Healthy Vineyards

Sustainable Farming and Changing Climates

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Vineyard Health

- ‘Health’ – the state of being **free** from illness or injury

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Vineyard Health

- ‘Health’ – the state of being **free** from illness or injury

- No way to be **totally free** of illness or injury

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Vineyard Health

- ‘Health’ – the state of being **free** from illness or injury
- No way to be **totally free** of illness or injury
- The next best option is to keep illness or injury to a minimum

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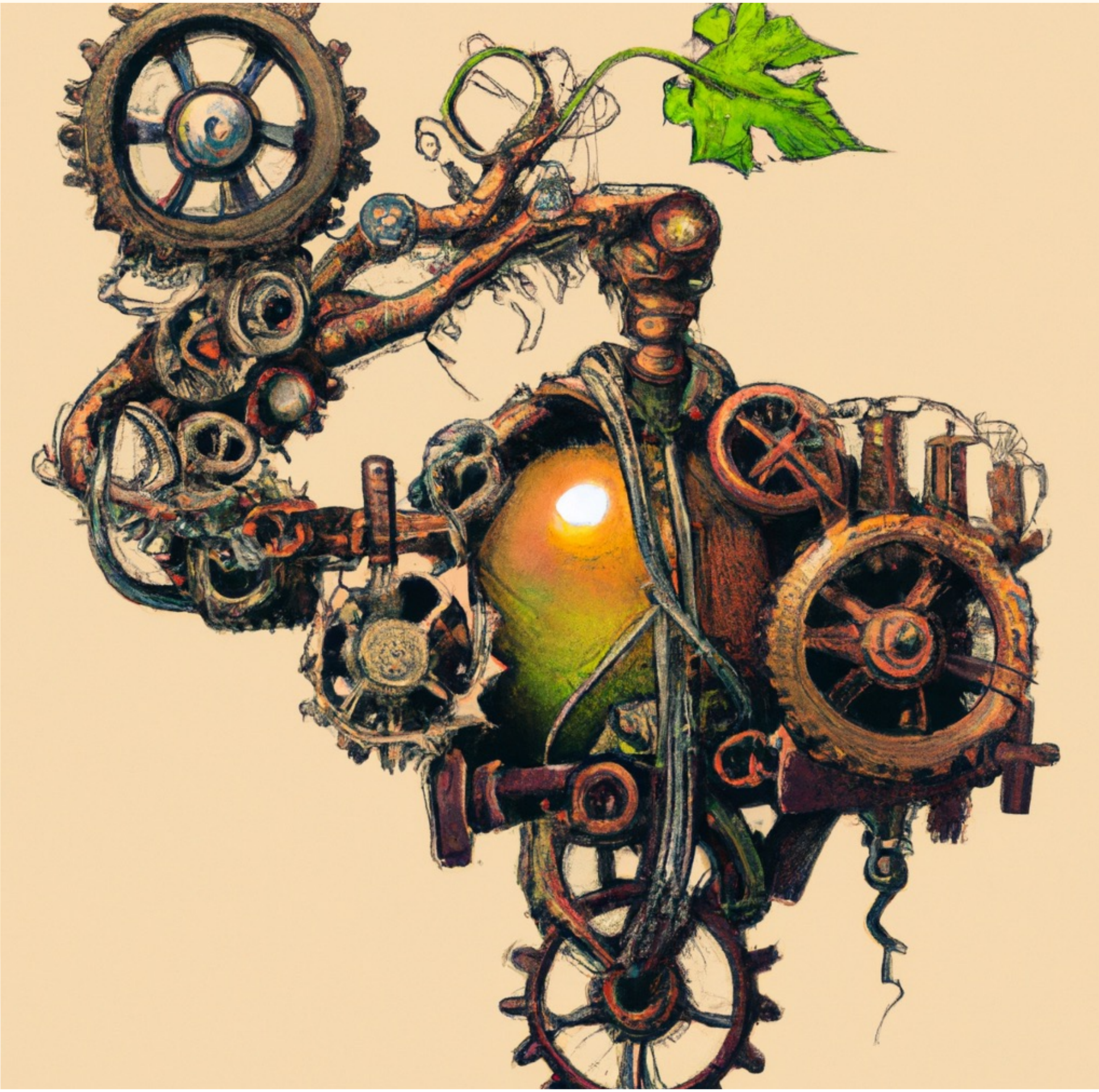
Vineyard Health

- **Vine Function ≈ Vine Health**

- Important Vine Functions
  i. Photosynthesis
  ii. Vascular system
  iii. Reproductive efficacy
  iv. Physical support

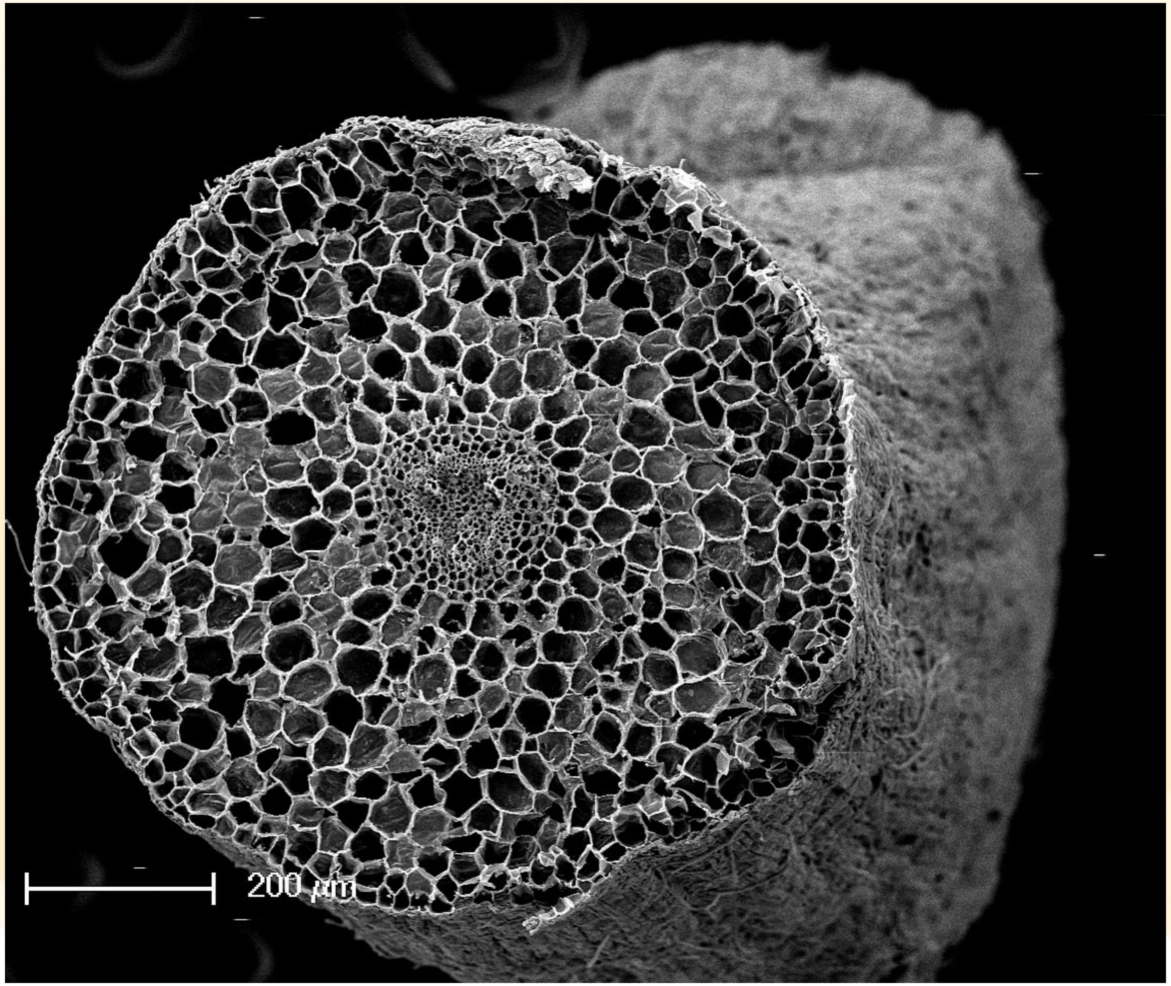


Vineyard Health

- **Photosynthesis**
  - Source = Leaves
  - Rate = Vigor & canopy size
  - Dependencies
    1. Resource availability
    2. Vascular function
    3. Minimal stressors

Vineyard Health

- **Vascular System**
  - Source = Phloem & Xylem
  - Rate
    1. Vigor & canopy size
    2. Carbohydrate production
    3. Atmospheric pull
    4. Temperatures
  - Dependencies
    1. Vascular system connectivity
    2. Xylem vessel diameters
    3. Resource availability



Vineyard Health

- **Reproductive efficacy**
  - Source = Inflorescences
  - Rate
    i. Vigor & canopy size
    ii. Grower decisions
    iii. Conditions over two years
  - Dependencies
    i. Resource availability
    ii. Temperatures
    iii. Precipitation and other disturbances

Vineyard Health

- **Physical Support**
  - Source = Trellising and Stakes
  - Dependencies
    1. Growing style
    2. Material used

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Changing Climates

- Climates are changing and impacting the factors that affect vine health.

   i. Temperatures
      - Affects all aspects of vine health

   ii. Precipitation
      - Affects all aspects of vine health

   iii. Extreme weather events
      - Heatwaves, fire, and late frost events
      - Impacts photosynthesis and reproduction

   iv. Pests and Diseases
      - Directly limits vine health

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Changing Climates

Temperatures

- Impact all living things
- Alter physiology
- Ideal range differs by species
- Range differs by cultivar too

Changing Climates

Precipitation

- Mediterranean climates with unique precipitation patterns
- Changing with the climate
- No precipitation in late-Summer
- Limits Summer diseases

Changing Climates

Extreme weather events

- Affects regions differently
- Impacts dependent on microclimates
- Existing infrastructure matters
  - Heatwaves
    - More damaging in coastal regions
  - Spring Frosts
    - More damaging inland

Climate Concerns

- Global average temperatures have risen by at least 3 ^{o}F since the start of the 20th century
- Drought persists in the West Coast
- Extreme weather events have become more frequent
- Pests and diseases are migrating or adapting

1. V Masson-Delmotte, P Zhai, H P˙ortner, D Roberts, J Skea, Shukla P.R., A Pi- rani, W Moufouma-Okia, C P´ean, R Pidcock, S Connors, J B R Matthews, Y Chen, X Zhou, M I Gomis, E Lonnoy, T Maycock, M Tignor, and T Wa- terfield. Ipcc, 2018: Global warming of 1.5àc, 2018.
2. NDMC, USDA, and NOAA. Drought in california from 2000-present, 2022.
3. Alexander Gershunov and Kristen Guirguis. California heat waves in the present and future. Geophysical Research Letters, 39, 9 2012. ISSN 0094-8276. doi: https://doi.org/10.1029/2012GL052979.

Climate Concerns

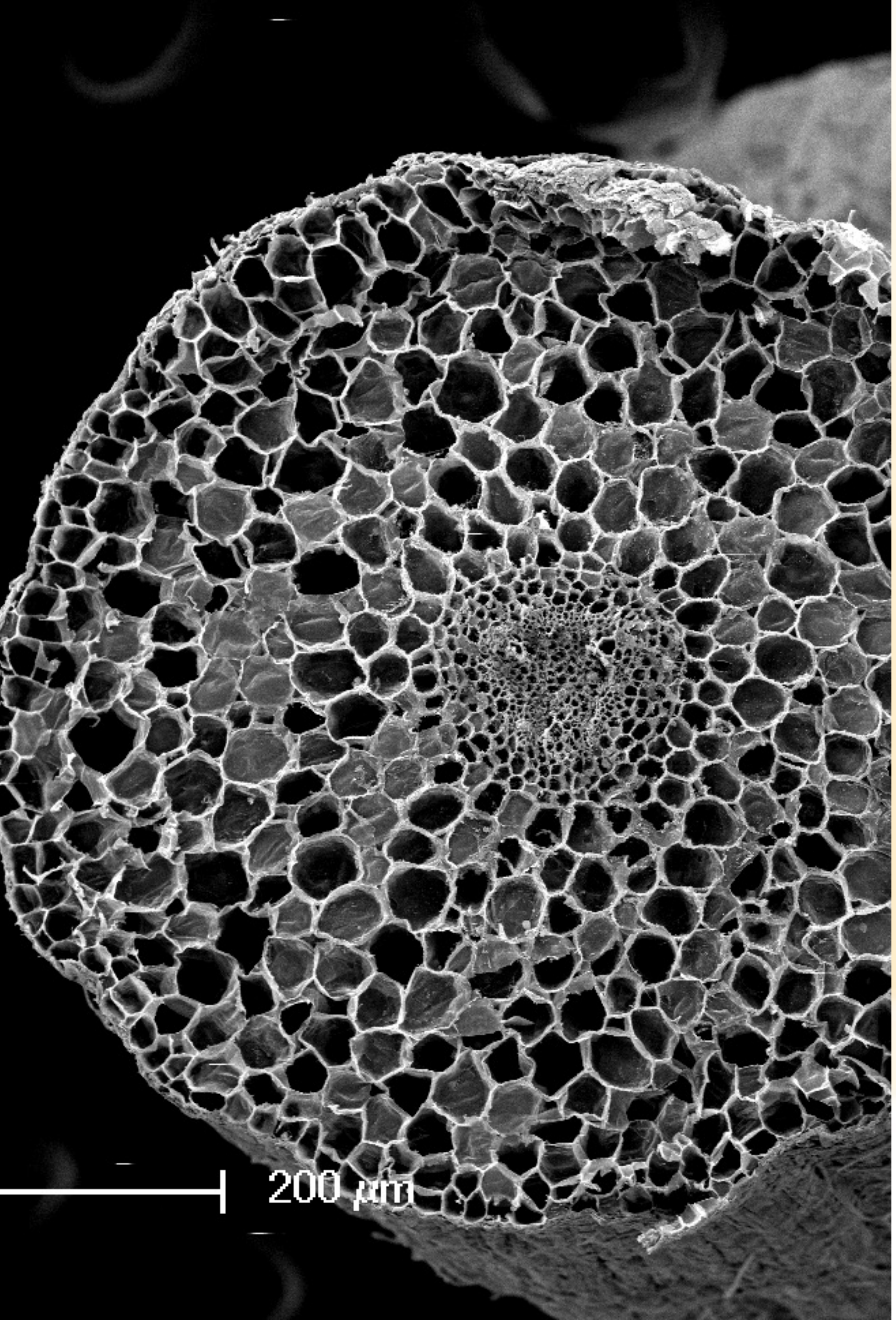
Frost damage, heat, and drought

Vine susceptibility ~ abiotic stress

No natural immune system

- Additive resistance
- Defense compound synthesis
- Abiotic stressors redirect resources

Can tolerate pests/diseases under best conditions



Physiological impact of abiotic stressors

1. Heat stress:
   - Increases vine water demand
   - Increases vine respiration
   - Timing of heat stress can increase foliar growth
     i. Resulting in more sugars for phytophagous insect pests
2. Drought stress:
   - Can result in whole-vine oxidative stress
   - Polyphenol synthesis increases (abiotic stress response)
   - Modified morphological and phenological characteristics
     i. e.g., xylem vessel size and hydraulic conductivity

4. Claudio Lovisolo and Andrea Schubert. Effects of water stress on vessel size and xylem hydraulic conductivity in Vitis vinifera L. Journal of Experimental Botany, 49(321):693–700, 04 1998. ISSN 0022-0957. doi: 10.1093/jxb/49.321.693.

Pest Responses to Climate Change

Worldwide Temperature Increases

Heatwaves have increased in frequency and severity

Fungi tolerance to high temps is bookended

- Unless they can adapt to hotter climates; opening more niches for themselves
- *Candida auris* – human fungal pathogen simultaneously emerged

Viral temperature ranges are similarly problematic

- However, viruses can adapt rapidly to new conditions

Pest and disease responses to climate change

As a result of the indirect impacts of:

1. Increased average temperatures
2. Higher atmospheric CO_2
3. More environmental pollutants
4. Changes in distribution and range of host plants

We expect to see changes in:

1. Pest and disease migratory behavior
2. Over wintering success
3. Species interactions
4. Effectiveness of pest predators and parasitoids

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Pest and disease responses to climate change

Both the pest and host can respond to changing climates in unpredictable ways (5)

Changes in temperature and atmospheric CO_2 levels have impacted the timing of generational cycles of insect species in vineyards (6, 7, 8)

- Resulting in some asynchrony between pest and predator/parasatoid

5. Rumbidzai Katsaruware, Paramu Mafongoya, and Augustine Gubba. Responses of insect pests and plant diseases to changing and variable climate: A review. Journal of Agricultural Science, 9:160, 11 2017. doi: 10.5539/jas.v9n12p160.
6. Diego Tomasi, Gregory V Jones, Mirella Giust, Lorenzo Lovat, and Feder- ica Gaiotti. Grapevine phenology and climate change: Relationships and trends in the veneto region of italy for 1964–2009. American Journal of Enol- ogy and Viticulture, 62:329, 9 2011. doi: 10.5344/ajev.2011.10108
7. Amelia Caffarra, Monica Rinaldi, Emanuele Eccel, Vittorio Rossi, and Ilaria Pertot. Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew. Agriculture, Ecosystems Environment, 148:89–101, 2012. ISSN 0167-8809. doi: https://doi.org/10.1016/j.agee.2011.11.017.
8. Sandra Skendˇzi´c, Monika Zovko, Ivana Pajaˇc Zˇivkovi´c, Vinko Leˇsi´c, and Dar- ija Lemi´c. The impact of climate change on agricultural insect pests. In- sects, 12, 2021. ISSN 2075-4450. doi: 10.3390/insects12050440.

Insect responses to climate change

Insects can respond to climate change in several ways, however three major responses that have been cited are [9] :

1. Moving to a climate more suitable to them
2. Shifting their phenology to correspond with the local changes in environmental conditions, or
3. Adapt to the new conditions and the associated impacts on the ecosystem

9. Deepa S Pureswaran, Audrey M Maran, and Shannon L Pelini. Chapter 18 - insect communities, 2021.

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Disease Expression

- Host-Pathogen interaction is broadly impacted by environmental conditions
- Certain abiotic stressors can increase susceptibility of grapevines to pathogens or trigger symptomatic expression of the pathogen (10)
- Fungal trunk diseases
  - Have expressed more symptoms in vines than usual in N. Coast
  - Two years of extreme drought followed by late spring frost and summer rains

10. A Songy, O Fernandez, C Cľement, P Larignon, and F Fontaine. Grapevine trunk diseases under thermal and water stresses. Planta, 249:1655– 1679, 2019. ISSN 1432-2048. doi: 10.1007/s00425-019-03111-8.

Overwinter Recovery – *Xylella fastidiosa*

Overwinter recovery from Pierce's Disease relies on cold Winter temperatures < 53 °F for prolonged periods (11)

Warmer winter temperatures could impede the phenomenon of overwinter recovery

Winter temperatures in California have risen around 2 °F since the 1970s (12) and made overwinter recovery of *X. fastidiosa* less likely to occur in hotter regions.

11. Helene Feil and Alexander H. Purcell. Temperature-dependent growth and sur- vival of xylella fastidiosa in vitro and in potted grapevines. Plant Disease, 85 (12):1230–1234, 2001. doi: 10.1094/PDIS.2001.85.12.1230
12. Tapan B Pathak, Mahesh L Maskey, Jeffery A Dahlberg, Faith Kearns, Khaled M Bali, and Daniele Zaccaria. Climate change trends and impacts on california agriculture: A detailed review. Agronomy, 8, 2018. ISSN 2073-4395. doi: 10.3390/agronomy8030025.

Susceptibility of stressed vines to pests and diseases

Water stress has been shown to increase transmission of *Xylella fastidiosa* in grapevines (13)

Combined biotic and abiotic stress responses in plants often involve numerous signaling pathways

Plants can tailor their response to specific stress combinations through hormone signaling, receptors, and transcription factors (14)

13. Celia Del Cid, Rodrigo Krugner, Adam R Zeilinger, Matthew P Daugherty, and Rodrigo P P Almeida. Plant Water Stress and Vector Feeding Preference Mediate Transmission Efficiency of a Plant Pathogen. Environmental Ento- mology, 47(6):1471–1478, 09 2018. ISSN 0046-225X. doi: 10.1093/ee/nvy136.
14. Venkategowda Ramegowda and Muthappa Senthil-Kumar. The in- teractive effects of simultaneous biotic and abiotic stresses on plants: Mechanistic understanding from drought and pathogen com- bination. Journal of Plant Physiology, 176:47–54, 2015. ISSN 0176-1617. doi: https://doi.org/10.1016/j.jplph.2014.11.008.

'New' diseases in vineyards

Often can be difficult to identify:

- Lime disease on the West Coast or GRBV in vineyards

Grapevine Red-Blotch Associated Viruses

- Flagship example for grapevines
- Not known until 2008 (Oakville, CA)

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Case Study: GRBV

Red blotch was an unknown disease in grapevines for decades and likely was already present in the north coast during the 20th century.

Large, clean-material vineyards used to source pathogen-free material did not know it existed and thus, did not know what to test for.

The future of our climate may increase the likelihood of new diseases we cannot test for or expression of existing pathogens becoming more problematic

Changes in pathogen virulence in vineyards

Temperatures can directly affect the biosynthesis of 2° metabolites and enzymes in GTDs and other pathogens (10)

Pest and disease pressure is likely to increase over time with invasive species benefiting from increased CO_2, higher temperatures, and better overwintering success. (15)

15. David W Wolfe, Lewis Ziska, Curt Petzoldt, Abby Seaman, Larry Chase, and Katharine Hayhoe. Projected change in climate thresholds in the northeastern u.s.: implications for crops, pests, livestock, and farm- ers. Mitigation and Adaptation Strategies for Global Change, 13:555– 575, 2008. ISSN 1573-1596. doi: 10.1007/s11027-007-9125-2.

Wetter or Drier?

- Wetter environments can lead to higher expression of fungal and bacterial diseases and may disturb insect-pest populations [5].

- Drier environments can encourage insect and viral outbreaks [5]

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Pests – Moving North

Increased functional ranges

- Changes in temperature, CO2 levels, water availability, and frequency of extreme weather events are likely to expand the range of existing insect pests in the vineyard (16).
- Preference for a given climate can help predict the spread of pathogens like GTDs using weather data and on-the-ground observations (17)
- Some pests/pathogens be more generalized than others and have higher potential to spread (10)

16. Tomasz Jaworski and Jacek Hilszczań ski. The effect of temperature and hu- midity changes on insects development their impact on forest ecosystems in the expected climate change. Forest Research Papers, 74, 12 2013. doi: 10.2478/frp-2013-0033.
17. Y Qiu, C C Steel, G J Ash, and S Savocchia. Effects of temperature and water stress on the virulence of botryosphaeriaceae spp. causing dieback of grapevines and their predicted distribution using climex in australia. pages 171–182. International Society for Horticultural Science (ISHS), Leuven, Bel- gium, 3 2016. ISBN 2406-6168. doi: 10.17660/ActaHortic.2016.1115.26.

Combined stressors: heat and drought

Changes in morphology and physiology are greater with combined stressors:

- Heat and drought in combination decrease plant growth and yields more so that each stressor individually. (10, 18)

Responses include ROS production and/or hormonal signaling (10)

Grapevine Trunk Diseases and fungi in general tend to increase growth rates at higher temperatures (25-40 °C) (10)

- However, their intracellular morphology may be modified too (19)

18. Nobuhiro Suzuki, Rosa M. Rivero, Vladimir Shulaev, Eduardo Blumwald, and Ron Mittler. Abiotic and biotic stress combinations. New Phytologist, 203 (1):32–43, 2014. doi: https://doi.org/10.1111/nph.12797.
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Insect/pathogen migration in response to changing climates

A migration of insects and pathogens is expected to move northward as climates change. [15]

- This is the case for more crops than grapevines

Temperatures and elevated CO_2 levels are essential components to estimate the potential for pest/disease migration [20]

20. Holly A. Ameden and David R. Just. Pests and agricultural production under climate change, 2001.

Pest Management Strategies for New Pest Challenges

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The unpredictable nature of climate change

We know what to expect, but not when and where to expect it

- e.g., Spring frost damage as far south as Fresno in April 2022

Extreme events are occurring more frequently and unexpectedly, with long-term weather forecasts are becoming less reliable. (21)

Impact of such events like heatwaves are more noticeable in regions unaccustomed to them (i.e., coastal heatwave impacts > inland heatwaves) (3)

21. Stephen Ornes. How does climate change influence extreme weather? impact attribution research seeks answers. Proceedings of the National Academy of Sciences, 115(33):8232–8235, 2018. doi: 10.1073/pnas.1811393115.

Tools for tolerance

1. Breeding and genetic solutions (GRN rootstocks; PD-resistant scions)
2. New monitoring techniques/Proximal sensing (LiDAR sensing; non-invasive disease ID)
3. Promotion of beneficials
4. Research on combined-stress responses in grapevines

Resistant Cultivars

Rootstocks have long been used as a method of tolerance to both biotic and abiotic stressors. [22]

- GRN rootstocks for nematode tolerance

Scions are also being developed to help impart tolerance to specific pests and/or diseases [23]

- Pierce's Disease resistant scions

22. M. Mumtaz Khan, Muhammad Tahir Akram, Rashad Waseem Khan zQadri, and Rashid Al-Yahyai. Role of grapevine rootstocks in mitigating environmental stresses: A review. Journal of Agricul- tural and Marine Sciences [JAMS], 25(2):1–12, Sep. 2020.
23. A. F. Krivanek and M. A. Walker. ¡i¿vitis¡/i¿ resistance to pierce's disease is characterized by differential ¡i¿xylella fastidiosa¡/i¿ populations in stems and leaves. Phytopathologyà, 95:44–52, 1 2005. ISSN 0031-949X. doi: 10.1094/PHYTO-95-0044.

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New Monitoring Solutions

Remote sensing for pest and disease monitoring in vineyards

Examples

1. LiDAR sensing and modeling to identify flying insects on site
2. Radio Wave surveys of internal biological components of a living vine
3. Drone-based NDVI for disease impacted vines

Promotion of Beneficials

New phenological cycles of phytophagous insect pests may require a 'reworking' of our understanding of efficacy of certain beneficial species.

An asynchronous hatching of pest and beneficial may lead to a decline in their effectiveness

New distribution methods may increase survival rate of introduced beneficials in vineyards

- e.g., Drone-distributed beneficial mites

Research into combined stress responses

Plant responses to combined stressors may be unique to the specific combination of stressors.

- e.g., drought and *Xylella fastidiosa*

Research on phytotoxic metabolite biosynthesis in response to changing environmental conditions (10)

Combined stressors may be thought of as a third-type of stress beyond biotic and abiotic (14)

Other Promising Research

Biostimulants [24]

- Formulations of natural substances and/or microorganisms used to improve vine health and efficiency or tolerance from abiotic or biotic stressors.
- Currently show promise as a buffer against stress damage in grapevines
- But much more research is needed
  1. What mechanisms does each biostimulant act on to induce the observed results?
  2. What are safe levels of application?
  3. What phenological stage should they be applied at?
  4. How and how often should they be applied?

24. Eliana Monteiro, Berta Gon¸calves, Isabel Cortez, and Isaura Castro. The role of biostimulants as alleviators of biotic and abiotic stresses in grapevine: A review. Plants, 11(3), 2022. ISSN 2223-7747. doi: 10.3390/plants11030396.

Summary

1. Climate change is unpredictable
2. The impact on both host and pathogen must be accounted for when designing any IPM strategy for changing climates
3. Existing solutions are in development to address larger functional ranges for pests and diseases
4. Research is still needed in most cases for grapevine responses to combined stressors and potential methods of stress alleviation

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Thank You

Sources

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