Tri-Nut Irrigation Project for the North-East Catchment Area

The Phenology of Chestnuts, Hazelnuts & Walnuts

Trevor Ranford & Associates, 29th November 2023

Contents

This project is managed by the North-East Catchment Management Authority and funded by the Victorian Government through Agriculture Victoria.

This phase of the project involves recording the phenological scales used for each of the nuts. Considerable work on climate change scenarios has already been carried out by the North-East CMA, and this work has served as a framework to develop, suggest and comment on adaptations and strategies that will assist growers in coping with climate change.

Hazelnut Growers of Australia is the lead industry organisation for this “Tri-Nut” project in cooperation with Chestnuts Australia and the Australian Walnut Industry Association.

1. EXECUTIVE SUMMARY

The Tri-Nut Irrigation Project's "Milestone 3: The Phenology of Chestnuts, Hazelnuts & Walnuts" report, authored by Trevor Ranford & Associates (29th November 2023), provides an in-depth analysis of the phenological stages of these nut trees and their response to climate change. The report serves as a comprehensive guide for Australian growers in the North-East Catchment Area, offering strategic adaptation methods to cope with the evolving climate conditions.

Key sections from the report include:

- **Chestnut Phenology & Climate Change**: It details the eight principal growth stages of chestnuts, emphasizing the importance of understanding these stages for effective cross-pollination and yield optimization. The report addresses the impact of climatic factors like temperature, precipitation, and pests on chestnuts, highlighting the challenges of extreme temperatures and water stress. Adaptation strategies focus on varietal selection, water management, soil health, and pest control.
- **Hazelnut Phenology & Climate Change**: This section outlines the consolidated phenological scale for hazelnuts and examines the variable impact of climate change on hazelnut farming, especially in southeast Australia. Strategies for adaptation include varietal selection for climate resilience, efficient water management, enhanced soil health, and pest management in the context of changing climate conditions.
- **Walnut Phenology & Climate Change**: The report presents a BBCH scale for walnuts and discusses the climatic factors affecting walnut cultivation, including temperature, chilling requirements, and precipitation. Adaptation strategies include selecting climate-resilient varieties, managing water and soil health effectively, adjusting planting schedules, and implementing pest and disease control measures.

Across all sections, the report emphasizes the need for better grower knowledge, sustainable practices, technological innovations, and research collaboration to ensure the resilience and productivity of north-east nut orchards in the face of climate change. The Tri-Nut project, led by Hazelnut Growers of Australia in collaboration with Chestnuts Australia and the Australian Walnut Industry Association, highlights the importance of industry cooperation and knowledge sharing to navigate the challenges posed by a changing climate.

2. Chestnut Phenology & Climate Change

2.1 Introduction

Chestnut trees (Castanea spp.) are economically significant in Australia where they are cultivated for their nutritious nuts. The phenology, or the study of seasonal plant life events, needs to be considered when selecting chestnut varieties for orchard cultivation.

The BBCH (Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie) scale, is a universal phenological scale which builds upon several phenological scales already used in some European countries for chestnuts.

Recent work by Larue et al. (2021)[1] has involved adapting the BBCH scale for chestnuts. This scale now encompasses eight of the ten principal growth stages typical for fruit trees and includes secondary growth stages unique to chestnut trees.

Chestnut trees are self-incompatible, necessitating the presence of different varieties within orchards for successful cross-pollination and fruit production. This underscores the importance of understanding the phenology of different varieties to ensure effective cross-pollination and optimal yield in chestnut orchards.

For chestnuts, there are eight main stages:

Stage	Physiological events
0	Sprouting/Bud development
1	Leaf development
3	Shoot development
5	Catkins growth (unisexual catkins / Female inflorescences / bisexual catkins)
6	Flowering (Male flowers of unisexual catkins / Female flowers / Male flowers of bisexual catkins)
7	Burr development
8	Fruit maturity
9	Leaf senescence

Each of these stages can be broken down further to reflect a more exacting description of the physiological changes happening in the plant. These changes are shown in Table 1.

[1] Larue, C., Barrenechec, T. & Petita, R. (2017) "Efficient monitoring of phenology in chestnuts", Doctorate thesis, Univ. Bordeaux. Published in Scientia Horticulturae 281 (2021). Retrieved 19OCT23 from https://doi.org/10.1016/j.scienta.2021.109958.

Table 1
Phenological growth stages of chestnuts according to the BBCH scale.

BBCH Code	Description
Stage 0: Sprouting/Bud development	
0	Dormant buds
07	Beginning of bud break
09	Green leaf tips visible: first green leaf tips just visible
Stage 1: Leaf development	
11	First leaves unfolded
15	More leaves unfolded, not yet at full size
19	All leaves unfolded and fully expanded
Stage 3: Shoot development	
31	Beginning of shoot growth
35	Shoots about 50 % of final length
39	Shoots about 90 % of final length
Stage 5: Catkins growth (unisexual catkins / Female inflorescences / bisexual catkins)	
Male catkins (unisexual or bisexual)	
50	Appearance of male catkins
55	Glomerules are visible, male catkins grow
59	Glomerules well differentiated, male catkins about 90 % of final length
Female inflorescences	
50	Appearance of buds of female inflorescences
55	Buds of female inflorescences are visible, bisexual catkins grow
59	Female inflorescences well differentiated, bisexual catkins about 90 % of final length

Stage 6: Flowering (Male flowers of unisexual catkins / Female flowers / Male flowers of bisexual catkins)

Male flowers (unisexual or bisexual catkins)

60	First male flowers open
61	Beginning of the flowering: 10–20% of male flowers open
62	20–30% of male flowers open
63	30–40% of male flowers open
64	40–50% of male flowers open
65	Full flowering: at least 50 % of male flowers open
67	Catkins fading: at least 50 % of brown male catkins
69	End of flowering: at least 50 % of male catkins have fallen

Female flowers (Option 1): Phenotypic stages

60	Female flowers visible
61	Stigmas of the central flower of the inflorescence visible
63	Stigmas of the central flower elongated, stigmas of lateral flowers visible
65	Full receptivity: stigmas of three female flowers are well developed
67	At least 50 % of female flowers have brown stigmas
69	End of flowering: all female flowers have brown stigmas

Female flowers (Option 2): Receptivity

61	Beginning of the flowering: 10–20% of female flowers are receptive
62	20–30% of female flowers are receptive
63	30–40% of female flowers are receptive
64	40–50% of female flowers are receptive
65	Full flowering: at least 50 % of female flowers are receptive
67	At least 50 % of female flowers have brown stigmas
69	End of flowering: all female flowers have brown stigmas

Stage 7: Burr development

72	Involucre is 3× larger than when the female inflorescence was receptive
75	Burrs about 50 % of final volume
79	Burrs about 90 % of final volume

Stage 8: Fruit development

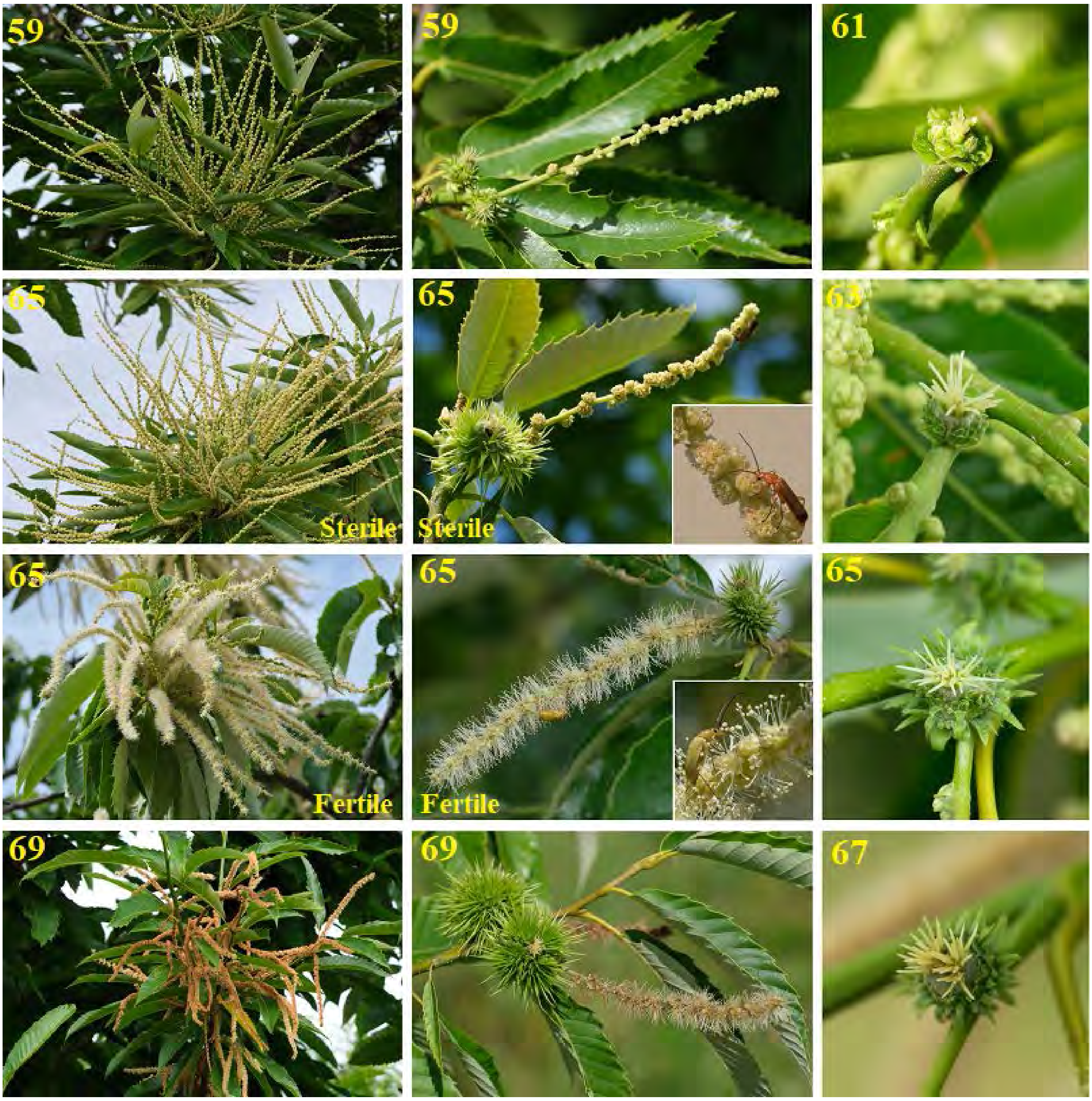
81	Burrs turn brown
83	First burrs open
85	At least 50 % of burrs open
87	At least 50 % of chestnuts/burrs fallen
89	All chestnuts/burrs fallen

Stage 9: Leaf senescense

90	Leaves begin to discolor or start to fall
91	About 10 % of leaves discolored or fallen
95	About 50 % of leaves discolored of fallen
97	All leaves fallen

Table 2

Images of Flowering phases of chestnuts with BBCH code. (Courtesy: Clements Larue)



2.2 Climatic factors and chestnuts

The impact of climate factors such as temperature, chill and post-chill warmth, and precipitation on chestnut growth highlights the complex interplay between environmental conditions and agricultural practices. Here's a breakdown of these key factors:

Temperature

1. **Heat tolerance**: "The chestnut tree tolerates well maximum temperatures up to 27–31 °C."[2] This means that there are consequences when trees are exposed to extreme temperatures, particularly over 40°C, as often experienced in many Australian growing areas.
2. **Impact on yield**: "..extreme summer or winter temperatures may restrict chestnut tree yield performances"[3]. This might be due to stress on the trees or disruption of the flowering and fruiting processes.
3. **Increased frost risk**: Higher temperatures can also lead to an increased risk of frost, possibly due to changing weather patterns and the timing of cold snaps.
4. **Pollination changes**: Warmer, drier conditions with lower humidity can enhance pollination but may also alter the synchrony of pollination among different varieties, which could affect cross-pollination and nut set.
5. **Earlier harvests**: Higher temperatures might lead to earlier harvests, impacting the agricultural calendar and market dynamics.
6. **Positive Effects**: In some environments, these temperature changes might have positive implications, perhaps by extending the growing season or improving certain aspects of fruit development.

Chill and Post-Chill Warmth

1. **Budburst timing**: "Budburst timing depends on the exposure to cool temperatures (chilling) to release dormancy, followed by optimal temperatures to promote plant growth in spring."[4] Different varieties may respond differently due to genetic variations.
2. **Impact of cooler temperatures post-budburst**: Cooler temperatures following budburst can delay ripening, thus pushing back the maturation of the fruit.

Precipitation

1. **Essential for growth**: Precipitation is crucial for chestnut growth, affecting soil moisture and overall plant health.
2. **Impact of reduced precipitation**: A decrease in precipitation can lead to soil water deficits and plant water stress, affecting growth and development, reducing leaf size and number, and potentially impacting fruit quality.
3. **Findings from Ciordia, M. et al. (2012)**: Their work with chestnut trees showed that:

> "The restricted water supply reduced the water potential of all the families as well as their growth, both in terms of height and weight. Root development increased whilst leaf area decreased as a result of reduction in number and surface area of individual leaves as well as

[2] Freitas,T., Santos, J.,Silva, A. & Fraga, H. 2021 "Influence of Climate Change on Chestnut Trees: A Review" Retrieved 13NOV23 from. doi: 10.3390/plants10071463
[3] ibid
[4] ibid

sprouting rather than through defoliation. Drought stress also modified the morphology of the leaves and the relationships indicating the rate of relative development of the leaves compared to the rest of the plant.[5]"

4. **Drought and mortality risk**: Chestnuts are particularly susceptible to water stress during droughts, increasing the risk of tree mortality. The duration of drought periods is a significant climatic limitation for chestnut growth.

Pests and Diseases

The impact of climate change on pest and disease patterns in chestnut cultivation is a critical issue. As the climate changes, the prevalence and severity of various pests and diseases can shift, posing new challenges for growers. Here's an overview of how climate change might affect specific pests and diseases associated with chestnuts:

1. **Chestnut blight:** Chestnut blight poses a significant risk to Australia's chestnut industry, approximately 70 per cent of which is produced in Victoria.[6] Caused by the fungus *Cryphonectria parasitica*, there could see an increased risk as climate stress intensifies. Warmer temperatures and altered moisture conditions can create environments conducive to the spread of this pathogen.
2. **Chestnut rot:** While the fungus *Gnomoniopsis smithogilvyi* is a critical post-harvest disease impacting chestnuts in Australia, the fungus is found within the orchard well before nut development. Climatic conditions play a significant role in the disease's prevalence. Cool and wet weather during the summer and autumn seasons tends to favour the development of chestnut rot. Conversely, hot and dry conditions during the growing season can inhibit the disease's progression.[7]
3. **Phytophthora**: "Phytophthora diseases [are] likely to increase with climate change. Milder and wetter winters, followed by increased spring rainfall, are likely to enhance the survival and infection potential of many tree pathogens."[8]
4. **Verticillium wilt**: Verticillium wilt, also known as blackheart, is caused by the fungus *Verticillium dahliae*. Chestnut trees are susceptible to this disease, which is usually observed in early summer as a progressive loss of leaves from infected limbs, starting at the base of each branch. Leaves may become yellow and dull in appearance before dropping prematurely. By late summer, only a tuft of leaves may remain at the tip of a severely affected branch. Caused by soil-borne fungi, Verticillium wilt could become more prevalent with increased drought conditions. [9]
5. **General Observations**: Humid conditions typically increase the risk of fungal infections, as many fungi thrive in warm, moist environments. Conversely, a reduction in humidity around harvest time can improve conditions, potentially reducing the incidence of fungal diseases and facilitating better harvest conditions.

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[5] Ciordia, M.; Feito, I.; Pereira-Lorenzo, S.; Fernández, A.; Majada, J. 2012 "Adaptive diversity in Castanea sativa half-sibs in response to drought stress". Environ. Exp. Bot. 2012, 78, 56–63. Retrieved 14NOV23 from DOI:10.1016/j.envexpbot.2011.12.018 (Accessed 14NOV23)

[6] Agriculture Victoria and Chestnuts Australia Inc; 2022 "Guide to managing chestnut blight", Retrieved 14NOV23 from www.chestnutsaustraliainc.com.au

[7] Agriculture Victoria, 2023 "Chestnut rot", Retrieved 22NOV23 from www.agriculture.vic.gov.au)

[8] Matika, D. et al, 2022 "Climate change and tree diseases (Phytophthora)", FactSheet for Forest Research, UK. Retrieved 210NOV23 from www.forestresearch.gov.uk/publications/factsheet-climate-change-and-tree-diseases-phytophthora

[9]Agriculture Victoria, 2022 "Verticillium wilt of deciduous fruit trees", Retrieved 23NOV23 from www.agriculture.vic.gov.au

2.3 Climate change impacts on tree growth

Climate change has significant implications for the cultivation of chestnuts. For chestnuts these include:

1. **Biodiversity and ecosystem impact**: Climate is a primary factor influencing biodiversity and ecosystem dynamics. Changes in the physical environment affect physiological processes in plants... such as respiration, photosynthesis... and water use efficiency.[10]
2. **Crop microclimate alterations**: Climate is considered one of the main drivers of biodiversity and ecosystem change. With climate change, modifications in crop microclimate conditions are projected to occur, with implications in the suitability of a given region to grow a specific crop. Climate change may modify the physiological and reproductive cycles of species, like anticipating or delaying phenological timings, with implications on yields and fruit quality characteristics.[11]
3. **Chestnut trees and climate**: Climate change has influenced the development of ... chestnut trees at phenological, physiological, biodiversity, and genetic levels. As much as ... the plant reveals acclimatisation characteristics, this will not be enough to overcome the new challenges. In the case of chestnuts, short- and long-term adaptation measures will have to be applied, such as irrigation and/or the application of protective compounds.[12]
4. **Warmer temperatures and longer growing seasons**: Changes in the seasons as a result of global warming can have serious consequences on plants and ecosystems. Plants have evolved to seasonal cycles. Seasonal temperature changes trigger flowering and pollinations which are essential to reproduction. Shifting seasons are directly linked to warmer global temperatures: a slight change in temperature can bring an earlier spring and delay the first frost until later in autumn. [13]
5. **Extreme weather events**: Across Australia, extreme weather events are projected to worsen as the climate warms further. Heatwaves are becoming hotter, lasting longer and occurring more often. Extreme heat is projected to increase across the entire continent, with significant increases in the length, intensity and frequency of heatwaves in many regions. Extreme fire weather and the length of the fire season is increasing, leading to an increase in bushfire risk. The intensity of extreme rainfall events is also projected to increase across most of Australia. The time spent in drought is projected to increase across Australia, especially in southern Australia. Extreme drought is expected to increase in both frequency and duration.[14]
6. **Impact on crop physiology and reproduction**: High temperatures can influence fruit trees at multiple levels, including morphological, physiological and molecular. At the phenological level, high temperatures can decrease flowering, premature fruit drop and the incidence of fruit deformities and it can also slow fruit growth. While at the physiological level, heat stress can affect the rates of photosynthesis and transpiration, and the concentrations of various hormones and soluble osmolytes.[15]

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10 Steffen, W. et al 2009, "Australia's Biodiversity and Climate Change", Department of Climate Change. Retrieved 26NOV23 from https://www.dcceew.gov.au/sites/default/files/documents/biodiversity-vulnerability-assessment.pdf

[11] Freitas,T. et al (2021) pg 4

[12] ibid pg 13

[13] Dykes, J. 2021. "As the world warms, the seasons are shifting", Retrieved 27NOV23 from www.geographical.co.uk/climate-change/as-the-world-warms-the-seasons-are-shifting

[14] South-west Climate Change Portal 2023, "Extreme Weather Events" Retrieved 26NOV23 from www.swclimatechange.com.au

[15] Li, S. et al. 2023, "Responses and adaptations of fruit trees to high temperatures", Retrieved 25NOV23 from www.maxapress.com/article/doi/10.48130/FruRes-2023-0023

7. **Yield and quality concerns**: When temperatures exceed the optimal range for a particular tree-fruit species, depending on phenological stage, a whole range of growth effects will appear, including poor pollination or fertilisation, slowed fruit growth and early senescence of the leaves. Heat stress can also cause sunburn and wilting of the fruit, both of which impair fruit quality.[16] In the case of chestnuts, this could mean changes in size, taste, or nutritional content.

2.4 Adaptation strategies for climate change

Adapting to climate change is crucial for sustainable chestnut cultivation in Australia. Here are some key strategies that can be employed:

1. **Choice of varieties:** Selecting chestnut varieties that are better adapted to warmer temperatures or have a lower chilling requirement can help in coping with rising temperatures and changing winter conditions. However, finding new drought-hardy varieties of chestnut trees presents a range of challenges, particularly in the context of changing climate conditions and the specific needs of these tree species. Here are some key issues:

    - Genetic Diversity and Breeding Timeframes: Chestnut trees have relatively long breeding cycles. This makes the process of developing new drought-resistant varieties time-consuming. Moreover, the genetic diversity available within these species can limit the scope of developing traits like drought resistance.
    - Climate Change and Unpredictable Weather Patterns: Climate change is leading to more extreme and unpredictable weather patterns, including prolonged droughts. This unpredictability makes it difficult to breed tree varieties that can cope with all possible future conditions.
    - Soil and Water Requirements: Chestnuts have specific soil and water needs. Developing varieties that require less water without compromising the quality and yield of the nuts is a complex task. Drought-hardy trees might also need to adapt to different soil types where water retention is lower.
    - Disease Resistance and Overall Health: Any new variety developed for drought resistance must also maintain or enhance resistance to diseases and pests. Drought conditions can stress trees, making them more susceptible to diseases and pests, which further complicates the breeding process.
    - Economic and Market Factors: The development of new varieties must also consider market demands. Nut quality, size, and taste are important for commercial viability. There's a need to balance these qualities with drought resistance, which might sometimes be at odds.
    - Long-term Adaptation and Sustainability: Trees are long-term investments. Varieties that are drought-hardy now might need to adapt to future environmental changes over decades. Ensuring long-term sustainability and adaptability of these varieties is a significant challenge.
    - Resource Allocation and Research Support: Adequate funding and resources for research into breeding and testing new varieties are essential. This includes support for both field trials and laboratory research, which can be resource-intensive.

[16] Li, S. et al. 2023, "Responses and adaptations of fruit trees to high temperatures", Retrieved 25NOV23 from www.maxapress.com/article/doi/10.48130/FruRes-2023-0023

2. **Water management**: Efficient water use is critical, especially with the increased likelihood of drought conditions. Implementing drip irrigation systems, mulching to retain soil moisture, and potentially investing in water storage facilities can be effective.
3. **Soil health management**: Maintaining soil health is vital for chestnut trees, especially under changing climatic conditions. Practices like cover cropping, composting, and reduced tillage can improve soil structure, fertility, and water retention.
4. **Shade and windbreaks**: Use of shade cloth during extreme heat events and planting windbreaks can protect trees from heat stress and wind damage. This can also aid in reducing evapotranspiration rates during hot periods.
5. **Pest and disease management**: Climate change may alter the prevalence and severity of pests and diseases. Integrated Pest Management (IPM) strategies will need to be adjusted accordingly. This includes regular monitoring, biological controls, and selective use of pesticides and fungicides.
6. **Altered planting and harvesting schedules**: Adjusting the timing of planting and harvesting to suit the changing climate conditions can help in optimising the yield and quality of chestnuts.
7. **Pruning and canopy management**: Effective pruning can help in managing tree health, including improving air circulation within the canopy to reduce disease risk and managing sun exposure to prevent sunburn on fruits and branches.
8. **Use of technology**: Employing technology like weather forecasting tools, soil moisture sensors, and climate modelling can aid in making informed decisions about irrigation, pest control, and other management practices.
9. **Building resilience**: Diversifying crops and income sources, and investing in insurance schemes can help in building economic resilience against the impacts of climate change.

These strategies require ongoing evaluation and adaptation, as the impacts of climate change can vary over time and by region. Collaboration with agricultural extension services, research institutions, and climate experts can also provide chestnut growers with the latest information and best practices for adapting to climate change in Australia.

3. Hazelnut Phenology & Climate Change

3.1 Introduction

The European hazelnut is a deciduous shrub or small tree that grows from 3-10 m in height, occasionally up to 15 m. In cultivation, the plants are usually trained to a single trunk with a vase-shaped branch structure arising from the trunk, 20-80 cm above ground level. In some situations they are trained to just a few stems as a multi-stem bush. Hazelnuts are monoecious, with separate male and female flowers. The plants are wind pollinated and self-incompatible. Flowering and pollination occur from late autumn through to late winter. However, fertilisation does not occur until late spring or early summer.[17]

A number of systems to describe the growth stages (phenology) of hazelnuts have been developed. These include:

[17] Baldwin, B. 2015, The Growth and Productivity of Hazelnut Cultivars (*Corylus avellana* L.) in Australia, University of Sydney, p72, Ph.D. thesis

- The International Union for the Protection of New Varieties of Plants (UPOV) descriptor (1979) which classify hazelnut phenological stages from the time of leaf budbreak to leaf fall
- The International Plant Genetic Resources Institute (IPGRI) descriptor (2008)
- The Italian phenological scale (GFI system, Malossini, 1993)
- The French phenological scale (Germain and Sarraquigne 2004)
- In 2022, Taghavi, Rahemi and Suarez[18] proposed a standardised phenological coding model for hazelnut orchards based on the guidelines of the BBCH (Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie) coding method.
- In 2023, Toillon et al[19] merged all the above scales into proposed a consolidated phenological scale which has been used in this report.

Table 3: Eight growth stages for hazelnuts[20]

Code	Physiological events
0	Bud development
1	Leaf development
3	Stem elongation
5	Male inflorescence emergence
6	Male and female flowering
7	Fruit development
8	Fruit ripening
9	Dormancy or winter rest

Each of these 8 stages can be broken down further to reflect a more exacting description of the physiological changes happening in the plant.[21] These descriptions are shown in Table 4 and 5.

[18] Taghavi, T. et al, 2022, "Development of a uniform phenology scale (BBCH) in hazelnuts", Scientia Horticulturae, Vol. 296, 5 April 2022. Retrieved 27NOV23 from https://doi.org/10.1016/j.scienta.2021.110837

[19] Toillon, J; Hamidi, R; Paradinas, A; Ramade, L; Thomas, M; Suarez, E. (2023). "Consolidated BBCH scale for hazelnut phenotyping". Acta Horticulturae. 159-168. 10.17660/ActaHortic.2023.1379.23.

[20] ibid

[21] *Toillon, J; Hamidi, R; Paradinas, A; Ramade, L; Thomas, M; Suarez, E. (2023). "Consolidated BBCH scale for hazelnut phenotyping". Acta Horticulturae. 159-168. 10.17660/ActaHortic.2023.1379.23.*

Table 4: Growth stages 00 – 69

BBCH code	Description
Bud development	
00	Dormant buds, no distinction between glomerulus and vegetative buds
07	Beginning of vegetative bud swell
09	Green leaf tip perceptible
Leaf development	
10	Green leaf tips 10 mm above the bud scales
11	First leaf spread
12	Second leaf spread
13	Third leaf spread
14	More than three leaves spread on shoot
17	Most leaves unfolded in most of the trees
19	The leaves are fully developed
Stem elongation	
30	Starting of stem elongation
31	<10% of final stem length
35	>50% of final stem length
39	>90% of final stem length; cessation of stem growth
Inflorescence emergence	
51	Pink tip of catkins emerging from the bud
53	Catkins visible but peduncles are not yet fully developed
55	All young catkins and their peduncles visible
57	Catkins 4-5 cm long
59	Separation of the protective bracts
Flowering (male organs, catkins)	
60	Well-differentiated anthers taking a yellow coloration
61	5% to 50% of catkins on trees elongated
65	51% to 75% of catkins on trees elongated
67	End of flowering: browning of anthers
68	Drying of catkins
69	Dried catkins fall
Flowering (female organs, glomeruli)	
600	Red dot stage
611	Styles exserted from 10 to 50% on 10 to 50% of flowers on the tree
615	Styles exserted from 10 to 50% on 51 to 100% of flowers on the tree
651	Styles exserted from 51 to 70% on 10 to 50% of flowers on the tree
655	Styles exserted from 51 to 70% on 51 to 100% of flowers on the tree
671	Styles exserted from 71 to 100% on 10 to 50% of flowers on the tree
675	Styles exserted from 71 to 100% on 51 to 100% of flowers on the tree
691	Future fruits visible on 10 to 50% of flowers
695	Future fruits visible on 51 to 100% of flowers

Table 5: Growth stages 70 – 99

BBCH code	Description
Fruit development (nuts and kernel)	
710	Shell reaches about 10 to 50% of the final size
750	Shell reaches about 51 to 100% of the final size. Kernel has not begun to grow
751	Shell reaches about 51 to 100% of the final size. Kernel reaches about 10 to 50% of the final size
755	Shell reaches about 51 to 100% of the final size. Kernel reaches about 51 to 100% of the final size
799	Shell and kernel reach 100% of their final size
Fruit ripening (coloration change)	
81	10 to 50% of the shells has changed colour
85	51 to 100% of the shells have changed colour
89	Nuts separate from the husk at the basal scar. The basal scar turns brown, and the nuts fall freely from the husk at maturity for 'Barcelona' hazelnut. In other cultivars (including many Turkish types), the entire cluster dehisces and falls to the ground
891	<10% dropped nuts
895	>50% dropped nuts
899	Nuts have completely dropped to the ground
Senescence	
91	>90% of leaves have elongated to their mature size, are still green, and prepared to go dormant
92	Beginning of leaf blanching, the leaves take on colours different from green due to senescence
921	10% of discoloured/desiccated leaves
923	25% of of discoloured/desiccated leaves
925	50% of discoloured/desiccated leaves
927	75% of discoloured/desiccated leaves
929	100% of discoloured/desiccated leaves
93	Beginning of leaf fall.
95	50% to 70% of the leaves have fallen
97	>90% leaf abscission. Winter dormancy period. Branches are bare

3.2 Climatic factors, yields and hazelnuts

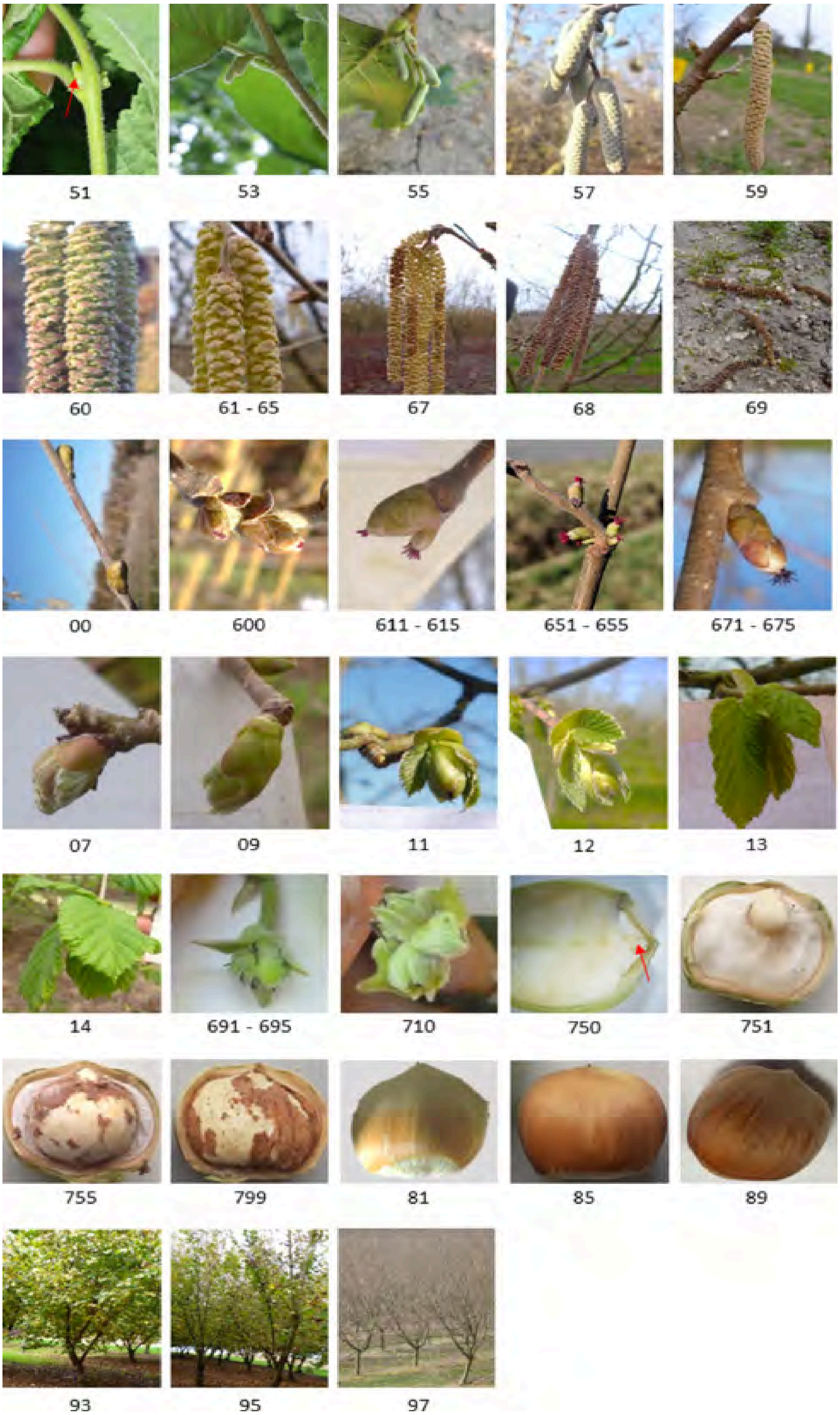
The effect of climate change on hazelnut farming is variable across agro-climatic zones, except in the southeasternmost part of Australia, where all simulations agree in predicting a yield increase ranging from 18 to 52%.[22]

Temperature increase can have beneficial effects on hazelnut production. The damages to catkins, female flowers and early leaves from severe winter temperature are expected to be less frequent in the future. Temperature increase can also have positive effects on pollen fertilisation, kernel filling and in preventing damage to the newly emerged shoots.

A number of recent studies report that an increase in the number of days with maximum temperature higher than 35°C and relative humidity lower than 70% caused severe water stress leading to yield

[22] Jha, P; Materia, S; Zizzi, G; Costa-Saura, J; Trabucco, A; Evans, J; Bregaglio, S. 2020. "Climate change impacts on phenology and yield of hazelnut in Australia". Agricultural Systems. 186. 102982. 10.1016/j.agsy.2020.102982.

Table 6: Images corresponding to the consolidated BBCH scale.



Images: Courtesy Dr J. Toillon

decline and shortened vegetative growth, combined with a reduction in kernel filling and weight. An increase in minimum temperature during the cold season could limit the accumulation of chilling hours required to break dormancy of vegetative buds, and to trigger pollen shed and female anthesis.[23]

There is no agreement among climate models regarding the future changes in precipitation. Some models are projecting drier conditions over most of southeast Australia, while other models are projecting an increase in precipitation.[24] Irregular rainfall and droughts can be mitigated through implementing efficient water management strategies such as drip irrigation and water storage systems.

The timing and intensity of frosts are changing. Unseasonal late frosts can damage blossoms and young nuts, while reduced frost in winter can affect the chilling requirements.

Changing climate conditions can influence the prevalence and distribution of pests and diseases that affect hazelnut trees. Warmer temperatures might allow some pests and diseases to thrive or expand their range.

Hazelnuts rely on wind for pollination. Changes in wind patterns, as well as alterations in the synchrony between pollen release and female flower receptivity due to temperature changes, can impact pollination success.

Pests and Diseases

In Australia, hazelnut orchards face various pests and diseases, and the impact of climate change is likely to influence the prevalence and severity of these challenges. These impacts include:

- Increased temperatures which can accelerate the lifecycle of many pests, potentially leading to more generations per season and higher population densities.
- Altered rainfall which can affect disease prevalence, especially those that thrive in moist conditions or are spread by water splash
- Climate change-induced drought can weaken hazelnut trees making them more susceptible to pests and diseases
- Migration of pests and diseases into new areas where they were previously not a concern
- Adjustments in pest and disease management strategies such as the timing and type of treatments applied.

3.3 Climate change impacts on tree growth

Climate change has significant implications for the cultivation of hazelnuts. These include:

1. **Biodiversity and ecosystem impact**: Climate is a primary factor influencing biodiversity and ecosystem dynamics. Changes in the physical environment affect physiological processes in plants... such as respiration, photosynthesis... and water use efficiency.[25]
2. **Crop microclimate alterations**: Climate is considered one of the main drivers of biodiversity and ecosystem change. With climate change, modifications in crop microclimate conditions are projected to occur, with implications in the suitability of a given region to grow a specific crop. Climate change may modify the physiological and reproductive cycles of species, like

[23] Jha et al (2020)
[24] ibid
[25] Steffen, W. et al 2009, "Australia's Biodiversity and Climate Change", Department of Climate Change. Retrieved 25NOV23 from https://www.dcceew.gov.au/sites/default/files/documents/biodiversity-vulnerability-assessment.pdf

anticipating or delaying phenological timings, with implications on yields and fruit quality characteristics.[26]

3. **Warmer temperatures and longer growing seasons**: Changes in the seasons as a result of global warming can impact on plants and ecosystems. Plants have evolved to seasonal cycles. Seasonal temperature changes trigger flowering and pollinations which are essential to reproduction. Shifting seasons are directly linked to warmer global temperatures: a slight change in temperature can bring an earlier spring and delay the first frost until later in autumn. [27].

4. **Extreme weather events**: Across Australia, extreme weather events are projected to worsen as the climate warms further. Heatwaves are becoming hotter, lasting longer and occurring more often. Extreme heat is projected to increase across the entire continent, with significant increases in the length, intensity and frequency of heatwaves in many regions. Extreme fire weather and the length of the fire season is increasing, leading to an increase in bushfire risk. The intensity of extreme rainfall events is also projected to increase across most of Australia. The time spent in drought is projected to increase across Australia, especially in southern Australia. Extreme drought is expected to increase in both frequency and duration.[28]

5. **Impact on crop physiology and reproduction**: High temperatures can influence fruit trees at multiple levels, including morphological, physiological and molecular. At the phenological level, high temperatures can decrease flowering, premature fruit drop and the incidence of fruit deformities and it can also slow fruit growth. While at the physiological level, heat stress can affect the rates of photosynthesis and transpiration, and the concentrations of various hormones and soluble osmolytes.[29]

6. **Yield and quality concerns**: When temperatures exceed the optimal range for a particular tree-fruit species, depending on phenological stage, a whole range of growth effects will appear, including poor pollination or fertilisation, slowed fruit growth and early senescence of the leaves. Heat stress can also cause sunburn and wilting of the fruit, both of which impair fruit quality.[30] In the case of hazelnuts, this could mean changes in size, taste, or nutritional content.

3.4 Adaptation strategies for climate change

Adapting a hazelnut orchard to the challenges posed by climate change involves a series of strategic actions to enhance resilience and maintain productivity. Here are some key strategies:

1. **New climate resilient varieties**: The quest for developing new climate-resilient varieties of walnut trees is fraught with a range of challenges, primarily due to the specific horticultural characteristics of walnut trees and the increasingly unpredictable global climate. Here are the main issues:

    - Genetic Diversity and Breeding Cycle: Walnut trees have a limited genetic pool available for breeding, which restricts the potential for developing new traits such as climate resilience. Additionally, walnut trees have long breeding cycles. It takes years for a tree to

26 Freitas,T. et al (2021) pg 4
[27] Dykes, J. 2021. "As the world warms, the seasons are shifting", Retrieved 27NOV23 from www.geographical.co.uk/climate-change/as-the-world-warms-the-seasons-are-shifting
28 South-west Climate Change Portal 2023, "Extreme Weather Events" Retrieved 26NOV23 from www.swclimatechange.com.au
29 Li, S. et al. 2023, "Responses and adaptations of fruit trees to high temperatures", Retrieved 25NOV23 from www.maxapress.com/article/doi/10.48130/FruRes-2023-0023
30 ibid

mature and produce fruit, which slows down the process of identifying and propagating successful varieties.

- Adaptation to a Range of Climate Conditions: Climate resilience implies the ability to withstand not just one type of stressor (like drought) but multiple, such as extreme temperatures, irregular rainfall patterns, and possibly increased incidence of severe weather events. Developing a walnut variety that can cope with all these varying conditions is highly challenging.
- Soil and Water Requirements: Walnuts are known for their specific soil and water needs. Developing varieties that can tolerate poorer soil conditions or less water without a decrease in nut quality or yield is complex.
- Resistance to Pests and Diseases: Climate change can also lead to the proliferation of new pests and diseases or increase the prevalence of existing ones. Therefore, climate-resilient walnut varieties also need to be resilient to a range of pests and diseases.
- Commercial and Nutritional Qualities: Maintaining the nut's commercial qualities such as size, taste, and nutritional value is crucial. These factors should not be compromised in the pursuit of climate resilience.
- Long-term Sustainability: Walnut trees are a long-term investment, often bearing fruit for decades. Varieties developed for current climate conditions must also be adaptable to future changes, ensuring their viability over many years.
- Economic and Logistical Considerations: Research and development of new varieties require significant investment. This includes funding for genetic research, field trials, and possibly the development of new agricultural practices.
- Local and Global Variability: Different walnut-growing regions experience different climate challenges. A variety that is resilient in one area might not perform as well in another, necessitating a more localized approach to breeding and cultivation.

2. **Water management and irrigation efficiency**: With the likelihood of altered rainfall patterns and potential drought conditions, efficient water use becomes vital. Implementing drip or micro-sprinkler irrigation systems, optimising irrigation schedules based on soil moisture monitoring, and using mulches to conserve soil moisture are effective strategies.
3. **Pest and disease management**: Climate change can influence the prevalence and intensity of pest and disease outbreaks. Employ integrated pest management (IPM) strategies, monitor orchards regularly for signs of infestation or disease, and use resistant or tolerant hazelnut varieties.
4. **Soil health enhancement**: Maintaining and improving soil health through organic matter addition, cover cropping, and reduced tillage can increase the soil's capacity to retain water and nutrients, enhancing resilience against extreme weather events.
5. **Pruning and canopy management**: Adaptive pruning can help manage tree size and shape, improving air circulation and sunlight penetration, which is crucial in controlling disease outbreaks and reducing heat stress.
6. **Adaptation to temperature extremes**: Implement strategies to protect hazelnut trees from extreme temperatures, such as using shade cloth during heatwaves or whitewashing tree trunks to reflect sunlight and reduce heat absorption.
7. **Monitoring and record-keeping**: Keep detailed records of weather patterns, tree growth, yields, and incidences of pests and diseases. This data can be invaluable for understanding the impacts of climate change and for making informed management decisions.

8. **Carbon sequestration and sustainability practices**: Implement practices that enhance carbon sequestration, like maintaining permanent ground cover, using organic fertilisers, and practicing agroforestry. These practices not only contribute to mitigating climate change but also improve orchard health.
9. **Microclimate creation and modification**: Use windbreaks, strategic planting, or other landscaping techniques to create microclimates within the orchard that can buffer against extreme weather events.
10. **Risk management and insurance**: Consider insurance options to mitigate financial risks associated with extreme weather events and climate variability. Diversifying income sources can also provide additional financial stability.
11. **Staying informed and collaborative learning**: Engage with agricultural extension services, research institutions, and fellow growers to stay updated on the latest research and techniques in hazelnut cultivation under changing climate conditions.
12. **Investing in research and innovation**: Keep abreast of ongoing research in hazelnut cultivation, especially studies focusing on climate change adaptation. Investing in innovative technologies and approaches can be beneficial.

Overall, the impacts of climate change on hazelnut production in the north-east region will require careful monitoring and adaptive management to ensure the sustainability and productivity of the orchards.

4. Walnut Phenology & Climate Change

4.1 Introduction

A wide range of walnut (Juglans regia L.) cultivars are produced around the world. They are generally classed according to their phenology (bud break, flowering and nut fall). To date, phenological stages have been recorded using alphanumerical codes, although data analysis is difficult with such codes. This study converted the alphanumerical codes to fully numerical codes using the Biologische Bundesanstalt Bundessortenamt und Chemische Industrie (BBCH) scale.

This walnut BBCH scale was created for the main English walnut cultivars, which are the main cultivated cultivars around the world production area. The scale was constructed with at least two digits (0 to 9) for the main growth stages, male flowering, fruit ripening and fruit development; and three digits for female flowering.

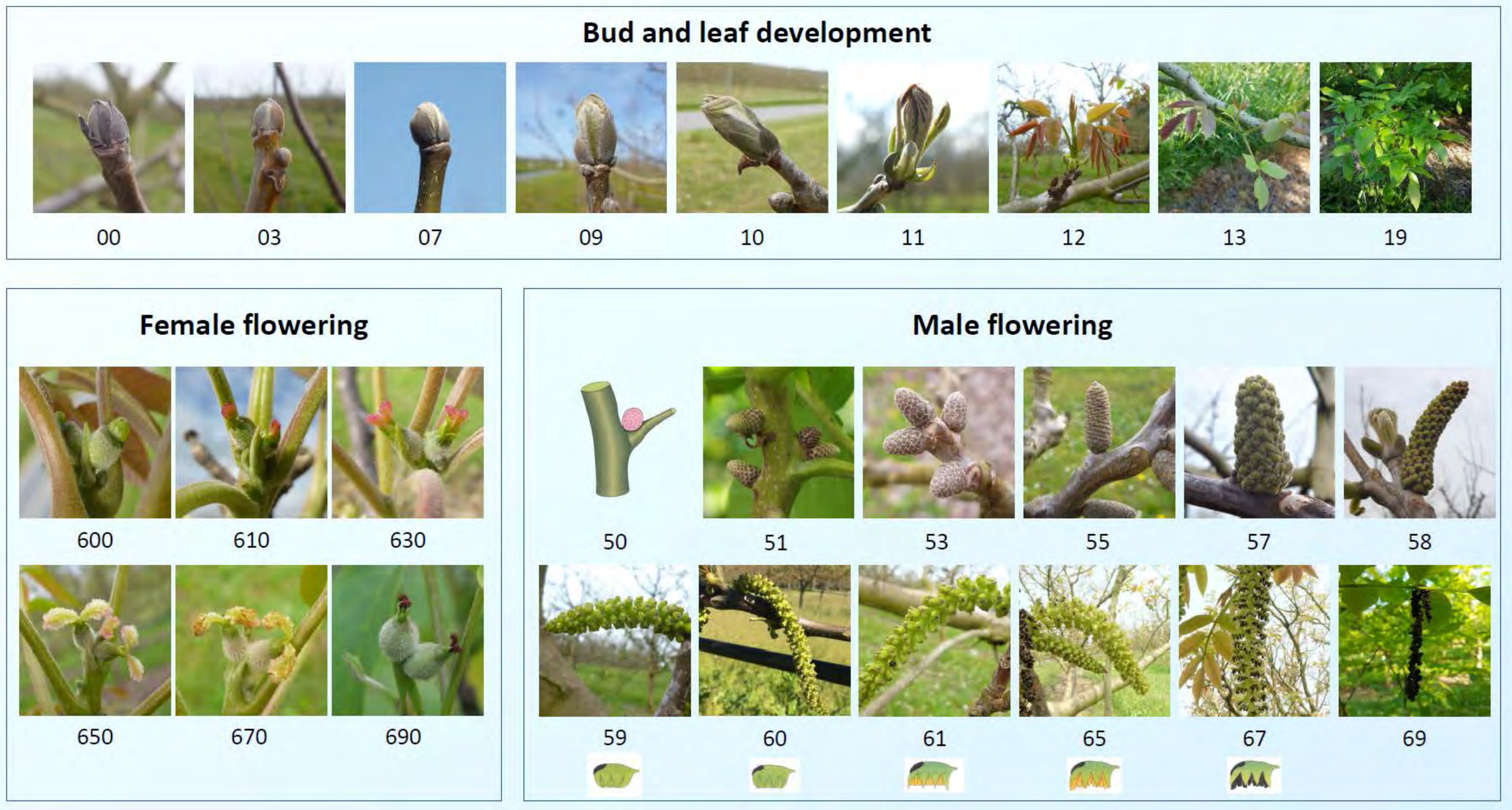
To avoid stage recording errors between male and female flowering during data collection, it was chosen to use a 2-digit code for male flowering and a 3-digit code for female flowering. The first number indicates the general growth stage, the second number indicates the growth stage at a specific time, and the third digit, when present, indicates a proportion during fruit ripening. Table below sets out the main growth stages for walnuts.

Code	Growth Stage
00-09	Bud development
10-19	Leaf development
50-59	Male - Inflorescence emergence
60-69	Male flowering
600-699	Female flowering
70-79	Fruit development
80-89	Fruit ripening
90-99	Senescence

Table 1: BBCH Scale for Walnuts[31]

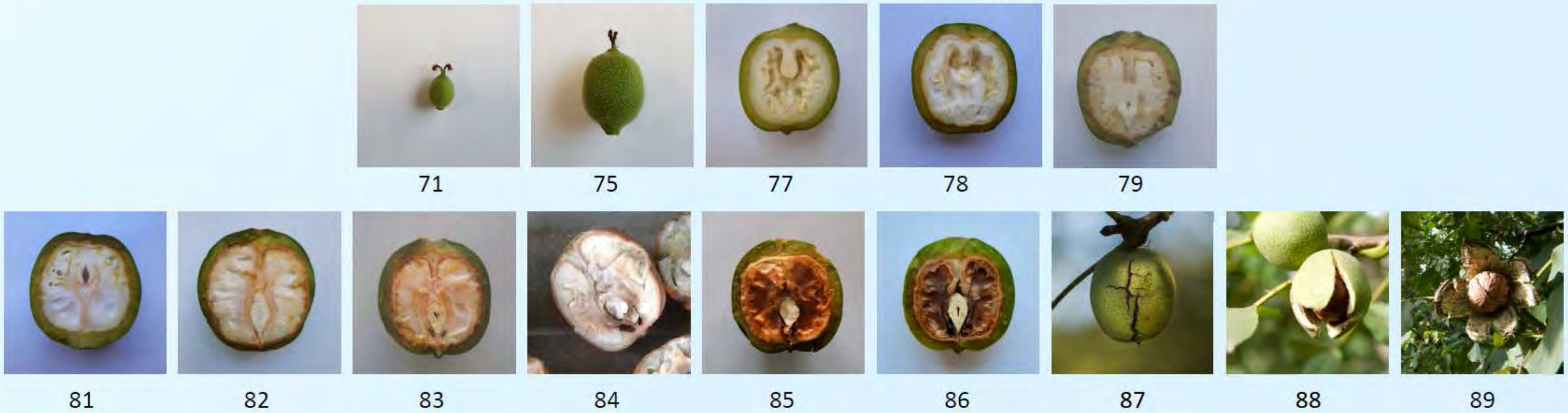
These stages are better shown by the following images:

[31] Derived from Sibylle Papillon, S. et al 2003, "Application of BBCH codification to walnut (Juglans regia L.) phenophase", Conference: IX International Symposium on Walnut & Pecan, Grenoble, France. Oline at DOI:10.13140/RG.2.2.25697.68968 (Accessed 21NOV23)



Images: Courtesy Dr. J. Toillon

Fruit development and ripening



Images: Courtesy of Dr. J. Toillon

4.2 Climatic factors, yields and walnuts

Climate change is expected to impact on the cultivation of walnut trees by influencing various aspects of growth, yield, and management.

1. **Temperature:** Warmer, drier summers and extreme weather events considered probable as the climate changes, would be especially troublesome and possibly fatal for walnut trees. Extreme heat in summer can stress trees and affect fruit development. Walnuts would have difficulty tolerating droughts that could be associated with a changing climate while changes in soil moisture could restrict its ability to survive without irrigation.[32] High temperatures, especially during critical growth periods, can cause heat stress to trees and lead to sunburn of fruits and branches, impacting both yield and quality. Walnuts are also sensitive to damage incurred during extreme heat events during the fruit-set period.[33]
2. **Chilling:** Warmer winters might impact on the chilling requirements that are necessary for proper bud break and flowering. Research in Australia has shown that decline in chill hours is likely to impact nut and fruit production across many sites in southern Australia. More southerly and higher altitude locations, such as in the North-East region may be less affected. The fact that walnuts have relatively high chilling requirements (800-1000 hours) warrants concern, especially because no low-chill cultivars are currently available.[34]
3. **Precipitation:** Walnuts are sensitive to water limitation, and do not generally fare well under deficit irrigation.[35] Changes in rainfall patterns, with the likelihood of more frequent and severe droughts, can lead to water stress. This not only impacts tree health and nut yield but also necessitates more efficient water management and irrigation strategies.
4. **Pests and diseases:** Warmer temperatures and altered humidity levels can lead to increased prevalence and new varieties of pests and diseases. Higher temperatures may also favour some walnut pests such as codling moth, which can increase from two to three or even four generations per year if fall temperatures are warm enough.[36] This requires adjustments in pest and disease management practices, potentially increasing reliance on pesticides and other control methods.
5. **Frost:** The timing and intensity of frost events are changing. Late frosts after bud break can damage the new growth and reduce yields. Earlier warming in spring followed by sudden frost events can be particularly damaging. Despite walnut's high freezing tolerance when fully dormant, spring frost injury appears to be important in English walnut, especially at the juvenile stage. Early bud break in English walnut can lead to apical bud death or shoot death during late spring frosts.[37]
6. **Flowering**: Changes in climate can affect the synchronization between the flowering of walnut trees and the activity of pollinators, potentially impacting pollination success. Some researchers have reported a correlation between high temperatures (≥ 35 °C) during

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[32] Wallheimer, B. 2011. "Walnut trees may not be able to withstand climate change", Purdue University. Retrieved 26NOV23 from www.sciencedaily.com/releases/2011/11/111129103312.htm

[33] Baldocchi & Wong (2008) in Korres, N. et al. 2016. "Cultivars to face climate change effects on crops and weeds: a review." Agron. Sustain. Dev. 36, 12. Retrieved 27NOV23 from https://doi.org/10.1007/s13593-016-0350-5

[34] Pope (2012) in Korres et al (2016)

[35] Chambers, J. et al 2015, "Walnuts: Crop Fact Sheet series", Southwest Regional Climate Hub and California Sub Hub". Retrieved 29NOV23 from https://swclimatehub.info/system/files/Walnuts.pdf

[36] University of California Davis (2013) in Korres et al (2016)

[37] Gauthier, M. & Jacobs, D. 2011. "Walnut (Juglans spp.) ecophysiology in response to environmental stresses and potential acclimation to climate change", Annals of Forest Science volume 68, pages 1277–1290. Retrieved 26NOV23 from www.annforsci.biomedcentral.com/articles/10.1007/s13595-011-0135-6

receptivity and increased non-pollination-drop in walnut trees. This indicates that walnut flowers are susceptible to extreme heat during stigma receptivity.[38]

7. **Tree health:** Increased temperatures and altered precipitation patterns can affect soil moisture, structure, and fertility, thereby impacting overall tree health.

All the above factors cumulatively affect the quality and quantity of walnut harvests. Inconsistent yields and quality fluctuations might become more common.

4.3 Climate change impacts on tree growth

The implications of climate change for the cultivation of walnuts involve several critical factors, primarily related to the species' sensitivity to environmental conditions:

1. **Sensitivity to climate extremes**: Research at Purdue University[39] indicates that walnut trees are particularly sensitive to climatic extremes. Warmer, drier summers and extreme weather events, which are likely outcomes of climate change, could be especially troublesome for their cultivation. There is concern about their ability to tolerate the drought conditions predicted with climate change. Changes in moisture could severely limit their ability to survive without additional irrigation. Walnut trees are also sensitive to cold and have developed mechanisms against late frosts. However, these defence mechanisms could be compromised by extreme weather events, making the trees more vulnerable to temperature increases and late spring frosts.
2. **Narrow ecological range**: Walnut trees thrive within a narrow range of environmental conditions, avoiding sites that are too wet or too dry. This specificity in their ecological requirements makes them susceptible to the impacts of climate change, which often involves alterations in precipitation patterns and temperature regimes. A shift in these conditions could lead to a decline in walnut species in their current growing regions.[40]
3. **Potential for acclimation and adaptation**: Despite the challenges, there are ongoing efforts to identify walnut trees that can adapt to changing climates. Current walnut breeding programs are seeking to identify walnut cultivars that can withstand heat or cold stresses associated with climate change.[41]
4. **Uncertain magnitude of effects**: While there is considerable uncertainty regarding the exact magnitude of climate change effects on walnut trees, some studies indicate potential negative impacts, particularly due to walnut's susceptibility to drought and frost injury. Research is needed to better project these effects and develop management strategies for acclimation and adaptation.[42]
5. **Physiological challenges**: Walnut trees exhibit both freezing tolerance and avoidance traits. However, spring frost injury, particularly at the juvenile stage, is a concern. The development of freezing tolerance in walnuts is related to soluble sugar accumulation, and climatic changes that cause early bud break could increase the risk of frost damage. Additionally, walnuts are semi ring-porous species and are more susceptible to cavitation (formation of air bubbles in

[38] Lang and Simpson (2018) in Thomas, E. 2022 "Impact and causes of non-pollination-drop of walnut flowers (Juglans regia) in a semi-arid climate of Australia.", Submitted to Charles Sturt University in fulfilment of the requirements for the degree of Doctor of Philosophy. Retrieved 29NOV23 from https://researchoutput.csu.edu.au/files/209019130/Emily_Thomas_Thesis_Final_submitted_16_Mar_2022.pdf)

[39] Wallheimer (2011)

[40] ibid

[41] ibid

[42] Gauthier& Jacobs (2011)

xylem vessels) during drought and winter freezing events, which could be exacerbated by climate change.[43]

4.4 Adaptation strategies for climate change

Adapting walnut cultivation to climate change in Australia involves several strategies aimed at mitigating risks and enhancing the resilience of walnut orchards. Here are some key adaptation measures:

1. **Select climate-resilient varieties**: Choose walnut varieties that are more tolerant to heat, drought, and altered chilling requirements.[44] Varieties [that are currently in development] with a lesser chilling requirement might be more suitable as winters become milder.[45] However, as with chestnuts, finding new drought-hardy varieties of walnut trees presents a range of challenges, particularly in the context of changing climate conditions and the specific needs of these tree species. Here are some key issues:
    - Genetic Diversity and Breeding Timeframes: Walnut trees have relatively long breeding cycles. This makes the process of developing new drought-resistant varieties time-consuming. Moreover, the genetic diversity available within these species can limit the scope of developing traits like drought resistance.
    - Climate Change and Unpredictable Weather Patterns: Climate change is leading to more extreme and unpredictable weather patterns, including prolonged droughts. This unpredictability makes it difficult to breed tree varieties that can cope with all possible future conditions.
    - Soil and Water Requirements: Walnuts have specific soil and water needs. Developing varieties that require less water without compromising the quality and yield of the nuts is a complex task. Drought-hardy trees might also need to adapt to different soil types where water retention is lower.
    - Disease Resistance and Overall Health: Any new variety developed for drought resistance must also maintain or enhance resistance to diseases and pests. Drought conditions can stress trees, making them more susceptible to diseases and pests, which further complicates the breeding process.
    - Economic and Market Factors: The development of new varieties must also consider market demands. Nut quality, size, and taste are important for commercial viability. There's a need to balance these qualities with drought resistance, which might sometimes be at odds.
    - Long-term Adaptation and Sustainability: Trees are long-term investments. Varieties that are drought-hardy now might need to adapt to future environmental changes over decades. Ensuring long-term sustainability and adaptability of these varieties is a significant challenge.
    - Resource Allocation and Research Support: Adequate funding and resources for research into breeding and testing new varieties are essential. This includes support for both field trials and laboratory research, which can be resource-intensive.
2. **Water management and efficiency**: Implementing efficient irrigation systems such as drip irrigation will help conserve water. Mulching and maintaining soil organic matter can help retain soil moisture. In areas prone to drought, establishing water storage facilities and

43 ibid
44 Rose, L. et al, 2023 "Climate Smart Farming: #3 Climate Change and Nut Trees", South-East Producers Assoc. Retrieved 27NOV23 from https://climatesmartfarming.scpa.org.au/pages/climate-change-and-nut-trees.
45 Gauthier & Jacobs (2011)

rainwater harvesting systems can be beneficial. Irrigation efficiency can also be assisted by identifying less water intensive production options, by developing better water delivery technologies, and by implementing and water-sharing arrangements.[46]

3. **Soil and water requirements**: Walnuts require deep, fertile soils with high water holding capacity. Understanding how changes in soil moisture and fertility under climate change can impact walnut growth is essential. This will involve improving soil and water management practices.[47]
4. **Soil health management**: In contrast to other crops, economically important trees require large amounts of energy to produce nuts and maintain normal growth. Therefore, a healthy soil environment and good soil fertility are crucial for walnut trees.[48] Enhancing soil health through organic amendments, cover crops, and reduced tillage can improve water retention, reduce erosion, and increase resilience against extreme weather events.
5. **Managing nutrient dynamics**: Translocation of stored nutrients, particularly nitrogen, is vital during active growth periods for walnut trees. Efficient nutrient management, considering changes in nitrogen availability due to climate change, can be crucial.[49]
6. **Adjusting planting schedules**: Altering the timing of key agricultural activities like planting and pruning to align with new climatic patterns can optimise growth and yield.
7. **Monitoring and record-keeping**: Keep detailed records of weather patterns, tree growth, yields, and incidences of pests and diseases. This data can be invaluable for understanding the impacts of climate change and for making informed management decisions.
8. **Microclimate management**: Use of shade structures and windbreaks can help in moderating temperature extremes and protecting trees from wind damage. At their peak effectiveness, windbreaks have been shown to reduce windspeed by 44%, reduce temperatures by 4°C and increase relative humidity by 10%.[50]
9. **Pest and disease control**: As a major driver of pest population dynamics, climate change will require adaptive management strategies to deal with the changing status of pests.[51] With the expected change in pest and disease dynamics due to climate change, integrated pest management (IPM) strategies should be updated. This includes regular monitoring, biological controls, and targeted use of pesticides when necessary.
10. **Diversification**: Diversification is a time-honoured strategy for distributing risk. Diversification can mean considering different cultivars in light of the best predictions available, diversification of products (e.g., processed products can allow a producer an outlet for less-than-perfect produce) and diversification with other nut varieties. This can spread risk and increase resilience against climate-related uncertainties.

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46 Stokes, C. & Howden, M. 2011 "Adapting agriculture to climate change", CSIRO. Retrieved 01DEC23 from https://www.publish.csiro.au/ebook/chapter/CSIRO_CC_Chapter%207
47 Gauthier & Jacobs (2011)
48 Du, T. et al 2022 "Positive effects of organic fertilizers and biofertilizers on soil microbial community composition and walnut yield", Applied Soil Ecology, Volume 175. Retrieved 27NOV23 from https://doi.org/10.1016/j.apsoil.2022.104457)
49 ibid
50 Baker, T. et al 2021 "Temporal, environmental and spatial changes in the effect of windbreaks on pasture microclimate", Agricultural and Forest Meteorology, Volume 297. Retrieved 29NOV23 from https://doi.org/10.1016/j.agrformet.2020.108265.
51 Skendžić, S. et al, 2021 "The Impact of Climate Change on Agricultural Insect Pests". Retrieved 30NOV23 from https://doi.org/10.3390/insects12050440

11. **Technological innovations**: Using technology such as remote sensing, precision agriculture, and climate forecasting tools will help growers make better informed decisions and managing resources more effectively.
12. **Pruning and canopy management**: Proper pruning and canopy management can improve air circulation, reduce disease risk, and manage sun exposure to prevent sunburn. Some growers are alternating pruning of one side of their rows each year to better manage yield.
13. **Research and collaboration**: Engaging in ongoing research and collaborating with agricultural extension services, universities, and climate experts can provide access to the latest knowledge and innovations in horticulture.
14. **Carbon footprint reduction**: Practices such as using renewable energy and reducing reliance on fossil fuels can help mitigate the broader impacts of climate change.

Implementing these strategies requires a dynamic approach, as the impacts of climate change can vary significantly over time and between regions. Walnut growers in Australia in the north-east will need to continually adapt their practices in response to ongoing climatic changes and new scientific insights.

5. Conclusion

The "Tri-Nut Irrigation Project for the North-East Catchment Area: Milestone 3" report, as compiled by Trevor Ranford & Associates, underscores the importance of understanding and adapting to the phenological changes and challenges posed by climate change in the cultivation of chestnuts, hazelnuts, and walnuts. The research and insights presented in this report provide nut growers in the North-East Catchment Authority region with a path forward in a future of climatic uncertainty.

The report illustrates that the impacts of climate change are multifaceted, influencing not just the phenological stages of these nut trees but also affecting their overall growth, yield, and susceptibility to pests and diseases. The need for adaptive strategies is clear and urgent. These strategies, ranging from varietal selection, water and soil management, to the use of technology and sustainable practices, are not just responses to current challenges but also proactive measures to ensure the future sustainability and productivity of nut orchards.

The collaborative approach of the Tri-Nut project, involving key industry organizations like Hazelnut Growers of Australia, Chestnuts Australia, and the Australian Walnut Industry Association, represents a collective effort in tackling the complex issues presented by climate change.

In conclusion, as the climate continues to evolve, so must our strategies and practices in horticulture. This report will hopefully contribute to the knowledge and direction that growers, in the North-East Catchment Management Authority region, will need to make informed decisions and adopt resilient practices in order to sustain and enhance their nut production in the face of climatic changes