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EVALUATION OF WALNUT TREE FLOWERING AND FROST OCCURRENCE PROBABILITY DURING 1961–2012

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Abstract

Strength and direction of the potential effect of climate change on walnuts is regionally specific (Gauthier and Jacobs, 2011) as climate change will probably affect the spatial distribution of the walnut. This paper evaluated the long-term phenological series (1961–2012) of the beginning of flowering, end of flowering and duration of flowering in walnut tree (*Juglans regia*) at two phenological stations located in different geographical locations of the Czech Republic but in the same climatic conditions (warm region). Phenological stages were analyzed in relation to growing degree days and to spring frosts occurrence. Onset of the beginning and end of flowering occurred earlier at Velké Pavlovice station (-2.1 and -1.3 days), and conversely occurred later at Doksany station (+1.8 and +1.0). Period of flowering shortened at Doksany station (-0.8 day) and prolonged at Velké Pavlovice station (+1.2 day). The occurrence of days with minimum air temperature < 0 °C during walnut tree flowering was more frequent at Doksany station (in total, 29 days) with absolute minimum value -5.5 °C. At Velké Pavlovice station 5 days with minimum air temperature below 0 °C were found during examined period with absolute minimum value -3.8 °C. The negative trend in number of frost days occurrence during flowering period was found at both stations. Pearson correlation coefficient between phenophase onset (and flowering period) and sums of growing degree days was stronger at Velké Pavlovice station, and the highest value was between period of flowering and temperature sums (0.782). The results confirmed our hypothesis of changes in phenophase onsets and duration of flowering including spring frosts occurrence according to west-east gradient (maritime climate-continental climate).

Keywords: *Juglans regia*, spring frost, phenology, minimum air temperature, Czech Republic

INTRODUCTION

Weather is an integral part of our lives, it is an important parameter in human activity e.g. in fruit growing, agriculture or forestry. Frost occurrence during flowering period can have very negative effects on plants. Walnut tree is considered a frost-sensitive species and is also threatened by the occurrence of early and late frosts (Barengo, 2001; Hemery and Savill, 2001). Risk of frost damage threatens walnut tree (*Juglans regia*) from autumn to spring. The nature of the risk may be generally classified into three groups due to a phase of the cold season: autumn frost (damage due to an insufficient acclimatization), winter frost (damage by excessive minimum temperatures), spring frost (damage due to precocious deacclimation) (Charrier *et al.*, 2017). Risk of spring frost comes after a bud break, when a tree begins a new vegetation season. In central Europe the chilling requirements for walnut trees are usually fulfilled already at the end of December (Mauget, 1988). Thus, for a determination of the bud-breaking date in this region is more important the heat accumulation during the subsequent phase of ecodormancy. The buds begin to swell earlier with an increase in the average temperature during the heat accumulation phase (Hassankhah *et al*., 2017), and therefore the warm springs have a clear advancing effect (Luedeling and Gassner, 2012).

Frost resistance depends on many factors e.g. on the type of plant, the health condition of the plant itself, and as well as on the vegetation stage (phenological phase). Spring frost can be a limiting factor in fruit trees production (Chmielewski *et al*., 2018). Spring frost damage risk is the highest in low (and thus warmer) elevations, especially for early walnut genotypes awakened by early warm spells (Charrier *et al*., 2017).

Phenological information is important in monitoring all aspects of ecosystems in agriculture, fruit growing, forestry or wildfire management (Beaubien and Freeland, 2000). Phenology is the simplest method for tracking the response of species to environmental change (Scheifinger and Templ, 2016) and the long-term phenological series are a valuable resource for climate change research. The fact, that many authors have documented a change in spring phenological onsets such as bud bursts, leaf folding and flowering occur earlier and earlier with each decade (e.g. Ahas *et al*., 2002; Schwartz *et al*., 2006; Menzel *et al*., 2006 or Hájková *et al*., 2015) is well known nowadays. Following the phenological series, an analysis of selected meteorological elements (e.g. the occurrence of a minimum air temperature below 0 °C at the time of fruit trees flowering) can be performed.

Our hypothesis was as follows: west-east gradient (maritime climate-continental climate) is important factor in the onsets of the beginning and end of flowering, duration of flowering and ongoing spring frosts occurrence during flowering.

The main goals of this paper were the following:

1. to make temporal evaluation of the beginning and end of flowering and duration of flowering of walnut tree (*Juglans regia)* from results at two long-term phenological stations located in the same climatic conditions and in different geographic locations of the Czech Republic in period 1961–2012;
2. to evaluate minimum air temperature during walnut tree flowering in period 1961–2012;
3. to analyze sums of growing degree days above 5 °C to onset of beginning and end of flowering, and during flowering in period 1961–2012;
4. to assess Pearson correlation coefficient between sums of effective temperature above 5 °C and phenophase onset and duration of flowering.

MATERIALS AND METHODS

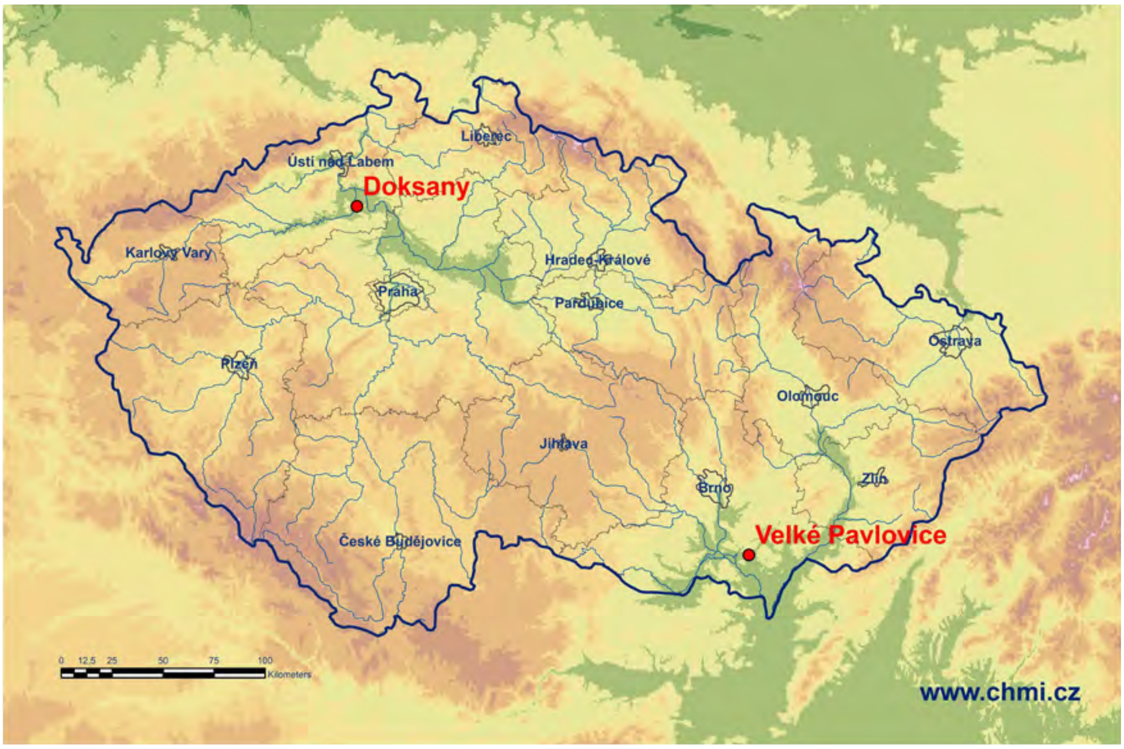
Phenological observations have a long tradition in the Czech Republic, the Czech Hydrometeorological Institute (CHMI) manages a phenological network as an integral part of its working activities. Historical phenological reports are stored in the CHMI (even since 1923 to nowadays). In this case study, a long-term series of *Juglans regia* (1961–2012) at two phenological stations located in the same climatic conditions (W4 region – see Tab. I) in different geographical parts of the Czech Republic (see Fig. 1) were used. In 2012, the the fruit tree phenological network was canceled. Beginning and end of flowering (Fig. 2) were selected into this study. The regular phenological observations of these two phases were performed according to a similar methodology (CHMI, 2009; Coufal *et al.*, 2004; Pifflová *et al*., 1956) throughout the whole observation period (1961–2012), phenological dates were listed in day of year (DoY). The phenological phases were given in BBCH codes (Beginning of flowering = BBCH 61; End of flowering = BBCH 69). The BBCH-scale is a system for a uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species (Meier, 1997). Phenological observations were performed on at least 5 individuals. The variety „Hroznovitý“ was monitored at Doksany station, the observed trees were older than 20 years. At Velké Bílovice station the variety „Polopapírek“ was observed and the observed trees were older than 15 years.

The frequency of spring frosts occurrence based on minimum air temperature measured in 2 meters (TMI) and calculation of sums of growing degree days (GDD) to phenophase onset and during the *Juglans regia* flowering were evaluated. GDD was calculated by subtracting a base temperature from the daily mean temperature, and the GDD values less than zero are set to zero. According to Glickman (2000) the base temperature for plants is 5 °C: GDD = tavg - tbase, where tbase = 5 °C.

The corresponding climatological station was assigned to each phenological station (Tab. I) to obtain values of minimum air temperature, and as well as to evaluate climatological conditions of the phenological station by modified Walter-Lieth climagram (e.g. Kožnarová and Klabzuba, 2010) based on the long-term average data 1961–1990, 1981–2010 and 1961–2010 (Fig. 3) in agrometeorological year. Agrometeorological year starts on 1st October and ends on 30th September.

The phenological data series (1961–2012) were obtained from the PHENODATA (the CHMI phenological database), meteorological data (1961–2012) were exported from CLIDATA (the CHMI climatological database).

Phenological trends were studied using onset dates of phenological phases; the mean temporal change (in days per year) was evaluated using the regression slope. All analyzes were performed in the framework of Microsoft Excel.



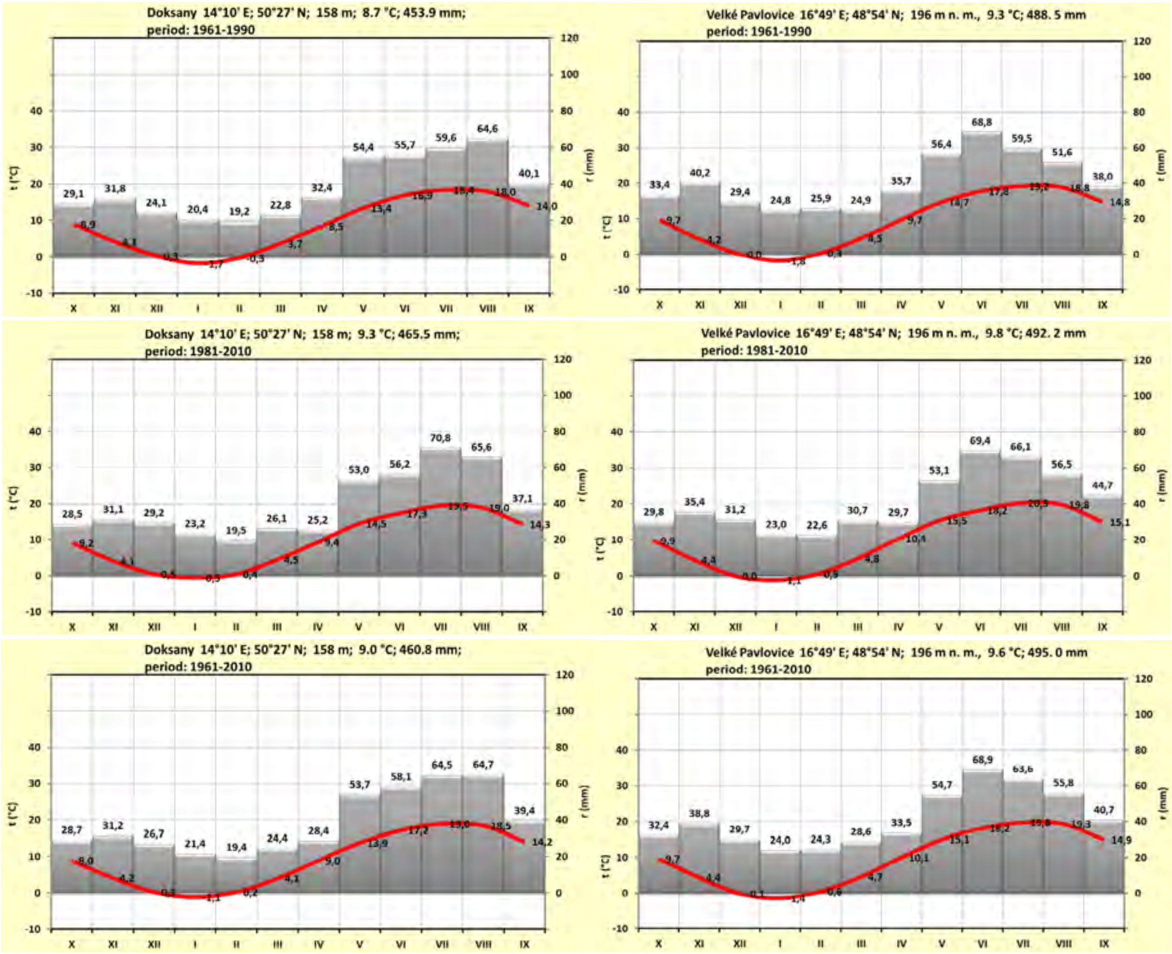
1: *Map of stations (highlighted in red)*

I: *Characteristics of phenological (P) and climatological (C) stations including Quitt's classification (Tolasz, 2007)*

Station	Longitude	Latitude	Altitude (m a.s.l.)	Station	Longitude	Latitude	Altitude (m a.s.l.)	Quitt's classification
Doksany (P)	17°48‘	48°52‘	155	Doksany (C)	14°10‘	50°27‘	158	W4
Velké Pavlovice (P)	15°18‘	49°31‘	200	Velké Pavlovice (C)	16°49‘	48°54‘	196	W4

Note: W4 – warm region

2: *Beginning of flowering (BBCH 61) of Juglans regia*



3: *Climagrams of climatological stations (Doksany station – left column; Velké Pavlovice station – right column) in periods 1961–1990, 1981–2010 and 1961–2010*

RESULTS

The onset and duration of flowering differed considerably between the years (Fig. 4, 5), descriptive statistics for beginning of flowering, end of flowering (BBCH 61, BBCH 69) and period of flowering of *Juglans regia (*period 1961–2012) were illustrated in box-plots (Fig. 6–8).

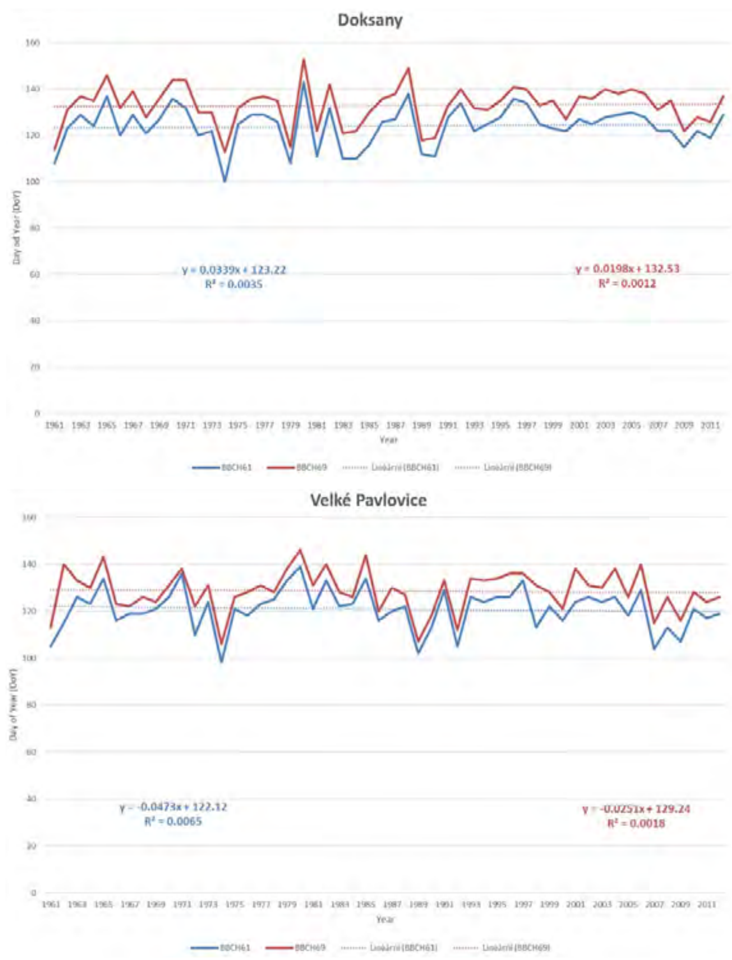
Tabs. II–IV represent descriptive statistics of GDD to phenophase onset and during period of flowering in periods 1961–2012, 1961–1990 and 1981–2010.

The average value of GDD during flowering period was similar at both stations (e.g. 70.5 °C and 71.8 °C in 1961–2012 perid) and moreover, all GDD sums were the highest in 1981–2010 period.

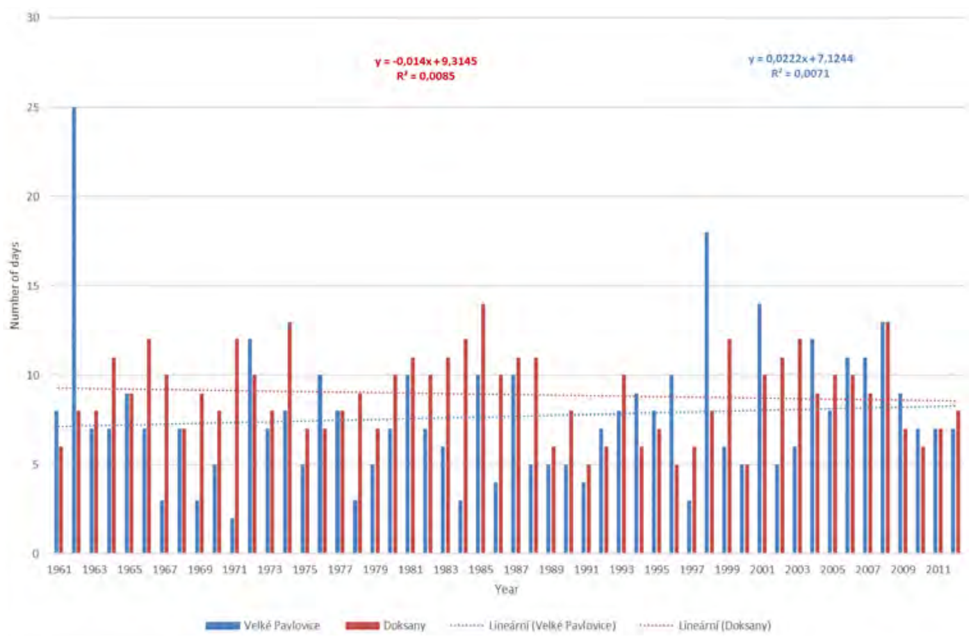
Tab. V shows linear trends of changes during examined period (1961–2012) at both stations. In total, linear trends in phenophase onsets were negative (it means earlier onset) at Velké Pavlovice station and the duration of flowering prolonged at this station. Conversely, at Doksany station was found the opposite trend (later onset of flowering and shorter period of flowering).

Tab. VI represents results of Pearson correlation coefficient (PCC) between phenophase onset and period of flowering and GDD.

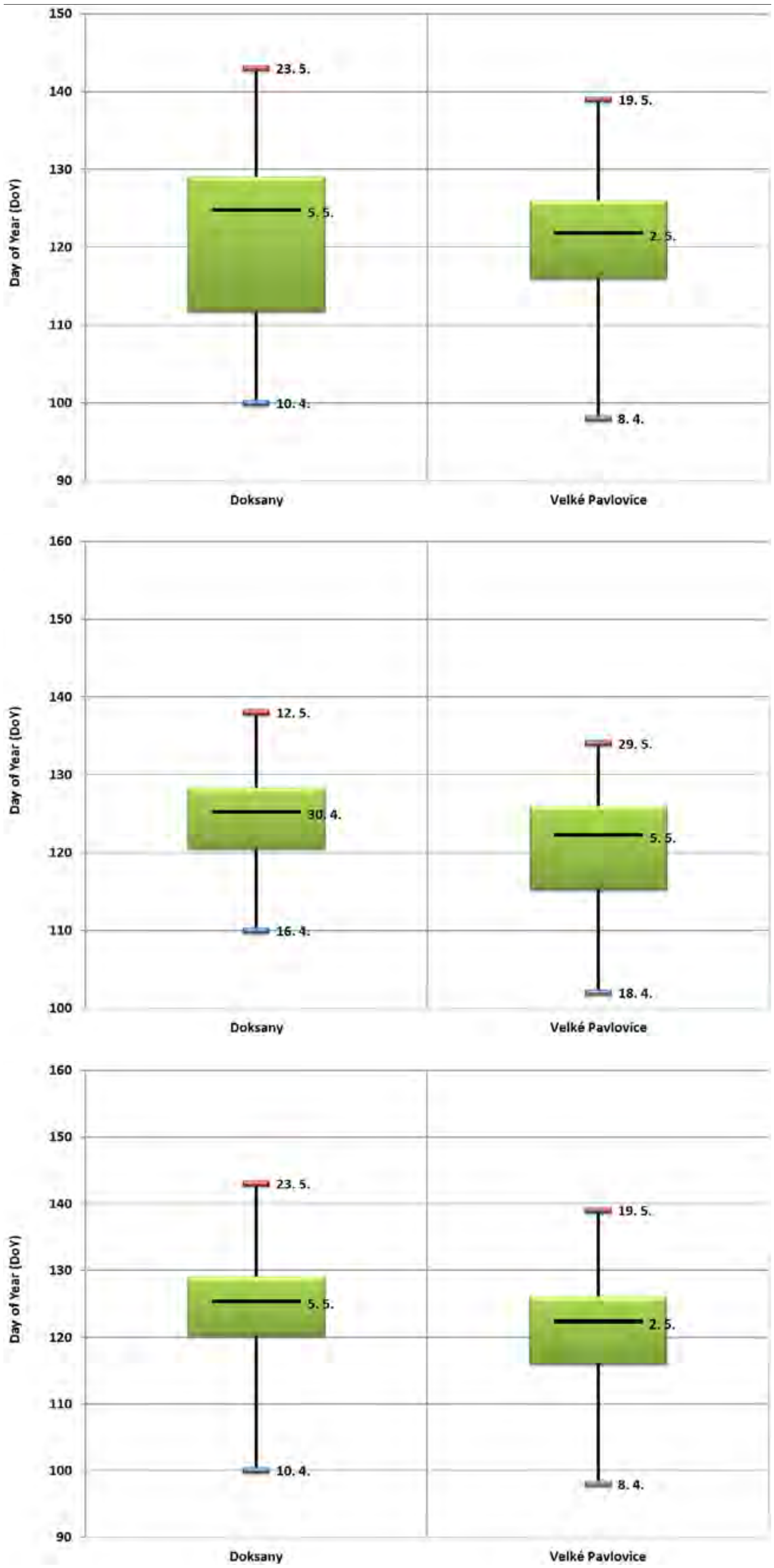
Figs. 9 and 10 show the progress of minimum air temperature (the lowest and average values in flowering period) in 1961–2012. And Fig. 11 illustrates number of days with TMI < 0 °C during flowering period. The number of days clearly predominate at Doksany station (29 days in total). Tab. VII represents linear trends of minimum air temperature development during period of flowering. The absolute minimum value of minimum air temperature occurred in flowering period had negative trend at both stations and it is lower at Velké Pavlovice station. On the contrary, average and maximum values of minimum air temperature during flowering period had positive trend at Velké Pavlovice station. These results indicated increasing risk of lower minimum air temperature occurrence during walnut tree flowering at both stations.



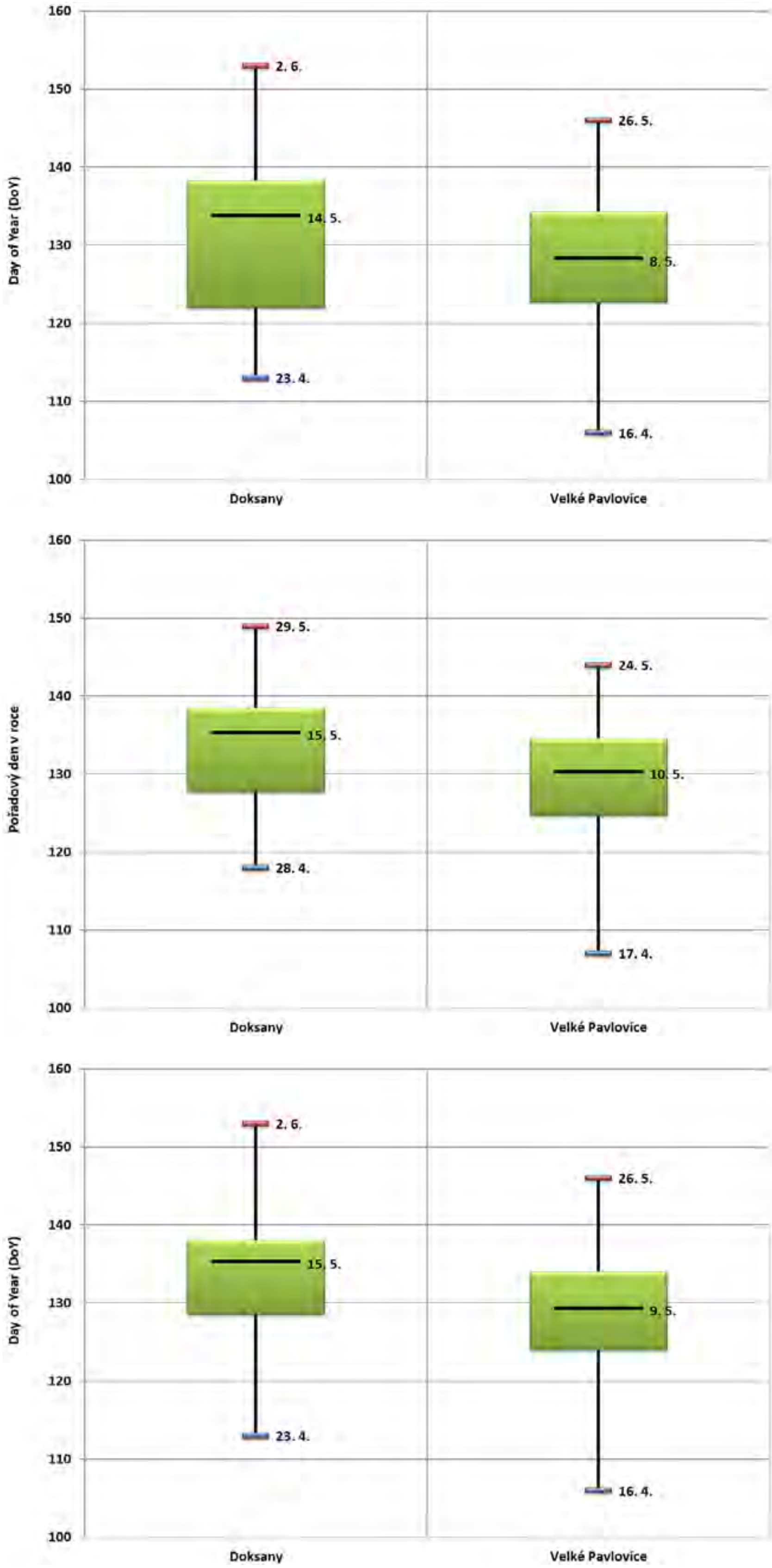
4: *Beginning of flowering (BBCH 61) and end of flowering (BBCH 69) of Juglans regia at Doksany and Velké Pavlovice stations in period 1961–2012 (in DoY)*
Note: lineární = linear trend



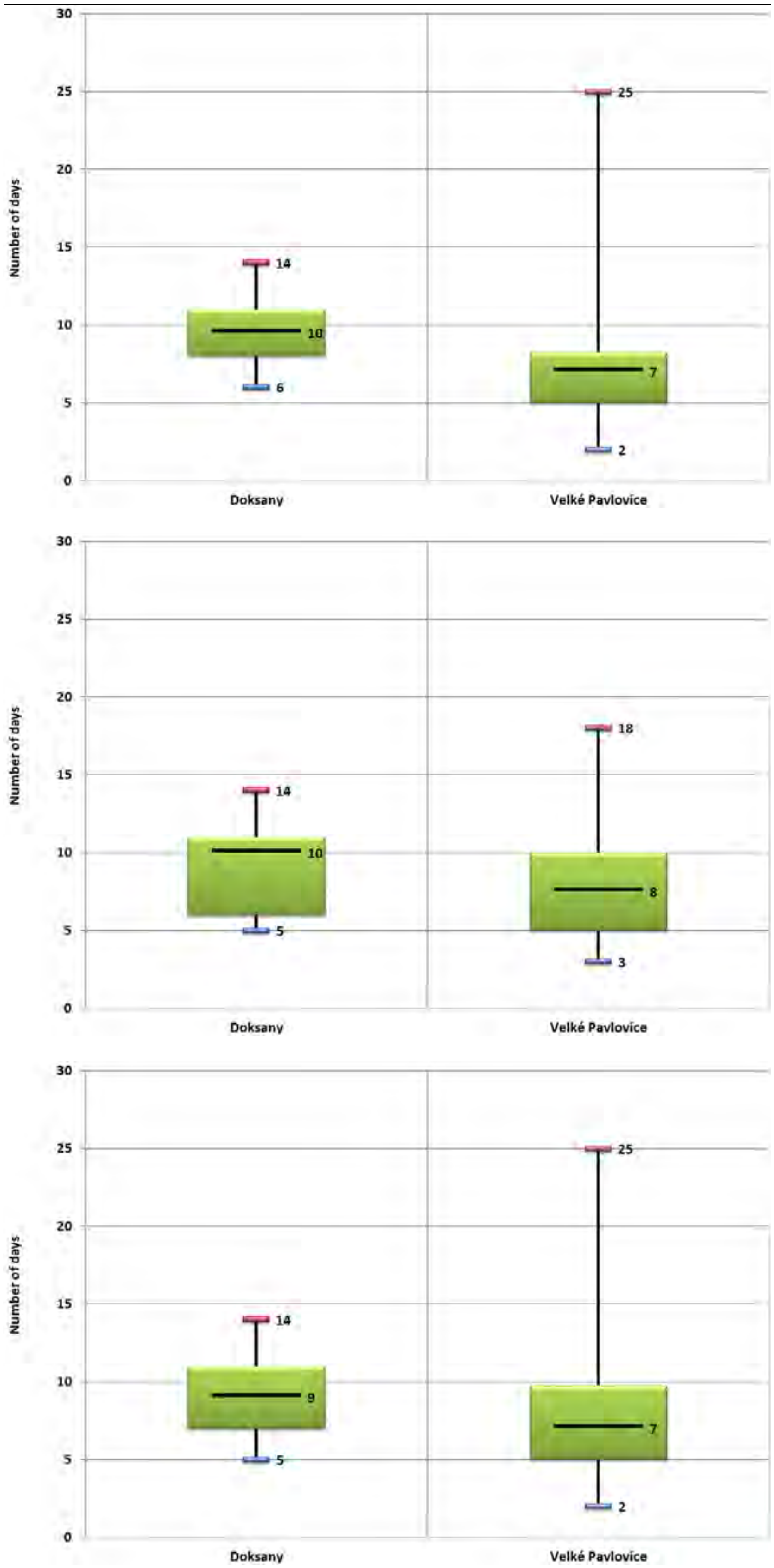
5: *Flowering period of Juglans regia at Doksany (red columns) and Velké Pavlovice stations (blue columns) in 1961–2012 (mentioned in days)*
Note: lineární = linear trend



6: *Box-plot of beginning of flowering (BBCH 61) of Juglans regia at Doksany (left column) and Velké Pavlovice (right column) stations in periods 1961–1990, 1981–2010 and 1961–2012 (in DoY)*



7: *Box-plot of end of flowering (BBCH 69) of Juglans regia at Doksany (lef column) and Velké Pavlovice (right column) stations in periods 1961–1990, 1981–2010 and 1961–2012 (in DoY)*



8: *Box-plot of flowering period of Juglans regia at Doksany (left column) and Velké Pavlovice (roght column) stations in periods 1961–1990, 1981–2010 and 1961–2012 (in number of days)*

II: *Descriptive statistics of GDD to beginning of flowering (BBCH 61) of Juglans regia in periods 1961–1990, 1981–2010 and 1961–2012 (in °C)*

Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum
				1961–2012			
Doksany	223.3	215.1	267.3	177.8	65.8	61.1	357.3
Velké Pavlovice	238.3	229.1	276.3	192.3	52.2	98.1	377.8
				1961–1990			
Doksany	185.8	189.8	212.4	160.4	52.8	61.1	355.9
Velké Pavlovice	221.9	214.9	228.7	187.9	45.8	169.8	377.8
				1981–2010			
Doksany	242.1	254.5	281.7	193.7	67.4	61.1	355.9
Velké Pavlovice	247.6	246.8	289.7	190.8	55.3	98.1	345.7

III: *Descriptive statistics of GDD to end of flowering (BBCH 69) of Juglans regia in periods 1961–1990, 1981–2010 and 1961–2012 (in °C)*

Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum
				1961–2012			
Doksany	295.2	285.6	355.8	233.9	81.5	103.3	470.3
Velké Pavlovice	308.8	305.9	350.6	247.2	68.4	119.9	256.6
				1961–1990			
Doksany	254.2	250.1	285.4	212.9	71.4	103.3	470.3
Velké Pavlovice	283.8	274.9	313.8	238.3	54.6	217.8	431.2
				1981–2010			
Doksany	317.3	321.0	391.9	240.4	85.1	122.0	470.3
Velké Pavlovice	324.0	324.7	385.4	272.1	75.7	119.9	456.6

IV: *Descriptive statistics of GDD for flowering period of Juglans regia in periods 1961–1990, 1981–2010 and 1961–2012 (in °C)*

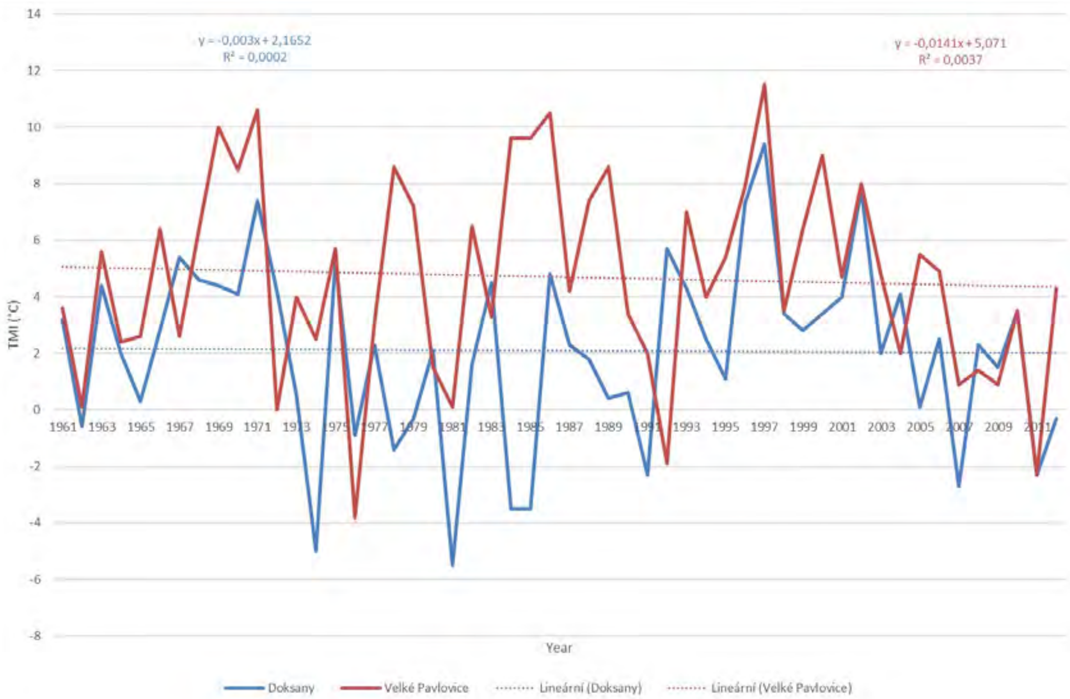
Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum
				1961–2012			
Doksany	71.8	66.3	99.7	49.3	31.4	15.9	149.4
Velké Pavlovice	70.5	63.7	85.9	49.9	34.0	20.2	198.0
				1961–1990			
Doksany	68.4	63.4	92.6	44.0	31.7	15.9	149.4
Velké Pavlovice	61.9	57.8	79.7	43.1	27.5	20.2	152.6
				1981–2010			
Doksany	75.2	74.6	106.6	47.0	32.3	15.9	127.0
Velké Pavlovice	76.8	78.9	94.3	49.8	36.8	21.8	198.0

V: *Linear trends for Juglans regia at long-term phenological stations (Doksany and Velké Pavlovice) during the period 1961–2012 (phenophases are mentioned in days and GDD are mentioned in °C)*

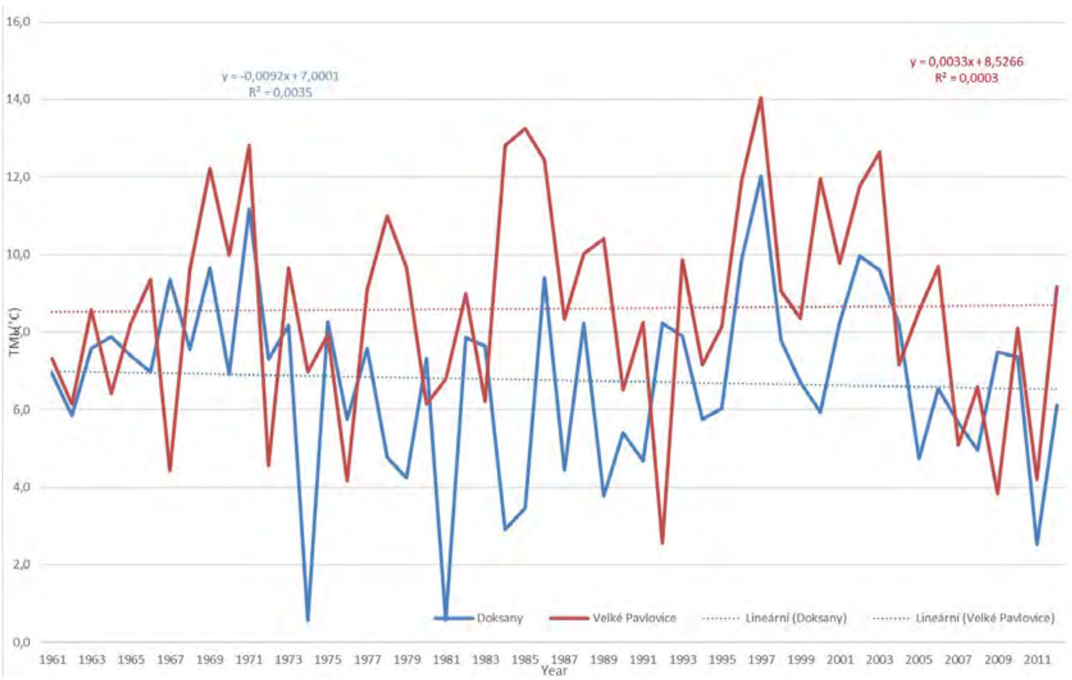
Station	Beginning of flowering (BBCH 61)	End of flowering (BBCH 69)	Period of flowering	GDD to BBCH 61	GDD to BBCH 69	GDD during flowering
			1961–2012			
Doksany	+1.8	+1.0	-0.8	+133.3	+140.5	+7.2
Velké Pavlovice	-2.1	-1.3	+1.2	+55.1	+80.1	+25.0

VI: *Pearson correlation coefficient between phenophase onset and period of flowering and GDD*

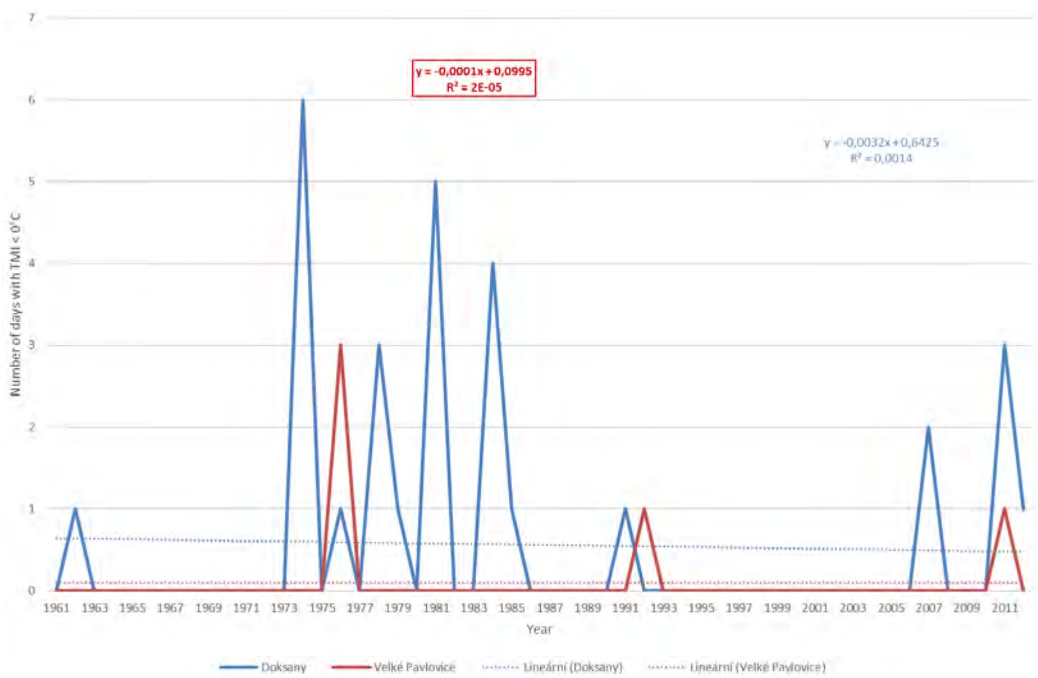
Station	GDD to BBCH 61	GDD to BBCH 69	GDD during flowering
Doksany	0.486	0.565	0.502
Velké Pavlovice	0.527	0.599	0.782



9: *The lowest minimum air temperature during flowering period in 1961–2012 (blue line means Doksany station and red line represents Velké Pavlovice station)*
Note: lineární = linear trend



10: *The average minimum air temperature during flowering period in 1961–2012 (blue line means Doksany station and red line represents Velké Pavlovice station)*
Note: lineární = linear trend



11: *Number of days with TMI < 0 °C during flowering period in 1961–2012 (blue line means Doksany station and red line represents Velké Pavlovice station)*
Note: lineární = linear trend

VII: *Linear trends of minimum air temperature (average - AVG, minimum – MIN and maximum – MAX values) during flowering period of Juglans regia at Doksany and Velké Pavlovice stations in 1961–2012 (mentioned in °C)*

	AVG minimum air temperature	MIN minimum air temperature	MAX minimum air temperature
Doksany	-0.5	-0.2	-0.5
Velké Pavlovice	+0.2	-0.7	+0.05

DISCUSSION

The mean air temperature is rising due to climate change (IPCC 2021) which causes shifts in the phenology of walnuts. The bud-breaking date occurs earlier and it is predicted that this phenomenon will be further accelerated, however the intensity of the trend will probably be cultivar specific (Črepinšek *et al.*, 2009) as various genotypes differ significantly in their reactions during ecodormancy and in the deacclimation (Charrier *et al.*, 2017).

The trend in GDD changes is positive at both stations – this trend is confirmed by IPCC 2021). The flowering date of both male and female flowers is also accelerated by the increase of temperature (Hassankhah *et al.*, 2017), though the higher springtime temperatures probably speeds-up especially the male flowers (Cosmulescu and Ionescu, 2018). And the explanation of the difference between two examined stations can be as follows: the colder oceanic flow will not allow the earlier onset of beginning of flowering at Doksany station (maritime climate). And moreover, it can be stated that the strength of the trends depends to a great extent, on the period considered (Roetzer *et al.*, 2000). Furthermore, it can be assumed that changes in phenophase onset and duration are influenced by more elements, not just the air temperature.

Findings of our results confirm global warming and dangerous influence of early spring frost risk on walnut tree flowering in lowlands (earlier onset of beginning of flowering is in jeopardy by sudden influx of cold air during spring). According to all climate change scenarious should increase spring frost losses even these developments will be highly localised, depending on whether the climate is continental or maritime, and whether a location is at altitude or in a valley. It is predicted that the climatic optimum of this species in Europe will shift northward, and that it might actually become invasive in the north, while in the southern part of Europe it will be threatened due to its susceptibility to frost injury and drought (Paź-Dyderska *et al.*, 2021).

Vitasse *et al.* (2018) pronounced in their results that frost risk needs to be considered carefully when promoting the introduction new varieties of fruit trees to warmer and drier climates or when considering new plantations at higher elevations. Chmielewski *et al.* (2018) stated in their study the importance of reliable phenological models which not only work for current but also for changed climate conditions and at different sites.

CONCLUSION

This paper evaluated the long-term phenological series (1961–2012) of the beginning of flowering, end of flowering and duration of flowering in walnut tree (*Juglans regia*) at two stations located in different geographical locations but in the same climatic conditions (W4) of the Czech Republic in relation to GDD and to spring frosts occurrence. The trend analysis showed that the onset of beginning and end of flowering were not the same at both stations within the entire period (1961–2012). At Velké Pavlovice station beginning and end of flowering occurred earlier (-2.1 and -1.3 days) and at Doksany station occurred later (+1.8 and +1.0 day). Moreover, period of flowering shortened at Doksany station (-0.8 day) and prolonged at Velké Pavlovice station (+1.2 day). The occurrence of days with minimum air temperature < 0 °C during walnut tree flowering was more frequent at Doksany station (29 days in total), and as well as the minimum value of TMI was lower at Doksany station (-5.5 °C). The trend analysis of number of days with minimum air temperature below zero during flowering period was negative at both stations. Pearson correlation coefficent between phenophase onset (and flowering period) and GDD was stronger at Velké Pavlovice station, and the highest value was between period of flowering and temperature sums (0.782). The results showed that the hypothesis was confirmed.

Strength and direction of the potential effect of climate change on walnuts is regionally specific (Gauthier and Jacobs, 2011) as climate change will probably affect the spatial distribution of the walnut. And as Zavalloni *et al*. (2006) stated in their research, knowledge and awareness of flower bud phenological stages and fruit growth development are important requirements for many facets of crop management. Unfortunately, regional studies with projections based on climate models are still missing and results from these studies would be essential to supplement risk management in fruit growing. However, generally the successful expansion of the distribution range of tree species due to climate change, is limited by compatibility of their phenology to future stochasticity of freezing temperatures in spring (Lenz *et al*., 2015).

Acknowledgements

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