybrids and, succeeded 18 F_1 hybrids and their 9 parental lines were screened to determine the presence of TYLCD resistant/tolerance namely, *Ty 1, Ty 2, Ty 3, Ty 4, ty 5* and *Ty 6* genes using gene specific primers. The results revealed the F_1 hybrids, T4 × T6, T6 × T4 and T7 × T15 possess homozygous resistance (RR) for *Ty 1*, *Ty* 2 and *Ty* 3 alleles with most promising tolerance to TYLCD, while T4 ×T8, T4 ×T9, T7 ×T5, T8 × T4, T8 × T6, T8 × T9, T9 × T4 and T9 × T6 hybrids possess homozygous resistance only for *Ty* 3 and *Ty* 2 genes, which is expected to have substantial potential for TYLCD tolerance. The 18 F_1 hybrids with their 9 parental lines were evaluated in a glass house over 2 planting cycles in randomized complete block design (RCBD) with 3 replications. Highly significant differences were observed among all genotypes at $p \leq 0.01$ for all the traits. Out of the 18 F_1 hybrids and their 9 parental lines, only 10 F_1 hybrids and their 5 parental lines were applicable in to half diallel analysis. Estimated general combining ability (GCA) revealed parental lines T4 and T2 had the highest values in yield per plant trait, 276.34

g/plant and 112.11 g/plant respectively, whereas T8 is the best in terms of disease incidence (GCA: -0.17) and index for disease severity (GCA: -0.11) toward TYLCD resistance. Specific combining ability (SCA) analysis revealed two hybrids, namely T2×T4 (SCA: 838.90 g/plant) and T4×T8 (SCA: 424.83 g/plant) as the best performers in terms of yield traits, while hybrid T6×T9 was identified as the best in terms of disease incidence (SCA: -0.08) and index for disease severity (SCA: -0.008) on TYLCD resistance. Hybrid T4 ×T8 has superior yield (2.06 kg/plant) and TYLCD resistance is highly recommended for further large-scale evaluation before release as a new developed variety for commercial cultivation in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN HIBRID TOMATO (*Solanum lycopersicum* L.) RINTANG PENYAKIT KERINTING DAUN KUNING DAN BERHASIL TINGGI MELALUI PEMILIHAN BANTUAN PENANDA DAN KACUKAN DIALEL

Oleh

HITIHAMY MUDIYANSELAGE VISHAKA THARANGANI WELEGAMA

Ogos 2022

Pengerusi : Profesor Mohd Rafii Yusop, PhD
Institut : Pertanian Tropika dan Sekuriti Makanan

Penyakit keriting daun kuning tomato (TYLCD) adalah penyakit yang sangat memusnahkan di kawasan penanaman utama tomato di seluruh dunia, serta menjadi tidak terkawal di kawasan tropika dan subtropika. TYLCD dicetuskan oleh beberapa spesies Begomovirus dan ia disebarkan oleh lalat putih (*Bemisia tabaci*). Pengawalan TYLCD dijalankan terutamanya dengan penggunaan racun perosak dengan menyasarkan vektor, tetapi telah mengakibatkan evolusi biotip vektor menjadi rintang kepada racun perosak. Oleh itu, varieti tomato yang rintang adalah cara yang paling mampan untuk mengawal TYLCD. Objektif kajian ini adalah untuk membangunkan hibrid tomato F_1 berhasil tinggi dan rintang/toleran TYLCD. Begomovirus penyebab TYLCD dalam kajian itu disahkan sebagai virus keriting daun kuning chili yang mempunyai homologi rapat dengan virus keriting daun kuning tomato. Empat puluh aksesi tomato telah nilai dan dibuat pencirian berdasarkan 15 ciri hasil dan komponen hasil, morfologi, fisiokimia dan keterukan simptom TYLCD menggunakan rekabentuk blok penuh rawak (RCBD) dengan 3 replikasi di Ladang 15, Institut Pertanian Tropika dan Sekuriti Makanan, Universiti Putra Malaysia, dan 9 aksesi terbaik telah dipilih sebagai titisan induk dalam kacukan dialel untuk menhasilkan kacukan F_1. Daripada 40 aksesi, sembilan aksesi terpilih telah digunakan untuk menghasilkan kacukan F_1 dan, 18 hibrid F_1 telah berjaya dihasilkan berserta 9 titisan induknya disaring untuk menentukan kehadiran gen kerintangan/toleransi TYLCD iaitu gen *Ty 1*, *Ty 2*, *Ty 3*, *Ty 4*, *ty 5* dan *Ty 6* menggunakan penanda gen spesifik. Keputusan menunjukkan, hibrid $F_{1,}$ T4 × T6, T6 × T4 dan T7 × T15 mempunyai kerintangan homozigot (RR) untuk alel *Ty 1*, *Ty 2* dan *Ty 3* dengan tahap toleran yang terbaik terhadap TYLCD, manakala hibrid T4 ×T8, T4 ×T9, T7 ×T5 , T8 × T4, T8 × T6, T8 × T9, T9 × T4 dan T9 × T6 mempunyai kerintangan homozigot hanya untuk gen *Ty 3* dan *Ty 2* yang dijangka mempunyai potensi yang besar untuk toleran terhadap TYLCD. Lapan belas hibrid F_1 dengan 9 titisan induknya telah dinilai dalam rumah kaca yang melibatkan 2 pusingan penanaman dalam rekabentuk blok lengkap rawak (RCBD) dengan 3 replikasi. Terdapat perbezaan yang sangat signifikan diperhatikan di antara semua genotip pada $p \leq 0.01$ untuk semua ciri. Daripada

18 kacukan F_1 dan 9 titisan induknya, hanya 10 kacukan F_1 dan 5 titisan induknya digunakan dalam analisis separa dialel. Anggaran keupayaan bergabung am (GCA) menunjukkan titisan induk T4 dan T2 mempunyai nilai tertinggi untuk ciri hasil sepokok, masing-masing 276.34 g/pokok dan 112.11 g/pokok, manakala T8 adalah yang terbaik dari segi kejadian penyakit (GCA: -0.17) dan indeks untuk keterukan penyakit (GCA: -0.11) terhadap kerintangan TYLCD. Analisis keupayaan bergabung khusus (SCA) mendapati dua hibrid iaitu T2×T4 (SCA: 838.90 g/pokok) dan T4×T8 (SCA: 424.83 g/pokok) sebagai prestasi terbaik dari segi ciri hasil, manakala hibrid T6×T9 dikenal pasti sebagai yang terbaik dari segi insiden penyakit (SCA: -0.08) dan indeks keterukan penyakit (SCA: -0.008) terhadap kerintangan TYLCD. Hibrid T4×T8 mempunyai hasil unggul (2.06 kg/pokok) dan kerintangan TYLCD, sangat disyorkan untuk dijalankan penilaian berskala besar sebelum diistiharkan sebagai satu varieti maju baharu untuk penanaman komersial di Malaysia.

ACKNOWLEDGEMENTS

Firstly, I would like to extend my sincere gratitude to the Sri Lanka Department of Agriculture for selecting me for a scholarship awarded by the Sri Lanka Council of Agricultural Research Policy (SLCARP) to carry out my Ph.D study at Universiti Putra Malaysia. An immense and sincere thanks with heartiest gratitude, extended to the Chairman of the supervisory committee Prof. Dr. Mohd Rafii Yusop for his continuous support, guidance and advice for the successful completion of my research. I would also like to thank the members of the supervisory committee Associate Prof. Dr. Khairulmazmi Ahmad and Dr. Shairul Izan Ramlee for their continuous encouragement. The numerous ways of support given by academic and non-academic officers of Institute of Tropical Agriculture and Food Security (ITAFoS) including post graduate coordinators, lab staff, and field staff are highly acknowledged. I am very much grateful to Dr. Oladosu Yusuff for his guidance and comments throughout my research work and to Ms. Nadzirah Sulaiman for Malay translation of my abstract. Apart from that I wish to thank all the fellow post graduate colleagues of ITAFoS for their support in many ways. My heartiest thanks go to all SLCARP scholars at UPM for their invaluable helping hands extended during the study period in many ways.

Finally, I convey my deepest gratitude from the bottom of my heart to my beloved husband, daughter, son, mother, sister, my in-laws and closest family members for their patience, dedication moral encouragement and for bearing all the difficulties during the COVID 19 pandemic period that kept me apart from thousands of miles away from home. I wish to extend my sincere thanks to everyone that I couldn’t mention here, for helping me every way during my studies.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Rafii bin Yusop, PhD
Professor
Institute of Tropical Agriculture and Food Security
Universiti Putra Malaysia
(Chairman)

Khairulmazmi bin Ahmad, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Shairul Izan binti Ramlee, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 11 January 2024

TABLE OF CONTENTS

Page

ABSTRACT i
ABSTRAK iii
ACKNOWLEDGEMENTS v
APPROVAL vi
DECLARATION viii
LIST OF TABLES xiv
LIST OF FIGURES xvii
LIST OF APPENDICES xx
LIST OF ABBREVIATIONS xxi

CHAPTER

1 INTRODUCTION 1
- 1.1 General Introduction 1
- 1.2 Research Problem 2
- 1.3 Research objectives 3
- 1.4 Expected outcome 3

2 LITERATURE REVIEW 4
- 2.1 Tomato 4
- 2.2 Taxonomy of tomato 5
- 2.3 Botany and floral biology 5
- 2.4 Origin and domestication 6
- 2.5 Breeding goals of tomato over past decades 6
- 2.6 Constraints for tomato cultivation 7
  - 2.6.1 Abiotic stresses 7
  - 2.6.2 Biotic stresses 7
- 2.7 Tomato yellow leaf curl disease (TYLCD) 8
  - 2.7.1 Whitefly (TYLCD vector) 10
  - 2.7.2 TYLCD Control measures at present 12
  - 2.7.3 Tomato Yellow Leaf Curl Virus 12
  - 2.7.4 Evolution and spreading of TYLCD over the world 13
  - 2.7.5 Construction of phylogenetic tree to understand the evolutionary relationship among TYLCD causative Begomoviruses 14
  - 2.7.6 Field screening of TYLCD resistant/ tolerant tomato lines 15
  - 2.7.7 Development of TYLCD resistance in tomato cultivars 15
- 2.8 Marker-assisted selection (MAS) as a tool of tomato breeding 15
  - 2.8.1 Molecular marker assisted selection to screen TYLCD resistant/tolerant cultivars 16

2.8.2 Begomovirus causative TYLCD resistant *Ty* genes in tomato genome 17
2.9 Tomato hybrid development 21
2.9.1 Diallel analysis 21

3 **MOLECULAR IDENTIFICATION OF TOMATO YELLOW LEAF CURL DISEASE (TYLCD) CAUSATIVE BEGOMOVIRUS SPECIES** 24
3.1 Introduction 24
3.2 Materials and Methods 25
3.2.1 DNA extraction from TYLCD typical symptomatic tomato plants 25
3.2.2 Quantification of DNA using Nano drop spectrophotometer 26
3.2.3 Dilution of the quantified DNA 26
3.2.4 Gel and 1X TBE buffer preparation 27
3.2.5 Quality testing of diluted DNA for checking the suitability for PCR 27
3.2.6 Primer dilution and polymerase chain reaction (PCR) 27
3.2.7 Polymerase chain reaction (PCR) 28
3.2.8 Gel electrophoresis and gel viewing 29
3.2.9 Sequencing of the PCR product 29
3.2.10 Analyzing sequencing results, BLAST in NCBI and construction of molecular phylogenetic tree 29
3.3 Results and discussion 30
3.4 Conclusion 38

4 **GENETIC DIVERSITY ANALYSIS AMONG FORTY TOMATO LINES AND SCREENING BEST TOMATO LINES FOR HIGH YIELDING AND TOMATO YELLOW LEAF CURL DISEASE (TYLCD) TOLERANCE** 39
4.1 Introduction 39
4.2 Materials and methods 40
4.2.1 Experimental location 40
4.2.2 Seed treatment and nursery establishment 40
4.2.3 Experimental design 41
4.2.4 Tomoto seedling and its plant maintenance 41
4.2.5 Fertigation 41
4.2.6 Pest and disease management 42
4.2.7 Data collection 42
4.2.7.1 Data on growth, yield, yield related and physiochemical parameters 42
4.2.7.2 Screening of best tomato lines with resistant/tolerant trait to TYLCD using Disease incidence (DI %) and Index for disease severity (IDS) 44
4.2.7.3 Variance components and heritability analysis 47
4.2.8 Data analysis 49

4.3 Results and Discussion 50
4.3.1 Evaluation of growth, yield, yield related, physiochemical, disease incidence and index for disease severity parameters 50
4.3.1.1 Growth parameters 52
4.3.1.2 Yield and yield related parameters 52
4.3.1.3 Fruit morphological parameters 53
4.3.1.4 Physiochemical parameters 53
4.3.1.5 Disease incidence (DI %) and index for disease severity (IDS) parameters 54
4.3.2 Correlation coefficient among yield related parameters, TYLCD disease incidence and index for disease severity 59
4.3.3 Genetic component analysis 63
4.3.4 Clustering and principal component analysis 65
4.4 Conclusions 68

5 F_1 SEED PRODUCTION USING NINE SELECTED PARENTAL INBRED LINES AND SCREENING THEM FOR BEGOMOVIRUS CAUSATIVE TYLCD RESISTANT TY GENES USING MOLECULAR MARKERS 69
5.1 Introduction 69
5.2 Materials and Methods 70
5.2.1 Production of F_1 seeds using nine selected inbred lines 70
5.2.2 DNA extraction for screen *Ty* genes in parental lines and F_1 hybrids 74
5.2.3 Restriction enzyme SINAC I digestion to screen *ty* 5 recessive gene 74
5.2.4 Confirmation of *Ty* 6 gene by Sanger sequencing and BLAST in NCBI 74
5.3 Results and discussion 76
5.3.1 F_1 seed production 76
5.3.2 Screening for *Ty* genes 80
5.4 Conclusion 88

6 IDENTIFICATION OF BEST PARENTAL LINES AND F_1 HYBRID COMBINATIONS IN TERMS OF YIELD AND TYLCD RESISTANCE/TOLERANCE IN TWO SEASONS HYBRID EVALUATION TRIAL 90
6.1 Introduction 90
6.2 Methodology 90
6.2.1 Experimental design and establishment 90
6.2.2 Data collection 93
6.2.3 Data analysis 93
6.2.3.1 Linear model for Diallel analysis Method II 93
6.2.3.2 Estimation of variance components (As stated in Table 6.3) 94

6.2.3.3 Estimation of the narrow sense heritability (h^2) 94
6.2.3.4 Estimation of GCA (*gca effects* g_i) 95
6.2.3.5 Estimation of SCA (*sca effects* s_{ij}) 95
6.3 Results and Discussion 96
6.3.1 Evaluation of growth, yield, yield related, physiochemical, disease incidence and index for disease severity parameters 96
6.3.1.1 Growth parameters 99
6.3.1.2 Yield and yield related parameters 99
6.3.1.3 Fruit morphological parameters 99
6.3.1.4 Physiochemical parameters 100
6.3.1.5 TYLCD symptom severity parameters: 100
6.3.2 Additive and dominance variance components for the fifteen parameters 105
6.3.2.1 Plant growth parameters 105
6.3.2.2 Yield and yield related parameters 105
6.3.2.3 Fruit morphological parameters 105
6.3.2.4 Physiochemical parameters 106
6.3.2.5 TYLCD symptom severity parameters 106
6.3.3 Narrow sense heritability (h^2) for the fifteen parameters 106
6.3.4 General combining ability of the five parental lines 109
6.3.5 Specific combining ability for ten F_1 hybrids 110
6.3.6 Mean squares of GCA, SCA and their interaction effects with seasons 113
6.4 Conclusion 114

7 SUMMARY, CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH 115
7.1 Summary 115
7.2 Conclusion 116
7.3 Recommendations for future research work 116

REFERENCES 117
APPENDICES 130
BIODATA OF STUDENT 139
LIST OF PUBLICATIONS 140

LIST OF TABLES

Table		Page
2.1	Nutritional composition of tomato (Nutrient Data Laboratory, ARS, USDA) from Singh et al., 2016	5
2.2	Summary of important markers associated with Begomovirus resistant QTLS and genes	19
3.1	Details of primers used to confirm disease causative virus species	28
3.2	Steps and conditions used in PCR	29
3.3	Primer details, FASTA sequence of amplified region with accession numbers allocated by NCBI after direct submission of nucleotide sequences	31
3.4	Descriptions of sequences producing significant alignments	34
3.5	Descriptions of sequences producing significant alignments	37
4.1	Nominal description of seed material assigned to each T1-T40 treatment used in genetic diversity analysis and parental line selection	40
4.2	Standard copper fertigation formulation recommended by Malaysian Agricultural Research and Development Institute (MARDI)	42
4.3	Electrical Conductivity recommended by Malaysian Agricultural Research and Development Institute (MARDI) for different growth stages of tomato crop	42
4.4	Mean squares of yield, yield related, growth, physiological and TYLCD symptom severity parameters	51
4.5	Mean performances of 40 tomato lines for FPP=Fruits per plant, PFW=Per fruit weight, PPY= Per plant yield, FLEN= Fruit length, FWID= Fruit width, DI= Disease incidence of TYLCD, IDS=, Index for disease severity for TYLCD	55
4.6	Mean performances of 40 tomato lines for PHT= Plant height, DFLO=Days to 50% flowering, DFRU=Days to 50% fruiting, DFRUM=Days to 50% fruit maturity, PERITH= Pericarp thickness, PH= PH of ripe fruit juice, TSS= Total soluble solids of ripe fruit, FRTFIR= Fruit firmness	57
4.7	Correlation coefficient among 15 quantitative traits for 40 tomato lines	62

4.8 Genetic and phenotypic variance, genotypic and phenotypic coefficient of variations, broad sense heritability and genetic advance of the 15 parameters 64

4.9 Genetic diversity groups based on the cluster analysis 65

5.1 Selected nine parental inbred lines for F_1 hybrid production 70

5.2 Markers and primer sequences used to screen resistant genes 75

5.3 PCR conditions of primers used in resistant genes screening 76

6.1 Eighteen F_1 hybrids, nine parental lines, check varieties (Commercial F_1 variety - COM and TYLCD susceptible check - SUS) with their treatment numbers 91

6.2 ANOVA for p (p+1)/2 =15 diallel progenies (Griffing, 1956) Method II 94

6.3 ANOVA for combining ability effects (Griffing, 1956) Method II 94

6.4 Mean squares of yield, yield related, growth, physiological and TYLCD symptom severity parameters for 9 parental lines and 18 F_1 hybrids (Season 1) 97

6.5 Mean squares of yield, yield related, growth, physiological and TYLCD symptom severity parameters for 9 parental lines and 18 F_1 hybrids (Season 2) 98

6.6 Mean performances of 9 tomato parental lines and 18 of their F_1 hybrids for FPP=Fruits per plant, PFW=Per fruit weight, PPY= Per plant yield, FLEN= Fruit length, FWID= Fruit width, PERITH= Pericarp thickness, DI= Disease incidence of TYLCD, IDS=, Index for disease severity for TYLCD (Season 1) 101

6.7 Mean performances of 9 tomato parental lines and 18 of their F_1 hybrids for PHT= Plant height, DFLO=Days to 50% flowering, DFRU=Days to 50% fruiting, DFRMT=Days to 50% fruit maturity, PH= PH of ripe fruit juice, TSS= Total soluble solids of ripe fruit, FRTFIR= Fruit firmness (Season 1) 102

6.8 Mean performances of 9 tomato parental lines and 18 of their F_1 hybrids for FPP=Fruits per plant, PFW=Per fruit weight, PPY= Per plant yield, FLEN= Fruit length, FWID= Fruit width, PERITH= Pericarp thickness, DI= Disease incidence of TYLCD, IDS=, Index for disease severity for TYLCD – Season 2 103

6.9 Mean performances of 9 tomato parental lines and 18 of their F_1 hybrids for PHT= Plant height, DFLO=Days to 50% flowering, DFRU=Days to 50% fruiting, DFRMT=Days to 50% fruit maturity, PH= PH of ripe fruit juice, TSS= Total soluble solids of ripe fruit, FRTFIR= Fruit firmness – Season 2 104

6.10 VA, VD and h^2 for 15 traits in season 1 108

6.11 VA, VD and h^2 for 15 traits in season 2 108

6.12 General combining abilities (GCA) of five parents 110

6.13 Specific combining abilities (SCA) of 10 F_1 hybrids 112

6.14 Mean squares of GCA, SCA and their interaction effects with seasons 113

LIST OF FIGURES

Figure **Page**

2.1 Graphical plant–virus Interaction of TYLCV as reported by Prasad *et al*. (2020). (ds)DNA- The double-stranded DNA; RCR- Rolling Circle Replication; (ss)DNA-single-stranded DNA, REn - replication enhancer protein; Rep - replication initiator protein; TrAP-transcription activator protein; AC4 – A protein in Begomovirus 9

2.2 Tomato plant with typical TYLCD symptoms 10

2.3 Graphical plant–virus nteraction of TYLCV as reported by Prasad *et al*. (2020) 11

2.4 Silver leaf whitefly feeding on tomato leaves 11

2.5 Prevalence of TYLCD in tomato cultivation areas in Malaysia 13

3.1 Molecular screening of presence of Begomovirus in TYLCD symptomatic tomato leaf samples using primer pairs (a) PAL1v1978/PAR1c496 and (b) Deng 541/Deng 540 30

3.2 Phylogenetic tree showing the percentage similarity among closely related Begomovirus species with significant sequence alignments (after amplification with primer pair PAL1v1978 and PAR1c496) 33

3.3 Phylogenetic tree showing the percentage similarity among few Begomovirus species with significant sequence alignments (after amplification with primer pair Deng 541and Deng 540) 36

4.1 Measurement of (a) Fruit weight, (b) Fruit firmness, (c) Total soluble solids, (d) pH of fruit juice 43

4.2 (a) Raring of whitefly, (b) whitefly inoculated plants from each parental line in separate net cages, (c) Maintenance of inoculated plants in net cages 45

4.3 TYLCD scoring scale (1 – 5): 1= no visible symptoms, inoculated plants show same growth and development as non-inoculated plants; 2 = very slight yellowing of leaflet margins on apical leaf; 3 = some yellowing and minor curling of leaflet ends; 4 = a wide range of leaf yellowing, curling and cupping, with some reduction in size, yet plants continue to develop; 5 = very severe plant stunting and yellowing, pronounced leaf cupping and curling 46

4.4 Relationship among 38 tomato genotypes based on 15 traits using SAHN clustering of UPGMA method 66

4.5 Principal component analysis (PCA) showing the relationship among 38 tomato genotypes in a two dimensional plot 67

5.1 (a) Transplants of batch 1 (b-c) Consecutive batches 2, 3 and 4 71

5.2 (a) Pollination tool kit: (70 % Ethanol, forceps, strings, tags, labels, cover bags, marker pen) (b-c) Steps of emasculation of female flower bud 72

5.3 Steps of artificial (hand) pollination of emasculated female flower (a) Male flower collection (b) Scraping out pollen from male flower anthers (c) Hand pollination of female flower (d) covering pollinated flower with an oil paper bag (e-f) Labelling and fruit nurturing until reaching >85% fruit ripening 73

5.4 (a-b) Ripened fruits of few successful hybrids, (c) Low seed set, (d) Zero seed set or parthenocarpy (e) Blossom drop (f) Premature fruit drop (g-i) Recording of high temperature at glass house 77

5.5 Seed extraction steps (a) Cut open fully ripened fruits, (b) Extracting out seeds to container of water and keep for overnight, (c) Wash off attached fruit tissues, (d) Processed seeds after wind drying 78

5.6 (a-b) 4% Gibberelic acid (GA3) treatment to break any associated dormancy before seed sowing (c) Germinating seeds after 4% GA3 treatment (d) Seedlings used for DNA extraction for screening Ty genes 79

5.7 Visualization of resistant, susceptible and heterozygous alleles for Ty-1 gene (i) 9 parental lines (ii) 18 F1 hybrids in 1.5 % agarose gel using Ty1SCAR1 marker 80

5.8 Visualization of resistant, susceptible and heterozygous alleles for Ty-2 gene (i) 9 parental lines (ii) 18 F1 hybrids in 1.5 % agarose gel using TO302 marker 82

5.9 Visualization of resistant, susceptible and heterozygous alleles for Ty-3 gene (i) 9 parental lines (ii) 18 F1 hybrids in 1.5 % agarose gel using P6-25 marker 84

5.10 Visualization of resistant, susceptible and heterozygous alleles for Ty-4 gene (i) 9 parental lines (ii) 18 F1 hybrids in 1.5 % agarose gel using 18IY13 marker 85

5.11 Visualization of resistant, susceptible and heterozygous alleles for ty-5 gene. (i) 9 parental lines (ii) 18 F1 hybrids in 2.0 % metaphor agarose gel after digesting PCR product with restriction enzyme SINAC I 86

5.12 Visualization of Ty-6 locus using UF_10.61192marker (i) 9 parental lines (ii) 18 F1 hybrids in 2.0 % metaphor agarose gel 88

6.1 Experimental lay out in glass house to evaluate 18 F_1 hybrids and their 9 parental lines in Randomized Complete Block Design with 3 replications 92

6.2 Diallel table used for diallel analysis Method 2 (Model II) by Griffing, 1956 includes n parents and n (n-1)/2 F_1 hybrids 93

LIST OF APPENDICES

Appendix		Page
A1	Origin, number of tomato lines and assigned treatment numbers of seed material used in genetic diversity analysis and parental line selection	130
A2	(a-b) Tomato nursery establishment and maintenance (c) 21 days old seedlings ready to transplant (d) Transplanted seedling	131
A3	Experimental lay out in glass house to evaluate 40 tomato lines in Randomized Complete Block Design with 3 replications	132
A4	Crop maintenance: (a-b) Crop supporting with strings (c) Shoot pruning (d) EC checking (e) Fertigation	133
A5	Description of measurements on growth, yield, yield related and physiochemical parameters	134
A6	Description of measurements on disease incidence (DI %) and index for disease severity (IDS) parameters	135
A7	Qualitative data of tomato germplasm using International Plant genetic Resources Institute (IPGRI) descriptor	136
B1	Best performed F_1 hybrids (a) AVTO 1003 × AVTO 1418 (T4×T8) and (b) AVTO 1314 × AVTO 1003 (T2×T4)	138

LIST OF ABBREVIATIONS

AFLPs	Amplified Fragment Length Polymorphism
ANOVA	Analysis of variance
AVRDC	Asian Vegetable Research and Development Center
AYVMV	Ageratum Yellow Vein Malaysia Virus
CAPS	Cleaved Amplified Polymorphic Sequence
CTAB	Cetyl Trimethyl Ammonium Bromide
DFLO	Days to 50% flowering
DFRU	Days to 50% fruiting
DFRUMT	Days to 50% fruit maturity
DI	Disease incidence
DOA	Department of Agriculture
EC	Electrical conductivity
FAO	Food Agriculture Organization
FPP	Fruits per plant
FRLEN	Fruit length
FRTFIR	Fruit firmness
FRWID	Fruit width
GCA	General combining ability
GS	Genomic selection
GWS	Genome-wide selection
IDS	Index for disease severity
InDels	Insertion Deletions
IPGRI	International Plant Genetic Resource Institute
LSD	Least significant differences
MABC	Marker-assisted backcrossing

MAPS	Marker-assisted pedigree selection
MARDI	Malaysian Agricultural Research and Development Institute
MARS	Marker-assisted recurrent selection
MAS	Marker-assisted selection
NTSYS	Numerical Taxonomy Multivariate Analysis System
PCR	Polymerase Chain Reaction
PepGMV	Pepper golden mosaic virus
PepLCV	Pepper leaf curl virus
PERITH	Pericarp thickness
PFW	Per fruit weight
PHT	Plant height at 50% flowering
PHYVV	Pepper huasteco yellow vein virus
PLCAV	Pepper leaf curl Aceh virus
PPY	Per plant yield
QTL	Quantitative trait loci
RCBD	Randomized Complete Block Design
RFLPs	Restricted Fragment Length Polymorphism
SAHN	Sequential Agglomerative Hierarchic and Non-overlapping
SCA	Specific combining ability
SCAR	Sequence Characterized Amplified Region
SNP	Single Nucleotide Polymorphism
TLCJV- Ageratum	Tomato leaf curl Java virus - Ageratum
TYLCD	Tomato Yellow Leaf Curl Disease
TYLCV	Toma to Yellow Leaf Curl Virus
UPGMA	Unweighted Pair Group Method with Arithmetic means

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Tomato which belongs to family Solanaceae has become the most important vegetable in the world due to its high nutrition and commercial value (Melomey *et al*., 2019) with an annual global production of approximately 182 million metric tons in a harvested area around 4.8 million ha (FAO, 2018).

Malaysian tomato industry has shown steady development through the past decade and the cultivation area is approximately 1300 hectares (Rahim *et al*., 2017) where the major cultivation regions are Jajahan Lojing, Kelantan; Cameron Highlands, Pahang and Kundasang, Sabah (Radam *et al*., 2015).

Tomato crop is affected by number of biotic (pest and diseases) and abiotic stresses such as high and low moisture, heat, temperature, salinity and nutrient imbalances (Foolad, 2007). Among the biological stresses, viral diseases are considerably devastative. In particular, Tomato Yellow Leaf Curl Disease (TYLCD) caused by a group of Begomoviruses of family Geminiviridae is a major viral disease transmitted by silver leaf whitefly (*Bemisia tabaci* Gennadius) around the world (Dhaliwal *et al*., 2020). TYLCD was first reported in Jordan Valley of Israel around nine decades ago (Cohen & Lapidot, 2007). At present TYLCD may cause symptom severity and yield losses depending on the varietal resistance, time of infection and many other biological, physiological causes and their interactions. Also, may cause up to 100 % yield reduction under uncontrolled conditions (Moriones and Navas-Castillo, 2000).

Cultivated tomato are extremely genetically poor due to occurrence of population bottle necks during domestication as a consequence of selection and also by genetic drift which is common for inbreeding species (Bai and Lindhout, 2007). Therefore, it is inevitably important to have large germplasm for an efficient screening of parental lines with variability in traits of interest. However, the selection of parental lines for higher fruit weight and larger fruit size is not much complicated as the trait is highly heritable and therefore could be easily selected phenotypically to utilize in breeding programmes (Foolad, 2007).

There are several standard methods (whitefly mediated and non-whitefly mediated) have been developed to screen for TYLCD resistant/ tolerant tomato plants. Among which white fly mediated inoculation cage method is identified as a method with higher accuracy (Czosnek, 2007). Resistant level of each genotype could be estimated using the TYLCD symptom severity score within 4-8 week post inoculation period (Lapidot *et al*., 2006).

Molecular marker assisted selection has become a popular tool in present day crop breeding for traits such as disease resistance as it is a low cost and fast selection tool with high accuracy (Barone, 2007). Early identification of tomato lines with Begomovirus resistant *Ty* genes allows breeders to accelerate cultivar development with TYLCD tolerance. Up to now, there are 6 genes (*Ty*1, *Ty*2, *Ty*3, *Ty*4, *ty*5 and *Ty*6) with TYLCD resistance have been identified in tomato wild relatives and been introgressed to cultivated tomato (Yan *et al*., 2021). Though, tomato wild relatives have been identified with TYLCD resistance; none of the cultivated tomato possess total resistance but only identified with field tolerance after introgression of the *Ty* genes. Therefore accumulation of more than one *Ty* gene in to a cultivar has led to higher protection from TYLCD causative Begomovirus attack.

TYLCD is induced by several Begomovirus species and it's important to confirm the disease causative species by specific molecular markers. Molecular confirmation of Begomovirus species is useful to evaluate the action of each *Ty* gene in host plant with respect to the confirmed Begomovirus. At the same time, molecular confirmation of Begomovirus helps to identify the evolutionary relationship with other similar Begomoviruses by phylogenetic analysis and to develop suitable control strategies.

Production of F_1 hybrids is a successful approach which results better tolerant cultivars for vegetables of family Solanaceae (Kaushik and Dhaliwal, 2018). Diallel analysis is extensively manipulating tool in tomato breeding to utilize the genetic variability and to identify better performing parents and hybrid combinations through measures of general combining ability (GCA), specific combining ability (SCA) and heritability studies (Kaushik and Dhaliwal, 2018; de Souza *et al*., 2012).

1.2 Research Problem

Tomato growers in Malaysia practice an intense and continuous crop cultivation without keeping a fallow period (Radam *et al*., 2015) hence led to an increase and survival of vector populations and thereby spread and prevalence of viral diseases. Apart from that, polyphagous nature of vector and virus, climate change and development of new vector and virus types have made difficult to break the disease cycle. At present, spreading of TYLCD is mostly controlled by vector targeted pesticides which leads to resistant build up in vectors, increasing of production cost and adverse effects to the environment (Firdaus *et al*., 2012). However, when there is severe outbreak of vector; pesticides too become inefficient in vector control so that virus transmission continues (Lapidot and Friedmann, 2002).

In Malaysia there are few tomato varieties have been tested against the leaf curl virus where MF 8 showed more tolerant than MT 1 (Roff *et al*., 2005). However, Malaysian tomato growers often rely on imported tomato seeds with high quality attributes besides its high cost (Radam *et al*., 2015). Therefore, resistant/ tolerant tomato cultivar development is a timely need for economically sustainable tomato industry in Malaysia while it is the most effective way of controlling the damage caused by TYLCD.

1.3 Research objectives

The main objective of this study was to production of high yielding tomato hybrids with Tomato Yellow Leaf Curl Disease resistance/tolerance.

The specific objectives of the study were;

1. Genetic diversity analysis among forty tomato lines and screening best tomato lines for high yielding using yield and yield related parameters
2. Screening of best tomato lines with resistant/tolerant trait to TYLCD using Disease incidence (DI %) and Index for disease severity (IDS) parameters.
3. Molecular identification of tomato yellow leaf curl disease causative Begomovirus species
4. F_1 seed production using nine selected parental inbred lines and screening them for Begomovirus causative TYLCD resistant *Ty* genes using gene specific primers
5. Identification of best parental lines and F_1 hybrids using additive and dominant genetic variations (V_A and V_D), general combining ability (GCA), specific combining ability (SCA) and narrow sense heritability (h^2) estimates

1.4 Expected outcome

Identification of tomato F_1 hybrid/s with TYLCD tolerance and higher yields to cultivate in Malaysia

REFERENCES

Acquaah G (2012). Breeding tomato. Principles of Plant Genetics and Breeding. pp. 667–678. John Wiley & Sons, Chichester, UK.

Adams, S. R., Cockshull, K. E., & Cave, C. R. J. (2001). Effect of temperature on the growth and development of tomato fruits. *Annals of Botany*, *88*(5), 869-877.

Aisya, S. I., Wahyuni, S., Syukur, M., & Witono, J. R. (2016). The estimation of combining ability and heterosis effect for yield and yield components in tomato (*Lycopersicon esculentum* Mill.) at lowland. Ekin Journal of crop breeding and genetics, 2(1), 23-29.

Ammara U, Mansoor S, Saeed M, Amin I, Briddon RW, Al-Sadi AM (2015). RNA interference-based resistance in transgenic tomato plants against Tomato yellow leaf curl virus-Oman (TYLCV-OM) and its associated betasatellite. Virology Journal 12: 38. DOI 10.1186/s12985-015-0263-y.

Anbinder I, Reuveni M, Azari R, Paran I, Nahon S, Shlomo H, Chen L, Lapidot M, Levin I (2009). Molecular dissection of Tomato leaf curl virus resistance in tomato line TY172 derived from *Solanum peruvianum*. Theoretical and Applied Genetics 119: 519–530. DOI 10.1007/s00122-009-1060-z.

Arah IK, Amaglo H, Kumah EK, Ofori H (2015). Preharvest and postharvest factors affecting the quality and shelf life of harvested tomatoes: A mini review. International Journal of Agronomy 2015: 1–6. DOI 10.1155/2015/478041.

Ayankojo, I. T., & Morgan, K. T. (2020). Increasing air temperatures and its effects on growth and productivity of tomato in South Florida. Plants, 9(9), 1245.

Bai Y, Feng X, van der Hulst R, Lindhout P (2004). A set of simple PCR markers converted from sequence specific RFLP markers on tomato chromosomes 9 to 12. Molecular Breeding 13: 281– 287. DOI 10.1023/B:MOLB.0000022535.82602.79.

Bai Y, Lindhout P (2007). Domestication and breeding of tomatoes: what have we gained and what can we gain in the future? Annals of botany 100:1085-1094.

Bai, Y., Kissoudis, C., Yan, Z., Visser, R. G., & van der Linden, G. (2018). Plant behaviour under combined stress: tomato responses to combined salinity and pathogen stress. The plant journal, 93(4), 781-793.

Banerjee MK (1990). Transfer of tomato leaf curl virus resistance from Lycopersicon hirsutum f. glabratum to L. esculentum. Plant Breeding 105: 156–159. DOI 10.1111/j.1439-0523.1990.tb00469.x.

Banga SS, Banga SK (1998). Hybrid cultivar development. pp. 436. Springer-Verlag, Berlin.

Barone, A., & Frusciante, L. (2007). Molecular marker-assisted selection for resistance to pathogens. Marker-assisted Selection: Current Status and Future Perspectives in Crops, Livestock, Forestry and Fish, 151.

Bergamin Filho, A., Macedo, M. A., Favara, G. M., Bampi, D., Oliveira, D. F. F., & Rezende, J. A. (2020). Amplifier hosts may play an essential role in tomato Begomovirus epidemics in Brazil. Frontiers in Plant Science, 414.

Biotechnology and Society. (2015). Flavr Savr tomato. Retrived from https://biotechnologysociety.wordpress.com/2015/02/16/flavr-savr-tomato/

Birchler JA, Yao H, Chudalayandi S, Vaiman D, Veitia RA (2010). Heterosis. Plant Cell 22: 2105–2112. DOI 10.1105/tpc.110.076133

Boriss, H., & Brunke, H. (2005). Commodity profile: processing tomatoes. University of California Agricultural Issues Center.

Bosco, D., Mason, G., & Accotto, G. P. (2004). TYLCSV DNA, but not infectivity, can be transovarially inherited by the progeny of the whitefly vector *Bemisia tabaci* (Gennadius). Virology, 323(2), 276-283.

Bradshaw JE (2016). Genetic basis of heterosis and inbred line versus hybrid cultivars. Plant Breeding: Past, Present and Future. Cham: Springer.

Bruening, G., & Lyons, J. (2000). The case of the FLAVR SAVR tomato. California Agriculture, 54(4), 6-7.

CABI. (2021). Invasive species compendium, *Solanum lycopersicum* (Tomato). Retrived from https://www.cabi.org/isc/datasheet/31837

Cathrin, P. B., & Ghanim, M. (2014). Recent advances on interactions between the *whitefly Bemisia tabaci* and Begomoviruses, with emphasis on Tomato yellow leaf curl virus. Plant Virus–Host Interaction, 79-103.

Chagué V, Mercier JC, Guenard M, De Courcel A, Vedel F (1997). Identification of RAPD markers linked to a locus involved in quantitative resistance to TYLCV in tomato by bulked segregant analysis. Theoretical and Applied Genetics 95: 671–677. DOI 10.1007/s001220050611.

Chandel, R., Sadashiva, A. T., Ravishankar, K. V., Das, A., Rout, B. M., & Singh, S. (2021). Genetic combining, heterosis analysis for horticultural traits in tomato (*Solanum lycopersicum* L.) using ToLCV-resistant lines and molecular validation of Ty genes. Plant Genetic Resources, 19(6), 512-521.

Chen ZJ (2013). Genomic and epigenetic insights into the molecular bases of heterosis. Nature Reviews Genetics 14: 471–482. DOI 10.1038/nrg3503.

Chernet, S., Belew, D., & Abay, F. (2014). Genetic diversity studies for quantitative traits of tomato (*Solanum lycopersicon* L.) genotypes in Western Tigray, Northern Ethiopia. Journal of Plant Breeding and Crop Science, 6(9), 105-113.

Chintapalli, I., & Rayalcheruvu, U. (2022). Leaf Curl Disease a Significant Constraint in the Production of Tomato: Impact, Challenges, and Management. In Tomato-From Cultivation to Processing Technology. IntechOpen.

Choudhary, M., Kumawat, K. R., & Kumawat, R. (2004). Diallel analysis and its applications in plant breeding. Biotech Articles.

Cohen, S., & Lapidot, M. (2007). Appearance and expansion of TYLCV: a historical point of view. In Tomato yellow leaf curl virus disease (pp. 3-12). Springer, Dordrecht.

Czosnek, H. (Ed.). (2007). Tomato yellow leaf curl virus disease: management, molecular biology, breeding for resistance. Springer Science & Business Media.

Das, S. P., Moharana, D. P., Aslam, T., Nayak, N. J., & Mandall, A. R. (2017). Correlation studies of different growth, quality and yield attributing parameters of tomato (*Solanum lycopersicum* L.). *Int J Agric Environ Biores, 2(*2), 217-223.

Datta, D. R., Rafii, M. Y., Misran, A., Jusoh, M., Yusuff, O., Haque, M., & Jatto, M. (2021). Half Diallel Analysis for Biochemical and Morphological Traits in Cultivated Eggplants (*Solanum melongena* L.). Agronomy, 11(9), 1769.

de Souza, L. M., Paterniani, M. E. A., de Melo, P. C. T., & de Melo, A. M. (2012). Diallel cross among fresh market tomato inbreeding lines. Horticultura Brasileira, 30(2), 246-251.

Deng, D., McGrath, P. F., Robinson, D. J., & Harrison, B. D. (1994). Detection and differentiation of whitefly-transmitted geminiviruses in plants and vector insects by the polymerase chain reaction with degenerate primers. Annals of applied Biology, 125(2), 327-336.

Devi, E. S., Singh, N. B., Devi, A. B., Singh, N. G., & Laishram, J. M. (2001). Gene action for fruit yield and its components in tomato (*Lycopersicon esculentum* Mill.). Heredity, 12, 371-390.

Dhaliwal MS, Jindal SK, Sharma A, Prasanna HC (2020). Tomato yellow leaf curl virus disease of tomato and its management through resistance breeding: A review. The Journal of Horticultural Science and Biotechnology 95: 425-444.

Diaz-Pendon JA, Canizares MC, Moriones E, Bejarano ER, Czosnek H, Navas-Castillo J (2010). Tomato yellow leaf curl viruses: ménage à trois between the virus complex, the plant and the whitefly vector. Molecular Plant Pathology 11: 441-450

Dong, P., Han, K., Siddique, M. I., Kwon, J. K., Zhao, M., Wang, F., & Kang, B. C. (2016). Gene-based markers for the tomato yellow leaf curl virus resistance gene Ty-3. Plant Breeding and Biotechnology, 4(1), 79-86.

Ebert, A. W., & Schafleitner, R. (2015). Utilization of wild Relatives in the breeding of tomato and other major vegetables. Crop Wild Relatives and Climate Change (John Wiley & Sons, Inc Hoboken, NJ, USA), 141-172.

Erika, C., Ulrich, D., Naumann, M., Smit, I., Horneburg, B., & Pawelzik, E. (2022). Flavor and Other Quality Traits of Tomato Cultivars Bred for Diverse Production Systems as Revealed in Organic Low-Input Management. Frontiers in Nutrition, 9.

Falconer, D. S., & Mackey, T. F. C. (1996). Introduction to Quantitative Genetics. 3rd Longman.

Felsenstein, J. (1985). Confidence limits on phylogenies: An approach using the bootstrap. Evolution, 39(4), 783-791.

Fentik DA (2017). Review on genetics and breeding of tomato (*Lycopersicon esculentum* Mill). Advances in Crop Science and Technology 5: 306

Firdaus S, van Heusden AW, Hidayati N, Supena EDJ, Visser RG, Vosman B (2012). Resistance to *Bemisia tabaci* in tomato wild relatives. Euphytica 187: 31–45. DOI 10.1007/s10681-012-0704-2.

Food FAO (2018). Agriculture Organization of the United Nations. FAOSTAT: Statistics database. http://www.fao.org/faostat/ en/#data/QC/visualize

Foolad MR (2007). Genome mapping and molecular breeding of tomato. International Journal of Plant Genomics 2007: 1– 52. DOI 10.1155/2007/64358

Foolad MR, Jones RA, Rodriguez RL (1993). RAPD markers for constructing intraspecific tomato genetic maps. Plant Cell Reports 12: 293–297. DOI 10.1007/BF00237139

Fufa F, Hanson P, Dagnoko S, Dhaliwal M (2009). AVRDC-The World Vegetable Center tomato breeding in sub-Saharan Africa: Lessons from the past, present work, and future prospects. In I All Africa Horticultural Congress 911, 87–98.

Garcia, B. E., Graham, E., Jensen, K. S., Hanson, P., Mejía, L., & Maxwell, D. P. (2007). Co-dominant SCAR marker for detection of the Begomovirus-resistance Ty-2 locus derived from *Solanum habrochaites* in tomato germplasm. Tomato Genetic Cooperative Report, 57, 21-24.

Gardner, C. O., & Eberhart, S. A. (1966). Analysis and interpretation of the variety cross diallel and related populations. Biometrics, 439-452.

Gautam, G. K. A Review on the Taxonomy, Ethnobotany, Chemistry and Pharmacology of *Solanum lycopersicum* Linn.

Gayosso-Barragán, O., López-Benítez, A., Rodríguez-Herrera, S. A., Ek-Maas, J. N., Hidalgo-Ramos, D. M., & Alcala-Rico, J. S. G. J. (2019). Studies on combining ability in tomato (*Solanum lycopersicum* L.).

Gelbart D, Chen L, Alon T, Dobrinin S, Levin I, Lapidot M (2020). The recent association of a DNA betasatellite with Tomato yellow leaf curl virus in Israel—A new threat to tomato production. Crop Protection 128: 104995. DOI 10.1016/j. cropro.2019.104995.

Gerszberg, A., & Hnatuszko-Konka, K. (2017). Tomato tolerance to abiotic stress: a review of most often engineered target sequences. Plant growth regulation, 83(2), 175-198.

Ghani, M. A., Abbas, M. M., Amjad, M., Ziaf, K., Ali, B., Shaheen, T., ... & Khan, A. N. (2020). Production and characterization of tomato derived from interspecific hybridization between cultivated tomato and its wild relatives. The Journal of Horticultural Science and Biotechnology, 95(4), 506-520.

Ghanim, M., Morin, S., Zeidan, M., & Czosnek, H. (1998). Evidence for transovarial transmission of tomato yellow leaf curl virus by its vector, the whitefly *Bemisia tabaci*. Virology, 240(2), 295-303.

Gill U, Scott JW, Shekasteband R, Ogundiwin E, Schuit C, Francis DM, Sim SC, Smith H, Hutton SF (2019). Ty-6, a major Begomovirus resistance gene on chromosome 10, is effective against Tomato yellow leaf curl virus and Tomato mottle virus. Theoretical and Applied Genetics 132: 1543– 1554. DOI 10.1007/s00122-019-03298-0

Giovannucci E (1999). Tomatoes, tomato-based products, lycopene, and cancer: review of the epidemiologic literature. Journal of the National Cancer Institute 91: 317-331.

Gorovits R, Moshe A, Amrani L, Kleinberger R, Anfoka G, Czosnek H (2017). The six Tomato yellow leaf curl virus genes expressed individually in tomato induce different levels of plant stress response attenuation. Cell Stress and Chaperones 22: 345–355. DOI 10.1007/s12192-017-0766-0.

Green, S. K., Tsai, W. S., Shih, S. L., Black, L. L., Rezaian, A., Rashid, M. H., ... & Hong, L. T. A. (2001). Molecular characterization of Begomoviruses associated with leafcurl diseases of tomato in Bangladesh, Laos, Malaysia, Myanmar, and Vietnam. Plant Disease, 85(12), 1286-1286.

Griffing, B. R. U. C. E. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Australian journal of biological sciences, 9(4), 463-493.

Hailu, A., Alamerew, A., Nigussie, M., & Assefa, E. (2016). Study of genetic diversity in different genotypes of barley (*Hordeum vulgare* L.) based on cluster and principal component analysis. Agric. Sci. Res. J, 6(2), 31-42.

Hanson, P. M., Bernacchi, D., Green, S., Tanksley, S. D., Muniyappa, V., Padmaja, A. S., ... & Chen, J. T. (2000). Mapping a wild tomato introgression associated with tomato yellow leaf curl virus resistance in a cultivated tomato line. Journal of the American Society for Horticultural Science, 125(1), 15-20.

Hanson, P., Green, S. K., & Kuo, G. (2006). Ty-2, a gene on chromosome 11 conditioning geminivirus resistance in tomato. Tomato Genet Coop Rep, 56, 17-18.

Hanssen, I. M., & Lapidot, M. (2012). Major tomato viruses in the Mediterranean basin. Advances in virus research, 84, 31-66.

Hidayat, S. H., Chatchawankanpanich, O., & Aidawati, N. (2008). Molecular identification and sequence analysis of tobacco leaf curl Begomovirus from Jember, East Java, Indonesia. HAYATI Journal of Biosciences, 15(1), 13-17.

Hillis, D. M., & Bull, J. J. (1993). An empirical test of bootstrapping as a method for assessing confidence in phylogenetic analysis. Systematic biology, 42(2), 182-192.

Hussain, I., Khan, S. A., Ali, S., Farid, A., Ali, N., Ali, S., ... & Raza, H. (2018). Genetic diversity among tomato accessions based on agro-morphological traits. Sains Malaysiana, 47(11), 2637-2645.

Hutton SF, Scott JW, Schuster DJ (2012). Recessive resistance to Tomato yellow leaf curl virus from the tomato cultivar Tyking is located in the same region as Ty-5 on chromosome 4. HortScience 47: 324–327. DOI 10.21273/HORTSCI.47.3.324

Iqbal, Q., Saleem, M. Y., Hameed, A., & Asghar, M. (2014). Assessment of genetic divergence in tomato through agglomerative hierarchical clustering and principal component analysis. Pak. J. Bot, 46(5), 1865-1870.

Islam, B. M. R., Ivy, N. A., Rasul, M. G., & Zakaria, M. (2010). Character association and path analysis of exotic tomato (*Solanum lycopersicum* L.) genotypes. Bangladesh Journal of Plant Breeding and Genetics, 23(1), 13-18.

Izzo, A. M., Khojah, H., & Murie, A. M. (2022). Combining ability and heterosis for yield and some fruit traits of tomato. DYSONA-Applied Science, 3(1), 15-23.

Jacob C, Carrasco B, Schwember AR (2016). Advances in breeding and biotechnology of legume crops. Plant Cell, Tissue and Organ Culture 127: 561–584. DOI 10.1007/s11240-016-1106-2.

Ji Y, Schuster DJ, Scott JW (2007a). Ty-3, a Begomovirus resistance locus near the Tomato yellow leaf curl virus resistance locus Ty-1 on chromosome 6 of tomato. Molecular Breeding 20: 271–284.

Ji Y, Scott JW, Hanson P, Graham E, Maxwell DP (2007b). Sources of resistance, inheritance, and location of genetic loci conferring resistance to members of the tomato-infecting Begomoviruses. Tomato Yellow Leaf Curl Virus Disease. pp. 343–362. Dordrecht: Springer.

Ji Y, Scott JW, Schuster DJ (2009a). Toward fine mapping of the Tomato yellow leaf curl virus resistance gene Ty-2 on chromosome 11 of tomato. HortScience 44: 614–618.

Ji Y, Scott JW, Schuster DJ, Maxwell DP (2009b). Molecular mapping of Ty-4, a new Tomato yellow leaf curl virus resistance locus on chromosome 3 of tomato. Journal of the American Society for Horticultural Science 134: 281–288

Johnson, H. W., H. F. Robinson and R. E. Comstock, 1955: Estimate of genetic and environmental variability in Soybean. Agron. J. 47 (6): 314.

Jolly, B. (2016). Tomato yellow leaf curl virus: a serious threat to tomato plants world wide. Journal of Plant Pathology and Microbiology, 7(4).

Jolly, B. (2016). Tomato yellow leaf curl virus: a serious threat to tomato plants world wide. Journal of Plant Pathology and Microbiology, 7(4).

Jones, R. A. (2020). Disease Pandemics and Major Epidemics Arising from New Encounters between Indigenous Viruses and Introduced Crops. Viruses, 12(12), 1388.

Kadirvel P, De la Peña R, Schafleitner R, Huang S, Geethanjali S, Kenyon L, Tsai W, Hanson P (2013). Mapping of QTLs in tomato line FLA456 associated with resistance to a virus causing tomato yellow leaf curl disease. Euphytica 190: 297–308.

Kathimba, F. K., Kimani, P. M., Narla, R. D., & Kiirika, L. M. (2021). Characterization of tomato germplasm accessions for breeding research. Journal of Agricultural Biotechnology and Sustainable Development, 13(2), 20-27.

Kaul MLH (1991). Reproductive biology in tomato. Genetic Improvement of Tomato. pp. 39–50. Berlin, Heidelberg: Springer.

Kaushik P, Dhaliwal M (2018). Diallel analysis for morphological and biochemical traits in tomato cultivated under the influence of tomato leaf curl virus. Agronomy 8: 153.

Kaushik, S. K., Tomar, D. S., & Dixit, A. K. (2011). Genetics of fruit yield and it's contributing characters in tomato (*Solanum lycopersicom*). *Journal of Agricultural Biotechnology and Sustainable Development*, 3(10), 209.

Knapp, S., & Peralta, I. E. (2016). The tomato (*Solanum lycopersicum* L., Solanaceae) and its botanical relatives. In The tomato genome (pp. 7-21). Springer, Berlin, Heidelberg

Koeda, S., Fujiwara, I., Oka, Y., Kesumawati, E., Zakaria, S., & Kanzaki, S. (2020). Ty-2 and Ty-3a conferred resistance are insufficient against tomato yellow leaf curl Kanchanaburi virus from Southeast Asia in single or mixed infections of tomato. Plant Disease, 104(12), 3221-3229.

Kon, T., Kuwabara, K., Hidayat, S. H., & Ikegami, M. (2007). A Begomovirus associated with ageratum yellow vein disease in Indonesia: evidence for natural recombination between tomato leaf curl Java virus and Ageratum yellow vein virus-[Java]. Archives of virology, 152(6), 1147-1157.

Kumar A, Tiwari KL, Datta D, Singh M (2014). Marker assisted gene pyramiding for enhanced Tomato leaf curl virus disease resistance in tomato cultivars. Biologia Plantarum 58: 792–797.

Kumar, K., Sharma, D., Singh, J., Sharma, T. K., Kurrey, V. K., & Minz, R. R. (2018). Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicum* L.). Journal of Pharmacognosy and Phytochemistry, 7(6), 1002-1005.

Kumar, R., & Srivastava, K. (2021). Gene Effects and Heritability for Yield Traits in Tomato (*Solanum Lycopersicum* L.). Bangladesh Journal of Botany, 50(3), 453-465.

Kumar, R., Srivastava, K., Singh, N. P., Vasistha, N. K., Singh, R. K., & Singh, M. K. (2013). Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicum* L.). Journal of Agricultural Science 5(2), 213.

Lapidot M, Friedmann M (2002). Breeding for resistance to whitefly-transmitted geminiviruses. Annals of Applied Biology 140: 109-127.

Lapidot, M., Ben-Joseph, R., Cohen, L., Machbash, Z., & Levy, D. (2006). Development of a scale for evaluation of Tomato yellow leaf curl virus resistance level in tomato plants. Phytopathology, 96(12), 1404-1408.

Lapidot, M., Legg, J. P., Wintermantel, W. M., & Polston, J. E. (2014). Management of whitefly-transmitted viruses in open-field production systems. Advances in virus research, 90, 147-206.

Lee, J. H., Chung, D. J., Lee, J. M., & Yeam, I. (2021). Development and application of gene-specific markers for Tomato Yellow Leaf Curl Virus resistance in both field and artificial infections. Plants, 10(1), 9.

Li, M., Li, X. J., & Su, Y. L. (2017). Flue-cured tobacco confirmed as a reservoir host plant for Tomato yellow leaf curl virus by agro-inoculation and *Bemisia tabaci* MED-mediated transmission. Plos one, 12(12), e0190013.

Liang, G., Liu, J., Zhang, J., & Guo, J. (2020). Effects of drought stress on photosynthetic and physiological parameters of tomato. Journal of the American Society for Horticultural Science, 145(1), 12-17.

Liptay, A., & Moore, L. A. (1988, September). High temperature damage encountered by tomato fruits and their seeds when the fruits are exposed directly to the sun and not covered by plant foliage. In IV International Symposium on Seed Research in Horticulture 253 (pp. 225-232).

Lone, S., Hussain, K., Malik, A., Masoodi, K. Z., Dar, Z. A., Nazir, N., ... & Hussain, S. M. Gene action studies in cherry tomato for yield and yield attributing traits in open and protected environment.

Mahdiyeh, Z. K., & Heidari, B. (2014). Diallel cross study for estimating genetic components underlying wheat grain yield. Journal of Biological and Environmental Sciences, 8(22).

Mahmoudieh, M., Noor, M. R. M., Harikrishna, J. A., & Othman, R. Y. (2020). Identification and characterization of Ageratum yellow vein Malaysia virus (AYVMV) and an associated betasatellite among Begomoviruses infecting *Solanum lycopersicum* in Malaysia. Journal of applied genetics, 61(4), 619-628.

Mattoo A, Handa A (2017). Modelling crop growth and yield in tomato cultivation Kenneth J. Boote, University of Florida, USA. Achieving Sustainable Cultivation of Tomatoes.

Melomey, L. D., Danquah, A., Offei, S. K., Ofori, K., Danquah, E., & Osei, M. (2019). Review on tomato (*Solanum lycopersicum*, L.) improvement programmes in Ghana. Recent advances in tomato breeding and production, 49.

Miller, J. C., & Tanksley, S. D. (1990). RFLP analysis of phylogenetic relationships and genetic variation in the genus *Lycopersicon*. Theoretical and applied genetics, 80(4), 437-448.

Morales-Aguilar, J. J., Rodríguez-Negrete, E. A., Camacho-Beltrán, E., López-Luque, C. A., Leyva-López, N. E., Jiménez-Díaz, F., ... & Méndez-Lozano, J. (2019). Identification of Tomato yellow leaf curl virus, Pepper huasteco yellow vein virus and Pepper golden mosaic virus associated with pepper diseases in northern Mexico. Canadian Journal of Plant Pathology, 41(4), 544-550.

Moriones, E., & Navas-Castillo, J. (2000). Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. Virus research, 71(1-2), 123-134.

Muhammad S. Nawaz-ul-Rehman, Nazia Nahid, Muhammad Mubin, Emerging Geminiviruses (Geminiviridae), Encyclopedia of Virology (Fourth Edition), Academic Press, 2021, Pages 21-31, ISBN 9780128145166.

Naika, S., de Jeude, J. V. L., de Goffau, M., Hilmi, M., & van Dam, B. (2005). Cultivation of tomato. Production, processing and marketing, Agromisa/CTA. Revised edition.

Nakhla, M. K., Sorensen, A., Mejía, L., Ramírez, P., Karkashian, J. P., & Maxwell, D. P. (2004, June). Molecular characterization of tomato-infecting Begomoviruses in Central America and development of DNA-based detection methods. In I International Symposium on Tomato Diseases 695 (pp. 277-288).

Nevame AYM, Xia L, Nchongboh CG, Hasan MM, Alam MA, Yongbo L, Wenting Z, Yafei H, Emon RM, Ismail MR, Efisue A, Gang S, Wenhu L, Longting S (2018). Development of a new molecular marker for the resistance to tomato yellow leaf curl virus. BioMed Research International 2018: 1–10. DOI 10.1155/2018/8120281

Njock, T. E., & Ndip, R. N. (2007). Limitation in detecting African cassava mosaic geminivirus in the lignified tissues of cassava stems. African Journal of Biotechnology, 6(20).

Noha, K., Mahfouze, S. A., Ahmed, S. A., Othman, B. A., & Mahmoud, M. (2014). Characterization, Genetic Diversity of Tomato Yellow Leaf Curl Virus Egyptian Isolate. Scientia, 3(2), 58-69.

Osei MK, Prempeh R, Adjebeng-Danquah J, Opoku JA, Danquah A, Danquah E, Blay E, Adu-Dapaah H (2018). Marker-Assisted Selection (MAS): A fast-track tool in tomato breeding. Recent Advances in Tomato Breeding and Production. IntechOpen.

Papayiannis, L. C., Katis, N. I., Idris, A. M., & Brown, J. K. (2011). Identification of weed hosts of Tomato yellow leaf curl virus in Cyprus. Plant disease, 95(2), 120-125.

Peralta IE, Spooner DM, Razdan MK, Mattoo AK (2006). History, origin and early cultivation of tomato (Solanaceae). Genetic Improvement of Solanaceous Crops 2: 1–27.

Polston, J. E., & Capobianco, H. (2013). Transmitting plant viruses using whiteflies. JoVE (Journal of Visualized Experiments), (81), e4332.

Prasad A, Sharma N, Hari-Gowthem G, Muthamilarasan M, Prasad M (2020). Tomato yellow leaf curl virus: impact, challenges, and management. Trends in Plant Science 25: 897-911

Prasanna HC, Sinha DP, Rai GK, Krishna R, Kashyap SP, Singh NK, Singh M, Malathi VG (2015). Pyramiding Ty-2 and Ty-3 genes for resistance to monopartite and bipartite tomato leaf curl viruses of India. Plant Pathology 64: 256–264. DOI 10.1111/ppa.12267.

Prasanna, H. C., & Rai, M. (2007). Detection and frequency of recombination in tomato-infecting Begomoviruses of South and Southeast Asia. Virology Journal, 4(1), 1-10.

Radam, A., Islam, G. M. N., Ng, K. Y., Arshad, F. M., & Alias, E. F. (2015). Impact of producing tomatoes under Malaysia-GAP certification on farming practices, Cameron Highlands. Food and Agriculture Organization of the United Nations (FAO), 1-24.

Rahim, H., Wahab, M. A. M. A., Amin, M. Z. M., Harun, A., & Haimid, M. T. (2017). Technological adoption evaluation of agricultural and food sectors towards modern agriculture: Tomato. Economic and Technology Management Review, 12(5), 41-53.

Rahman, M. M., Hossain, M., Hossain, K. F. B., Sikder, M. T., Shammi, M., Rasheduzzaman, M., ... & Uddin, M. K. (2018). Effects of NaCl-salinity on tomato (*Lycopersicon esculentum* Mill.) plants in a pot experiment. Open Agriculture, 3(1), 578-585.

Rai, A. K., Vikram, A., & Pal, S. (2017). Genetic characterization of tomato (*Solanum lycopersicum* L.) germplasm for yield and quality traits through principal component analysis. Research Journal of Agricultural Sciences, 8(5), 1171-1174.

Ram, B. K., Singh, D., Lalchan, C. P., & Joshi, B. K. (2016). Participatory F1 hybrid seed production of tomato and It’s economic benefit. Journal of Agriculture and Environment, 17, 46-55.

Ranc, N., Muños, S., Santoni, S., & Causse, M. (2008). A clarified position for *Solanum lycopersicum* var. cerasiforme in the evolutionary history of tomatoes (solanaceae). BMC plant biology, 8(1), 1-16.

Rick CM (1988). Tomato-like nightshades: Affinities, autoecology, and breeders' opportunities. Economic Botany 42: 145–154. DOI 10.1007/BF02858915.

Rick, C. M. (1978). Potential improvement of tomatoes by controlled introgression of genes from wild species. In Proceedings of the Conference on Broadening the Genetic Base of Crops (pp. 167-173).

Rick, C. M. (1982). The potential of exotic germplasm for tomato improvement. Plant improvement and somatic cell genetics, 1-28.

Rios, C. M. C. (2015). Exploiting wild tomato genetic resources for resistance to Tomato Yellow Leaf Curl Virus (Doctoral dissertation, Wageningen University and Research).

Roff, M. M., Norowi, H. M., Perry, J. N., & Green, S. K. (2005). Analysis on the spread of a whitefly-transmitted geminivirus on tomato in Malaysia. JOURNAL OF TROPICAL AGRICULTURE AND FOOD SCIENCE, 33(2), 357.

Rojas, M. R., Gilbertson, R. L., Russell, D. R., & Maxwell, D. P. (1993). Use of degenerate primers in the polymerase chain reaction to detect whitefly-transmitted geminiviruses. Plant disease (USA).

Saleem, M. Y., Asghar, M., Iqbal, Q., Rahman, A., & Akram, M. (2013). Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.). Pak. J. Bot, 45(4), 1247-1250.

Sani, I., Ismail, S. I., Abdullah, S., Jalinas, J., Jamian, S., & Saad, N. (2020). A review of the biology and control of whitefly, Bemisia tabaci (Hemiptera: Aleyrodidae), with special reference to biological control using entomopathogenic fungi. Insects, 11(9), 619.

Sau, A. R., Nazmie, N. M. F., Yusop, M. S. M., Akbar, M. A., Saad, M. M., Baharum, S. N., ... & Bunawan, H. (2020). First Report of Pepper Vein Yellows Virus and Pepper Yellow Leaf Curl Virus Infecting Chilli Pepper (*Capsicum annuum*) in Malaysia. Plant Disease, 104(7), 2037-2037.

Shahid, M., Salim J., Abd. Manas, M., & Ahmad S. A. (2009). Manual teknologi fertigasi penanaman cili, rock melon dan tomato [Manual fertigation technology of planting chilli, rock melon and tomatoes]. MARDI Press.

Sharma, J. R. (2006). Statistical and biometrical techniques in plant breeding. New Age International.

Singh RK, Rai N, Singh AK, Kumar P, Singh B (2019). A critical review on Tomato leaf curl virus resistance in tomato. International Journal of Vegetable Science 25: 373–393. DOI 10.1080/19315260.2018.1520379.

Singh, B.D. (2001). Plant breeding: Principles and methods. Kalyani publishers, New Delhi. 896p.

Singh, M., Prasanna, H. C., Tiwari, S., Gujar, R. S., & Karkute, S. G. (2016). Biology of *Solanum lycopersicum* (Tomato). New Delhi: Ministry of Environment, Forest and Climate Change Goverment of India.

Singh, R. K., & Chaudhary, B. D. (1977). Biometrical methods in quantitative genetic analysis. Biometrical methods in quantitative genetic analysis.

Sivasubramanian J and Madhavamenon P 1973. Genotypic and phenotypic variability in rice. Madras Agric. J. 12: 15-16.

Smith, H.A.; Stansly, P.A.; Seal, D.R.; Mcavoy, E.; Polston, J.E.; Phyllis, R.; Schuster, D.J. Management of Whiteflies, Whitefly-Vectored Plant Virus, and Insecticide Resistance for Tomato Production; ENY-735; University of Florida, IFAS, Florida A&M University and Cooperative Extension Program: Gainesville, FL, USA, 2018; pp. 1–8.

Sol Genomics Network (2020). Retrieved from https://solgenomics.net/community/links/related_sites.pl.

Somraj, B., Reddy, R. V. S. K., Reddy, K. R., Saidaiah, P., & Reddy, M. T. (2017). Genetic variability, heritability and genetic advance for yield and quality attributes in heat tolerant exotic lines of tomato (*Solanum lycopersicum* L.). Journal of Pharmacognosy and Phytochemistry, 6(4), 1956-1960.

Tareq, M. Z., Sarker, M. S. A., Sarker, M. D. H., Moniruzzaman, M., Hasibuzzaman, A. S. M., & Islam, S. N. (2020). Waterlogging stress adversely affects growth and development of Tomato. Asian Journal of Crop, 2(01), 44-50.

Usman MG, Rafii MY, Martini MY, Yusuff OA, Ismail MR, Miah G (2017). Molecular analysis of Hsp70 mechanisms in plants and their function in response to stress. Biotechnology and Genetic Engineering Reviews 33: 26–39. DOI 10.1080/ 02648725.2017.1340546.

Van de Wiel CCM, Schaart JG, Niks RE, Visser RGF (2010). Traditional Plant Breeding Methods 338, Wageningen UR Plant Breeding.

Vencovsky, R., & Barriga, P. (1992). Genética biométrica no fitomelhoramento.

Vidavski FS (2007). Exploitation of resistance genes found in wild tomato species to produce resistant cultivars; pile up of resistant genes. Tomato Yellow Leaf Curl Virus Disease. pp. 363–372. Dordrecht: Springer

Vijeth, S., Dhaliwal, M. S., Jindal, S. K., Garg, N., Kaushik, P., & Sharma, A. (2019). Diallel analysis of elite tomato lines comprising leaf curl virus resistance genes. Applied Ecology and Environmental Research, 17(3), 6457-6471.

Watson B (1996). Taylor’s guide to heirloom vegetables. New York, NY.

Weerasinghe, O. R., Perera, A. L. T., De Costa, W. A. J. M., Jinadase, D. M., & Vishnukanthasingham, R. (2004). Production of tomato hybrids for dry zone conditions of Sri Lanka using combining ability analysis, heterosis and DNA testing procedures.

Welegama, T., Rafii, M. Y., Ahmad, K., Ramlee, S. I., & Oladosu, Y. (2021). Development of high yield and tomato yellow leaf curl virus (TYLCV) resistance using conventional and molecular approaches: A review. Biocell, 45(4), 1069.

Willcox JK, Catignani GL, Lazarus S (2003). Tomatoes and cardiovascular health. Critical Reviews in Food Science and Nutrition 43: 1-18.

Xia, J., Guo, Z., Yang, Z., Han, H., Wang, S., Xu, H., ... & Zhang, Y. (2021). Whitefly hijacks a plant detoxification gene that neutralizes plant toxins. Cell, 184(7), 1693-1705.

Yan Z, Pérez-de-Castro A, Díez MJ, Hutton SF, Visser RGF, Wolters AM, Bai A, Li Y (2018). Resistance to tomato yellow leaf curl virus in tomato germplasm. Frontiers in Plant Science 9: 1198. DOI 10.3389/fpls.2018.01198.

Yan, Z., Wolters, A. M. A., Navas-Castillo, J., & Bai, Y. (2021). The global dimension of tomato yellow leaf curl disease: Current status and breeding perspectives. Microorganisms, 9(4), 740.

Yang W, Bai X, Kabelka E, Eaton C, Kamoun S, van der Knaap E (2004). Discovery of single nucleotide polymorphisms in Lycopersicon esculentum by computer aided analysis of expressed sequence tags. Molecular Breeding 14: 21–34. DOI 10.1023/B:MOLB.0000037992.03731.a5.

Yildiztekin, M., Ozler, M. A., Nadeem, S., & Tuna, A. L. (2019). Investigations on the effects of commonly used pesticides on tomato plant growth. Fresenius Environ Bull, 28(1), 376-382.

Yuan, J., Zhu, Q., & Liu, B. (2014). Phylogenetic and biological significance of evolutionary elements from metazoan mitochondrial genomes. PloS one, 9(1), e84330.

Zamir D, Ekstein-Michelson I, Zakay Y, Navot N, Zeidan M, Sarfatti M, Eshed Y, Harel E, Pleban T, van-Oss H, Kedar N, Rabinowitch HD, Czosnek H (1994). Mapping and introgression of a tomato yellow leaf curl virus tolerance gene, TY-1. Theoretical and Applied Genetics 88: 141–46. DOI 10.1007/BF00225889

Zeist, A. R., Silva, A. A., Resende, J. T. V., MalufWR, G. A., Zanin, D. S., & Guerra, E. P. (2018). Tomato breeding for insect pest resistance. Recent advances in tomato breeding and production, 1-20.