Scientific Papers. Series B, Horticulture. Vol. LXVII, No. 2, 2023
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

EVALUATION OF CHILLING AND HEAT REQUIREMENTS OF PAW-PAW (*ASIMINA TRILOBA* L. DUNAL) AND JUJUBE (*ZIZIPHUS JUJUBA* MILL.) (REVIEW)

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Abstract

Climate change is a reality of the difficult period we are going through. Plant evolution is generally strongly correlated with variations in temperatures, precipitation, and solar radiation being affected by extreme events. Late frosts influence fruit production, the number of cold hours (perhaps insufficient in recent years), and winter windows in which very high temperatures occur and negatively influence the dormancy of some fruit-bearing species. Paw-paw (Asimina triloba L. Dunal) and jujube (Ziziphus jujuba Mill.) are new fruit species for Romanian areas more resilient to climate change. This paper aims to present the available information on this new fruit species' chilling and heat requirements, focusing on the methods used for their determination. The results reflected the scarcity of research on these fruit species and the necessity to have a methodology with the possibility to extend to new cultivars in different areas.

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

INTRODUCTION

Climate change is a reality of the difficult period we are going through. Plant evolution is generally strongly correlated with variations in temperatures, precipitation, and solar radiation being affected by extreme events. Late frosts influence fruit production, the number of cold hours (perhaps insufficient in recent years), and winter windows in which very high temperatures occur and negatively influence the dormancy of some fruit-bearing species. Paw-paw (*Asimina triloba* L. Dunal) and jujube (*Ziziphus jujuba* Mill.) are new fruit species for Romania areas more resilient to climate change. This paper aims to present the available information on this new fruit species' chilling- and heat requirements, focusing on the methods used for their determination.

The timing of life-history events, or phenology, can reveal information about species' types and levels of interactions with their surroundings. For instance, a plant's ability to compete for light and its susceptibility to disease or cold are influenced by phenology, which is the time of leaf emergence, expansion, and abscission (Lechowicz, 1984; Sun et al., 2006).

According to Rosenzweig et al. (2008), long-term phenological investigations conducted at the species level and particular places can offer concrete proof of the effects of climate fluctuation and change. Global reports have shown that plant phenology has apparent responses to climate change. Despite these crops' significant economic and agricultural values, relatively little research has been done on how fruit trees respond to climate change, with most published studies concentrating on phenological changes in natural vegetation (Chmielewski et al., 2004).

According to Legave et al. (2008), fruit trees' flowering phenology significantly affects fruit set, pollination, and yield. Interest in how climate change affects fruit blossoming has grown globally. According to studies conducted by Chmielewski et al. (2004), Grab & Craparo (2011), Guédon & Legave (2008), Legave & Clauzel (2005), and Wolfe et al. (2005), global warming has caused various fruit trees to flower earlier in numerous regions. Nonetheless, delayed blossoming has been observed in certain fruit trees planted in regions significantly warmer than their natural habitat (Elloumi et al., 2013; Legave et al., 2013). The effect of climate change on plant dormancy is most likely the cause of flowering's timing.

Asimina triloba (L.) Dunal, commonly known as paw-paw, is the only member of the Annonaceae family growing in temperate zones and, in particular, grows wild in the eastern United States, ranging from northern Florida to southern Ontario (Canada) and as far west as eastern Nebraska. Today, it is found in temperate climate countries (i.e., Italy, China, Japan, Israel, Belgium, Portugal, and Romania). There are over 60 varieties cultivated in the world, which differ in trunk diameter tree, fruit size, skin and pulp color, fruit flavors, and ripening periods (Pomper & Layner, 2005; Brannan & Coyle, 2021).

Paw-paw has few disease problems thanks to the high content of acetogenins in roots, twigs, bark, immature fruits, and seeds (Ratnayake et al., 1992; McLaughlin, 1997).

Research suggests that paw-paw fruit pulp has the potential to be added to various consumer goods to add increased nutritional benefits or flavor enhancement (Brannan et al., 2012) (Lolletti et al., 2021)

Figure 1. *Asimina triloba* flowers

Ziziphus jujuba Mill. belongs to the family Rhamnaceae, and more than 170 species are in the *Ziziphus* genus.

Figure 2. *Zizizphus jujuba* flowers

The jujube tree is mainly distributed in the subtropical and tropical regions of Asia, Russia, northern Africa, southern Europe, the Middle East, and the southwestern USA. (Hernández et al., 2014). Furthermore, it is well-known for its highly nutritive fruits.

RESULTS AND DISCUSSIONS

Asimina (*Asimina triloba* L. Dunal)

Asimina is well adapted to different climatic zones and requires a minimum of 400 annual chill units, 160 frost-free days, and 80 cm of annual precipitation, with most falling during spring and summer (Peterson, 1991).

Abu-Asab et al. (2001) integrated the observation from more than 125 persons, who contributed with records for first-flowering dates through the years for 100 species, representing 44 families of angiosperms, for 29 years of the 30 years 1970-1999 (1984 not recorded) in the Washington, DC, area. *Asimina triloba* is included in the list.

Crabtree (2004) evaluated GDDs required for fruit ripening ranging from 2200 to 3200. Between the studied populations, the growing degree of days required for fruit ripening was not found to be significantly different. However, GDDs varied significantly between accessions, with trees from New York requiring the fewest GDDs to ripen, 2262, and the other five populations requiring a similar number of GDDs (2400-2500) for ripening. Growing degree days (GDDs) were calculated using a base temperature of 10°C, and the beginning degree day accumulation was on May 15, which was approximately the end of flowering (http://wwwagwx.ca.uky.edu/calculators.html).

Pomper et al. (2008) studied the flowering and fruiting characteristics of Middletown, Overleese, PA-Golden, Sunflower, Wells, Wilson, and NC-1 cultivars. The following results were obtained: Flowering peak and duration were not correlated with the growing degree days; Growing Degree Days from the first flower to the peak flower were similar in 2004 and 2006 and were significantly lower in 2005. The GDD from flower peak to harvest peak were fewer for 2004 than for 2005 and 2006, indicating that these later years had warmer temperatures than 2004. The number of days was similar for the tested cultivars.

Growing degree days (GDDs) were calculated using a base temperature of 10°C (http://wwwagwx.ca.uky.edu/calculators.html). Szilagyi et al. (2016) studied the flowering of Asimina in the northern part of Romania. It was noted that at the beginning, the button phase lasted three days, and the ornamental potential of the flowers, given by floral decoration that displays itself until the fall of the corolla, lasted 24 days (in 2016). The end of the floral decoration, marked by the fall of the corolla, lasted three days (April-May).

Bivariate model partial dependence graphs indicate that pawpaw is compatible with the warmest circumstances in the study region, with mean annual temperatures >9.0°C showing a significant increase in compatibility. It should be noted that the study area has a strong link between temperature and precipitation variables. This means warmer regions receive less precipitation; for instance, an average annual temperature of 9.0°C typically translates to ~44 cm of growing-season precipitation (May-September) (Tulowiecki, 2020).

Figure 3. *Asimina triloba* fruits

Jujube (*Ziziphus jujuba* Mill.)

Mishra & Krška (2008) studied to find a suitable base temperature for different phenological stages in *Ziziphus jujuba* Mill. They use temperatures above 7, 9, and 11 °C as threshold values for the phenology of jujube. 11°C was found to be the most suitable base temperature for jujube.

Du (2009) studied the chilling requirements of different jujube cultivars correlated with the changes in carbohydrates during dormancy. The cultivars were clustered according to their chilling needs, from 399 C.U. to 580 C.U. It also presented a method of identifying dormancy by measuring the changes in total soluble sugar and starch contents.

Guo et al. (2014) studied PLS regression between phenological dates, daily chilling, and heat accumulation, which can be used efficiently to identify chilling and forcing periods and to estimate the chilling and heat requirements of temperate trees provided long-term temperature and phenology data available. The forcing periods for jujube began after half of the chilling requirements were met. During the times shown to be significant for heat accumulation and cooling, rates of both were impacted by climate change. The heat buildup of jujube has increased by 92.3 GDH annually during the last 50 years. Although there was a tendency for winter cold to rise, this trend was not significant enough to rule out the null hypothesis that there was no change over time.

Jujube flowering times were dictated by heat accumulation, with a minor influence from cold buildup on bloom timing.

Zou et al. (2017) presented the time development for the jujube bud flower of Jinsi No. 4 in Hunan between 2010 and 2011. Pre-differentiation started on April 9th for 14 days, continuing with initial differentiation (3 days), sepal differentiation (3 days), petal differentiation (2 days), stamen differentiation (2 days), pistil differentiation (2 days), alabastrum (20 days), alabastrum break (2 days), sepal flattening (2 days), petal flattening (2 days), stamen flattening (2 days). Filament withering (2 days), ovule swelling (3 days), early flowering period (11 days), full blossom period (15 days), and the end of flowering period (16 days).

In a study by Krishna et al. (2018), Growing degree days were calculated following Mendes et al. (2017) for a base temperature of 4°C. They analyzed the phenological growth stages of Indian jujube (*Ziziphus mauritiana* Lamk.) according to the BBCH scale (Table 1).

Table 1. Phenological growth stages of Indian jujube and GDDs (source Krishna et al., 2018)

BBCH	Substage	Duration	Degree days
0	00	35	1,143.70
	01	6	166.2
	03	5	143.4
	07	4	113.9
	09	3	85.3

BBCH	Substage	Duration	Degree days
1	10	2	56.7
	11	1	30.8
	12	1	31.2
	13	1	30.4
	14	1	29.9
	15	1	32.7
	16	1	29.6
	19	2	59.5
3	31	8	228.6
	32	7	198.3
	33	6	168.5
	34	6	198.9
	35	5	125.7
	36	4	101.1
	37	5	129.1
	38	3	83.5
	39	4	110.2
5	51	16	430.1
	54	5	135.6
	56	5	132.6
	59	4	109.5
6	60	3	83.1
	61	2	52.9
	62	3	75.6
	63	3	75.6
	64	2	50.1
	65	2	52.4
	67	4	101.2
	69	3	76.7
7	71	9	224.7
	72	13	287.4
	73	8	166.9
	74	9	152.8
	75	14	155.5
	76	15	218.9
	77	17	166.4
	78	16	195.4
	79	8	83.8
8	80	4	36.3
	81	3	27.6
	85	3	26.3
	88	4	45.9
	89	15	189.9
9	91	35	640.1
	93	10	229.8
	95	10	256.3
	97	15	406.8
Total accumulated degree			8,183.40

The chilling requirement of the Zhanshanmizao cultivar was studied and presented by Deng et al. (2018). The preliminary calculation showed that the chilling requirement was 494 h, according to the 0-7.2°C model.

Bai et al. (2019) proposed a different model to assess the correlation between phenology stages and temperatures in their study regarding the WOFOST model in simulating jujube fruit tree growth under different irrigation regimes.

According to the study by Gao et al. (2021), the diploid Dongzao cultivar had higher levels of cold tolerance than autotetraploid due to its morphological and physiological analysis.

Figure 4. *Ziziphus jujuba* riped fruits

Chițu et al. (2022) presented a model-based assessment of Romania's climatic suitability for extending new fruit species, including jujube crops, considering the 100-180 growing days.

It was found that, from the point of view of climatic suitability, jujube trees present reduced restrictions in most areas of the country. In Romania, according to their study, *Ziziphus jujuba* Mill. Species are restricted only in areas where the temperature drops below -23°C.

CONCLUSIONS

The results reflected the scarcity of research on the phenology of these fruit species correlated to chilling and heat requirements and the necessity for a methodology that could extend to new cultivars in different areas.

ACKNOWLEDGEMENTS

This work was supported by a grant from the University of Agronomic Sciences and Veterinary Medicine of Bucharest, project number 2022-007/16.05.2022 acronym RealTimeFruit, within IPC 2022

REFERENCES

Abu-Asab, M.S., Peterson, P.M., Shetler, S.G. & Orli, S.S. (2021). Earlier plant flowering in spring as a response to global warming in the Washington DC area. *Biodiversity & Conservation*, *10*, 597–612.

Bai, T., Zhang, N., Chen, Y. & Mercatoris, B. (2019). Assessing the Performance of the WOFOST Model in Simulating Jujube Fruit Tree Growth under Different Irrigation Regimes. *Sustainability, 11*, 1466. https://doi.org/10.3390/su11051466

Brannan, R.G. & Coyle, M.N. (2021). Worldwide Introduction of North American Pawpaw (*Asimina triloba*): Evidence Based on Scientific Reports. *Sustainable Agriculture Research, 10* (3), 19-24.

Brannan, R.G., Salabak, D.E. & Holben, D.H. (2012). Sensory analysis of pawpaw (*Asimina triloba*) pulp puree: consumer appraisal and descriptive lexicon. *J Food Res 1* (1), 179.

Chițu, E., Călinescu, M., Mazilu, I., Coman, M. & Mateescu, E. (2022). Model-based assessment of Romania's climatic suitability for the extension of fig, Chinese persimmon, and jujube crops, *RJH, III*, 131-138.

Chmielewski, F.M., Müller, A. & Bruns, E. (2004). Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. *Agric For Meteorol, 121*, 69–78.

Crabtree, S.B. (2004). Sexual and asexual reproductive characteristics of the North American pawpaw [The North American pawpaw [*Asimina triloba* (L.) Dunal], *University of Kentucky Master's Theses. 409*. https://uknowledge.uky.edu/gradschool_theses/409.

Deng, Q., Wang, Y., Zhu, W., Zhou, Y. & Deng, Q. (2018). Study on the Chilling Requirement and Dormant Physiology of Ziziphus jujuba 'Zhanshanmizao'. Advances in Engineering Research, 170, 1385-1388.

Du, J.J. (2009). The determination of chilling requirement and changes of carbohydrate during dormancy for chinese jujube. *Acta Hortic. 840*, 369-374, doi: 10.17660/ActaHortic.2009.840.51.

Elloumi, O., Ghrab, M., Kessentini, H. & Ben Mimoun, M. (2013). Chilling accumulation effects on performance of pistachio trees cv.Mateur in dry and warm area climate. *Sci Hortic 159*, 80–87.

Gao, M., Wang, L., Li, M., Sun, P., Sadeghnezhad, E., Shi, H., Qian, J., Liu, Z., Liu, M., Liu, P. & Wang, L., (2021) Physiological and transcriptome analysis accentuates microtubules and calcium signaling in Ziziphus jujuba Mill 'Dongzao' autotetraploids with sensitive cold tolerance, *Scientia Horticulturae*.

Grab, S.& Craparo, A. (2011). Advance of apple and pear tree full bloom dates in response to climate change in the southwestern Cape, South Africa: 1973–2009. *Agric For Meteorol 151*, 406–413.

Guédon, Y. & Legave, J.M., (2008). Analyzing the time-course variation of apple and pear tree dates of flowering stages in the global warming context. *Ecol Model, 219*, 189–199.

Guo, L., Dai, J., Ranjitkar, S., Yu, H., Xu, J. & Luedeling, E. (2014). Chilling and heat requirements for flowering in temperate fruit trees, *Int J Biometeorol 58*, 1195–1206.

Hernández, F., Legua, P., Melgarejo, P., Martínez, R. & Martínez, J.J. (2014). Phenological growth stages of jujube tree (*Ziziphus jujube*): codification and description according to the BBCH scale, *Plant Science and Microbiology Department, Universitas Miguel Hernández*. Grupo de Fruticultura y Técnicas de Producción., Alicante, Spain

Krishna, H., Kumar, L., Haldhar, S.M., Singh, D. & Saroj, P.L. (2018). Phenological growth stages of Indian jujube (*Ziziphus mauritiana* Lamk.) according to the BBCH scale, *Plant Phenological Growth Stages*

Lechowicz, M. (1984). Why Do Temperate Deciduous Trees Leaf Out at Different Times? Adaptation and Ecology of Forest Communities. *American Naturalist 124*. 10.1086/284319.

Legave, J., Blanke, M., Christen, D., Giovannini, D., Mathieu, V. & Oger, R. (2013). A comprehensive overview of the spatial and temporal variability of apple bud dormancy release and blooming phenology in Western Europe. *Int J Biometeorol 57*, 317–331.

Legave, J.M. & Clauzel, G. (2005). Long-term evolution of flowering time in cultivars grown in the south-east of France: what impacts to come in the context of global warming.

Legave, J.M., Farrera, I., Almeras, T., Calleja, M. (2008). Selecting models of apple flowering time and understanding how global warming has had an impact on this trait. *J Hortic Sci Biotechnol 83*, 76–84.

Lolletti, D., Principio, L., Ciorba, R., Mitrano, F., Ceccarelli, D., Antonucci, F., Manganiello, R. & Ciccoritti, R. (2021). *Asimina triloba*: Crop years, cultivars and ripening time influence on qualitative parameters

McLaughlin, J.L. (1997). Anticancer and pesticidal components of pawpaw (*Asimina triloba*). *Ann. Rep. Northern Nut Growers Assoc. 88*, 97–106.

Mishra, S. & Krška, B. (2008). Temperature as the basic factor influencing phenological stages in *Ziziphus Jujuba* Mill. *Acta univ. Agric. et silvic. Mendel. Brun*., *LVII* (1), 89–96.

Peterson, R.N. (1991). Pawpaw (Asimina). In: More, J.N., Ballington, J.R. (Eds.), *Genetic Resources of Temperature Fruit and Nut Trees*. *Acta Hort.*, 567–600.

Pomper, K., Crabtree, S., Layne, D. & Peterson, R.N. (2008). Flowering and Fruiting Characteristics of Eight Pawpaw (*Asimina triloba* (L.) Dunal) Selections in Kentucky. *Journal- American Pomological Society. 62*, 89–97.

Pomper, K.W. & Layne, D.R. (2005). The North American Pawpaw. *Botany and Horticulture. Hortic. Rev. 31*, 351–384.

Ratnayake, S., Rupprecht, K.J., Potter, W.M. & McLaughlin, J.L. (1992). Evaluation of Various Parts of the Paw Paw Tree, *Asimina triloba* (Annonaceae), as Commercial Sources of the Pesticidal Annonaceous Acetogenins, *Journal of Economic Entomology*, *85* (6), 2353–2356.

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T.L., Estrella, N., Seguin, B., Tryjanowski, P., Liu, C., Rawlins, S. & Imeson, A. (2008). Attributing physical and biological impacts to anthropogenic climate change. *Nature 453*, 353–357.

Sun, S., Jin, D. & Li, R. (2006). Leaf emergence in relation to leaf traits in temperate woody species in East-Chinese Quercus fabri forests. *Acta Oecologica-International Journal of Ecology 30*, 212–222.

Szilagyi, B.A., Stănică, F. & Dănăilă-Guidea, S.M. (2016). Flowering of *Asimina triloba* (L.) Dunal in the conditions of Transylvania, *Muzeul Olteniei Craiova. Oltenia. Studii şi comunicări. Ştiinţele Naturii*, *32* (1), 50-54

Tulowiecki, S.J. (2021). Modeling the geographic distribution of pawpaw (*Asimina triloba* [L.] Dunal) in a portion of its northern range limits, western New York State, USA, *Plant Ecol*, *222*, 193–208.

Wolfe, N.D., Daszak, P., Kilpatrick, A.M. & Burke, D.S. (2005). Bushmeat hunting, deforestation, and prediction of zoonoses emergence. *Emerg Infect Dis. 11*(12), 1822-7.

Zou, F., Duan, J., Xiong, H., Yuan, D., Zhang, L. & Niu, G. (2017). Flower Bud Differentiation and Development of 'Jinsi No.4' Jujube (Mill.) in Hunan Province of Southern China. *The Open Biotechnology Journal, 11*. 09–15. 10.2174/1874070701711010009.