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METHODS OF EVALUATING THE CHILLING AND HEAT REQUIREMENTS OF APPLE AND PEAR TREES

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Abstract

The change in the occurrence of phenophases in fruit trees gave a challenge to climate change. Changes in average temperatures and rainfall and increased short- and long-term extreme events are already affecting crop yields worldwide. To avoid possible losses, it is necessary to provide helpful information to farmers in real time regarding initiating a particular stage of fruit tree development. Modern breeding programs have launched cultivars with low winter chill requirements onto the market, involving extensive zoning research in recent years. Also, there are species/cultivars with a chilling requirement that can no longer be satisfied in some areas, leading to losses in production/economic inefficiency. Climate change generated significant interest in developing specific tools and models adjusted for each crop. The paper aims to present the available information on apple and pear trees' chilling and heat requirements, focusing on the methods used for their determination. The results reflect comparing the methods used and their efficacy for those species.

Key words: *chilling hours; chilling units; chilling portions; growing degree hours.*

INTRODUCTION

The change in the occurrence of phenophases in fruit trees gave a challenge to climate change. Changes in average temperatures and rainfall and increased short- and long-term extreme events are already affecting crop yields worldwide.

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This paper aims to present information on apple and pear trees' chilling and heat requirements, focusing on the methods used for their determination.

RESULTS AND DISCUSSIONS

The apple (*Malus × domestica* Borkh.) and pear (*Pyrus communis* L.) are temperate fruit trees that need a resting period in the winter, correlated with low temperatures.

In this period, fruit trees enter a dormant state when most metabolic processes are temporarily inactivating to avoid chilling injury (Campoy et al., 2011). Dormancy includes endodormancy, when chilling is required, followed by ecodormancy, when budbreak is regulated by environmental factors (Salama et al., 2021; Cornelissen, 2021; Craven, 2022).

Apple and pear trees depend on winter chilling during endodormancy to ensure uniform flowering in spring. In recent years, climate changes led to a decline in winter chill with effects on the fulfillment of the chilling requirements, reducing yield potential and threatening the economic viability of temperate fruit production (Delgado et al., 2021; Craven, 2022; Pertille et al., 2022).

Insufficient winter chilling leads to delayed bud break, decreased flowering and fruit set, and reduced fruit quality.

Apples low chill cultivars have under 800 chilling hours requirement, compared to the 1000-1500 chilling hours (for example, at Golden Delicious), and can be a solution in these regions.

Many breeding programs brought to the market low chill cultivars, for example, apple Anna with less than 300 hours (Hauagge & Cummins, 2000; Cornelissen, 2021), Princesa with less than 450 CU, Baronesa 500-600 CU (Hauagge & Cummins, 2000; Castro et al., 2016).

For pear, low chill cultivars were used, such as Africana, Ayres, Ceres, Flordahome, etc. (Hauagge & Cummins, 2000).

In the tree phenology research history, there were more models for evaluating chilling hours and heat requirements for a specific cultivar from a species. The most used are:

For chilling accumulation

(1) The chilling hours model, which establishes that a cold hour (CH) corresponds to an hour with a temperature value between 0 and 7.2°C (Weinberger, 1950; Richardson et al., 1975; Anderson et al., 1986).

(2) The Utah model is based on quantifying cold units (CU). One cold unit corresponds to one hour for temperatures between 2.5-9.1°C, considered most effective in completing dormancy. Other temperature ranges have 0.5 unity (1.5-2.4°C and 9.2-12.4°C), zero contribution (<1.4°C and 12.5-15.9°C), or negative (>16°C) at rest (Richardson et al., 1974).

There were more extended variants for this model, like the North Carolina model (Shaltout & Unrath, 1983; Anderson & Seeley, 1992), the Positive Utah model (Linsley-Noakes & Allan, 1994), Modified Utah Model (Linvill, 1990), to simulate the local conditions better (Sheard, 2002).

(3) The dynamic model proposes accumulating an intermediate value according to low temperatures that can be reversed by higher temperatures (first stage). Once the value has reached a certain level, cold portions are added permanently, unaffected by higher temperatures (Fishman et al., 1987; Luedeling, 2012; Fadón et al., 2020; Pantelidis & Drogoudi, 2023).

The base variable in all models is the temperature, specifically hourly medium temperature. Special attention is given to local temperatures, which can be registered with data loggers or specific sensors in the meteo stations. More applications have been available for many years for the general public, especially for farmers and all the stakeholders directly affected by local climate conditions.

https://www.ecad.eu/ presents international meteo stations with free daily data for 50-100 years in the past. ECA&D receives data from 85 participants from 65 countries, with 13 elements at 23,335 meteorological stations.

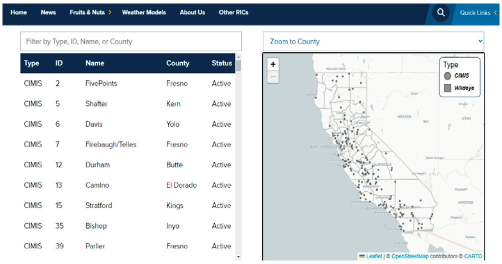

Figure 1. A platform with more meteo stations and applications for stakeholders (source: UCDAVIS)

Other local meteo stations (on site) with free data or not are https://fruitsandnuts.ucdavis.edu/chill-calculator (Figure 1), https://www.meteoblue.com, https://agrometeo.ch/ (Figures 2 and 3), etc.

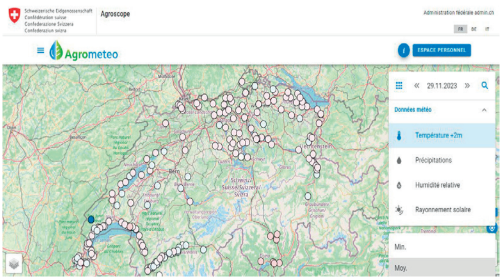

Figure 2. A platform for climatic data with more application for farmers includes (Agroscope.ch)

Temperature can be recorded daily (Tmin, Tmax, Tavg), hourly, every 30 minutes or 15 minutes, etc. In the phenology models, hourly temperature is most used.

The chill units can be determined in a specific region based on the available climatic data and included in historical climatic databases. These are very useful in validating phenology algorithms on a specific species.

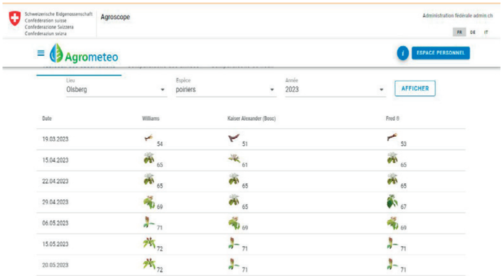

Figure 3. Application for phenology in dynamic (pear) on https://agrometeo.ch/

For heat accumulation

(1) GDD (growing degree days) calculates the days when the average temperature exceeds a certain threshold specific to each species.

GDD = Tavg – Tbase, if Tavg ≥Tbase

GDD = 0 if Tavg < Tbase (McMaster & Wilhelm, 1997).

(2) GDH (growing degree hours) was defined by Richardson et al. (1974) as the amount of energy in the form of accumulated growing degree hours, the number of hours above 4.4°C (40°F). Anderson et al. (1986) defined GDH:

(1) $GDH = F*A/2\ [1+\cos(\pi + \pi\ (TH-TB)/\ (TO-TB))]$, where: TH = hourly temperature, TB = base temperature (4°C for trees), TO = optimal temperature (25°C for trees), TC = critical temperature (36°C in trees), A = TO-TB, F = a stress factor (due to biotic/abiotic factors).

(2) $GDH = F*A\ [1+\cos(\pi/2 + \pi/2\ (TH-TO)/\ (TC-TO))]$

If TH < TO, equation (1) is used; if TH>=TO, equation (2).

More research was done in the tree phenology modeling, each on a specific area and species, respectively, cultivars.

Luedeling et al. (2021) proposed the PhenoFlex model to predict spring phenology based on the Dynamic Model for chilling accumulation and the Growing-Degree-Hours Model for heat accumulation.

The model was tested on apple (Boskoop grafted on M9 rootstock) and pear (Alexander Lucas grafted on Quince A until 2014, and Quince Adams from 2015) in the Campus Klein-Altendorf, in the experimental orchard of the University of Bonn (6.99°E, 50.63°N).

Miranda et al. (2021) proposed an R package for phenology modeling (fruclimadapt), including functions defined for chill hours(), chill_units(), chill_portions(), GDD_linear(), GDH_linear(), and GDH_asymcur().

A large area of research focused on local cultivars' chilling and heat requirements. Some of the findings are presented below.

Australia (Parkes et al., 2020) - Apple

They used the Chill Hours, Utah, and Dynamic models to assess chilling requirements for apple cultivars. According to their results, they grouped the studied cultivars with low requirements (Cripps Red, Manchurian crab apple), medium (RS103-110, Granny Smith, Cripps Pink, Kalei), and higher chill (Galaxy, Fuji, Hi-Early) classes.

Northwestern Spain (Delgado et al., 2021) - Apple

The local apple cultivars were analyzed using three chill models - the Chilling Hours Model, The Utah Model, and The Dynamic Model. The Growing Degree Hours Model (Anderson et al., 1986) was used as a heat accumulation model. Clara, Coloradona, Perezosa, Verdialona, Blanquina, De la Riega, Teorica, Xuanina, and Collaos were under 1300 CU, while Perico and Raxao were 1495 CU.

Winchester, VA, USA (Sapkota et al., 2021) - Apple

The endodormancy release for the two cultivars was achieved after accumulating 1000 CH. Ecodormancy release of Cripps Pink occurred at 3000 GDH and 4000 GDH at Honeycrisp cultivar.

Brazil (Pertille et al., 2022) - Apple

Gala and Fuji were analyzed in three regions with three chilling hours models and GDH for heat accumulation. The chill and heat requirements were different according to region and cultivar.

Fluvià river lower course subbasin, NE Spain (Funes et al., 2016) - Apple

Chilling and heat requirements for Brookfield Gala, Granny Smith, Fuji Chofu, Golden Smoothee, Early Read One, Red Chief, Aporo, and Golden Reinders ranged between 62.5-68.4 CR and 9229.7-10272.5 HR.

USA, the Pacific Northwest region (Noorazar et al., 2020) - Apple

Golden Delicious (50 CP) and Gala (50-55 CP) were at risk for insufficient chill accumulation.

North-eastern Belgium (Drepper et al., 2020) - Apple and pear

Four pear cultivars (Conference, Durondeau, Doyenné, and Triomphe) and four apple cultivars (Jonagold, Golden Delicious, Boskoop, and Cox Orange) were analyzed. Two models were used, including the Dynamic + GDH Model.

Australia (Parkes, 2017) - Apple and pear

They included climate change scenarios for pome fruit in 2030 and 2050, including the likely impact of climate change on winter chill and extreme heat.

The outcomes included historical trends in average temperatures, winter chill and heat days, climate projections for average winter chill and heat days, relationships between temperature and flowering (Dynamic, Utah, and Chill Hours were used), potential impacts of warming temperatures on flowering, options for adaptation: management of flowering under future climates, relationships between summer temperatures and the incidence of sunburn under net and no net.

Ethiopia (Melke & Fetene, 2014) - Apple

Description of the apple production and characteristics. Challenges identified included a lack of adequate chilling temperature.

KwaZulu-Natal, South Africa (Sheard, 2002) - Apple and pear

Utah chill unit model, Daily Positive Utah Chill unit model (DPCU), and Dynamic model were used. For apples, DPCU was determined for Royal Gala (800-1000+), Golden Delicious (800-1000+), Granny Smith (600), Braeburn (800), and Fuji (800-1000). For pear Bon Chretien and Golden Russet Bosc had 800-1000+ DPCU, Forelle 600-700, Rosemarie 700-800, Flamingo 700-900 DPCU.

Brazil (Carvalho et al., 2014) - Apple and pear

The research evaluated the dormancy dynamic of Imperial Gala apple tree buds and Hosui pear tree buds in a region of low chill occurrence.

Belgium (Drepper et al., 2022) - Pear

The study focused on identifying the spatiotemporal trends of flowering, spring frost, and their co-occurrence in Belgium at the pear and comparing the effectiveness of a set of recursive bias correction methods.

Subtropical climate (Verma et al., 2010) - Apple and pear

A collection of data for chilling accumulation and cultivars needs for different subtropical regions.

Romania (Chițu & Păltineanu, 2020) - Apple and pear

The research evaluated the effects of climate change in apples and pears on four phenological stages: bud swelling (BBCH 51), budburst (BBCH 53), beginning of flowering (BBCH 61), and end of flowering (BBCH 69).

Pacific Northwest (Houston et al., 2020) - Apple and pear

Identifying the chilling hour requirements and approximate hardiness zones for several apple and pear cultivars.

CONCLUSIONS

Apple and pear are well-studied fruit species, including the correlation between phenology and climate change. Besides diversified models applied to quantify the chilling and heat requirements, more cultivars are well known for their chilling and heat needs to complete a phenological stage.

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REFERENCES

Anderson, J.L. & Seeley, S.D. (1992). Modeling strategy in pomology: Development of the Utah models. *Acta Horticulturae, 313*, 297-306.

Anderson, J.L., Richardson, E.A. & Kesner, C.D. (1986). Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. *Acta Hortic. 184,* 71-78, DOI: 10.17660/ActaHortic.1986.184.7

Carvalho, R., Biasi, L., Zanette, F., Rendoke, J., Santos, J. & Pereira, G. (2014). Dormancy of 'Imperial Gala' apple and 'Hosui' pear tree buds in a region of low chill occurrence. *Acta Scientiarum Agronomy. 36*. 429-434. 10.4025/actasciagron.v36i4.17966.

Castro, D.C., Cerino, M.C., Gariglio, N. & Radice, S. (2016). Study of reproductive behaviour in low-chill apples in warmer zones of Argentina. *Scientia Horticulturae, 199*, 124-132.

Chitu, E. & Paltineanu, C. (2020). Timing of phenological stages for apple and pear trees under climate change in a temperate-continental climate. *Int J Biometeorol 64*, 1263–1271. https://doi.org/10.1007/s00484-020-01903-2

Cornelissen, S. (2021). Defining the QTL for chill requirement during dormancy and dormancy release in apple (*Malus x domestica* Borkh.). *Dissertation presented for the degree of Doctor of Philosophy in the Faculty of Science at Stellenbosch University* Supervisor: Prof J.T. Burger, Co-Supervisor: Prof D. J.G. Rees.

Craven, D. (2022). Managing lack of winter chilling in apple production, *Stellenbosch University Department of Horticulture, Faculty of AgriSciences*, Supervisor: Siboza, X.I. Co-supervisor: Prof. K.I. Theron.

Delgado, A., Egea, J.A., Luedeling, E. & Dapena, E. (2021). Agroclimatic requirements and phenological responses to climate change of local apple cultivars in northwestern Spain. *Scientia Horticulturae, 283*. 110093. 10.1016/j.scienta.2021.110093.

Drepper, B., Gobin, A., Remy, S. & Van Orshoven, J. (2020). Comparing apple and pear phenology and model performance: what seven decades of observations reveal. *Agronomy, 10*, 73. https://doi.org/10.3390/agronomy10010073

Drepper, B., Gobin, A., Van Orshoven, J. (2022). Spatio-temporal assessment of frost risks during the flowering of pear trees in Belgium for 1971–2068, *Agricultural and Forest Meteorology, 315*, 108822.

Fadón, E., Herrera, S., Guerrero, B.I., Guerra, M.E. & Rodrigo, J. (2020). Chilling and heat requirements of temperate stone fruit trees (*Prunus sp.*). *Agronomy, 10*, 409. https://doi.org/10.3390/agronomy10030409

Fishman, S., Erez, A. & Couvillon, G.A. (1987). The temperature dependence of dormancy breaking in plants: Two-step model involving a cooperative transition. *J. Theor. Biol. 124*, 473 – 483.

Funes, I., Aranda, X., Biel, C., Carbó, J., Camps, F., Molina, A.J., de Herralde, F., Grau, B. & Savé, R. (2016). Future climate change impacts on apple flowering date in a Mediterranean subbasin, *Agricultural Water Management, 164* (1), 19-27.

Hauagge, R. & Cummins, J.N. (2000). Pome Fruit Genetic Pool for Production in Warm Climates. In: *Erez, A. (eds) Temperate Fruit Crops in Warm Climates. Springer, Dordrecht*. https://doi.org/10.1007/978-94-017-3215-4_10

Houston, L., Capalbo, S., Seavert, C., Dalton, M., Bryla, D. & Sagili. R. (2018). Specialty fruit production in the Pacific Northwest: adaptation strategies for a changing climate. *Climatic Change 146*, 159–171. https://doi.org/10.1007/s10584-017-1951-y

Linsley-Noakes, G. & Allan, P. (1994). Comparison of two models for the prediction of rest completion in peaches. *Scientia Horticulturae, 59*, 107–113. https://doi.org/10.1016/0304-4238(94)90077-9

Linvill, D. E. (1990). Calculating chilling hours and chill units from daily maximum and minimum temperature observations. *HortScience, 25*(1), 14-16. https://doi.org/10.21273/HORTSCI.25.1.14

Luedeling, E. (2012). Climate change impacts on winter chill for temperate fruit and nut production: A review. *Scientia Horticulturae, 144*, 218–229, https://doi.org/10.1016/j.scienta.2012.07.011.

Luedeling, E., Schiffers, K., Fohrmann, T. & Urbach, C. (2021). PhenoFlex - an integrated model to predict spring phenology in temperate fruit trees. *Agricultural and Forest Meteorology, 307*, 108491.

McMaster, G.S. & Wilhelm, W.W. (1997). Growing degree-days: one equation, two interpretations. *Agricultural and Forest Meteorology, 87*, 4, 291–300.

Melke, A. & Fetene, M. (2014). Apples (*Malus domestica*, Borkh.) phenology in Ethiopian highlands: plant growth, blooming, fruit development and fruit quality perspectives. *American Journal of Experimental Agriculture. 4*. 1958-1995. 10.9734/AJEA/2014/9783.

Miranda, C., Urrestarazu, J. & Santesteban, L.G. (2021). fruclimadapt: An R package for climate adaptation assessment of temperate fruit species. *Computers and Electronics in Agriculture, 180,* 105879, https://doi.org/10.1016/j.compag.2020.105879.

Noorazar, H., Kalcsits, L., Jones, V.P., Jones, M.S. & Rajagopalan, K. (2020). The risk for insufficient chill accumulation: a climate change perspective for apple and cherry production in the United States, https://doi.org/10.1101/2020.08.26.268979.

Pantelidis, G. & Drogoudi, P. (2023). Exploitation of genotypic variation in chilling and heat requirements for flowering in *Prunus armeniaca* and *Prunus persica* (L.) Batsch cultivars. *Scientia Horticulturae, 321*, 112287.

Parkes, H. (2017). Final Report. Understanding apple and pear production systems in a changing climate. The Department of Agriculture and Fisheries (DAF). *Hort Innovation*, ISBN 978-0-7341-4336-5.

Parkes, H., Darbyshire, R. & White, N. (2020). Chilling requirements of apple cultivars grown in mild Australian winter conditions, *Scientia Horticulturae, 260*, 108858

Pertille, R.H., Citadin, I., de Oliveira, L.de S., de Camargo Broch, J., Kvitschal, M.V. & Araujo, L. (2022). The influence of temperature on the phenology of apple trees grown in mild winter regions of Brazil, based on long-term records. *Scientia Horticulturae, 305*, 111354.

Richardson, E.A., Seeley, S.D. & Walker, D.W. (1974). A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience, 9*(4), 331–332.

Salama, A.M., Ezzat A., El-Ramady H., Alam-Eldein, S.M., Okba, S.K., Elmenofy, H.M., Hassan, I.F., Illés, A. & Holb, I.J. (2021). Review Temperate Fruit Trees under Climate Change: Challenges for Dormancy and Chilling Requirements in Warm Winter Regions, *Horticulturae, 7*, 86.

Sapkota, S., Liu, J., Islam, M.T., Ravindran, P., Kumar, P.P. & Sherif, S.M. (2021). Contrasting bloom dates in two apple cultivars linked to differential levels of phytohormones and heat requirements during ecodormancy. *Scientia Horticulturae, 288*, 110413.

Shaltout, A.D. & Unrath, C.R. (1983). Rest completion prediction model for Starkrimson Delicious apples. *Journal of the American Society for Horticultural Science, 108*, 957-961.

Sheard, A.G. (2002). Measuring winter chilling in the south west region of Kwazulu-Natal during 2001 and its implications for deciduous fruit production. *Specialist Advisory Services South West Region*, KZN Agri-Report No. N/A/2002/02

Verma, M. K., Awasthi, O.P. & Giri, R. (2010). Prospectus of temperate fruit production in subtropical climate, *Conference: National Seminar on "Precision Farming in Horticulture"*, December 28-29, 2010At: Horticulture College, Jhalawar, Rajasthan India

Weinberger, J.H. (1950). Chilling requirements of peach varieties. *Proceedings of American Society for Horticultural Science, 56*, 122-128.