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The Impact of Climate Change on the Vernalization Requirements of Spring-Flowering Bulbous Plants

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Abstract. Winter chilling is required for the vernalization of several spring-flowering bulbous plants, such as tulips, narcissi, and hyacinths, enabling them to complete floral induction within their bulbs before spring and produce normal blooms upon its arrival. However,because mean global temperatures are continuing to rise, fewer cumulative hours of sufficiently low winter chill are available today in many parts of the world where these bulbs traditionally thrived. Hence, concern arises over insufficient vernalization, delayed or irregular flowering, and the resulting poor ornamental quality should this problem persist. With respect to the current state of research, this article reviews recent studies on the relationship among climate change, plant phenology, and vernalization, examines current changes in the chilling requirements of spring-flowering bulbs under warmer winters, and evaluates the feasibility of the cultivation methods, conservation approaches, and breeding programs currently recommended as solutions, drawing on findings from these studies. It appears that adjusting growing conditions according to weather forecasts and selecting varieties with lower demands for cold treatment in winter will probably work best among all existing options for ensuring continued availability of bulbs for cut flowers under future scenarios involving more extreme warming of winter seasons, even though scientific evidence regarding certain kinds of ornamental geophytes still requires further study for the time being.

Keywords: Climate change, vernalization, spring-flowering bulbous plants, plant breeding, plant conservation

1. Introduction

Climate change is altering seasonal temperatures across much of the geophytes' range. Winter lows have risen especially sharply in many midlatitude places where these plants grow. Many spring-flowering geophytes cannot form flowers within their bulbs unless they experience sufficiently cool weather before emergence—a process growers call "vernalization." However, since the precise duration and temperature required to trigger flower formation remain unknown for most tulip (Tulipa spp.), daffodil (Narcissus spp.) and related varieties, it is also uncertain whether sufficient winter chill will persist in all regions where these plants are desired for continued blooming — especially given that breeders originally selected many cultivars precisely for their performance in specific places [1, 2].

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This paper addresses three core research questions: first, how climatic warming alters the physiological chilling accumulation required by spring-blooming bulbs; second, the horticultural impacts of insufficient vernalization on bloom timing and floral quality; third, which cultivation techniques, germplasm conservation strategies and breeding pipelines can maintain stable flowering performance under sustained climate warming in the next decades. It does not offer new research results but relies instead on existing literature. For this reason, the authors rely mainly on phenological and horticultural studies of temperate trees, for which much longer observational records are available than for geophytes. They then apply this knowledge analogically to bulbous plants.

Beyond curiosity about an important export crop, this review offers broader insights into plant dormancy and phenology generally, and provides initial guidance on how breeders, growers, and conservationists who care for flowering geophytes might prepare should winter warming continue.

2. Background of climate change and vernalization

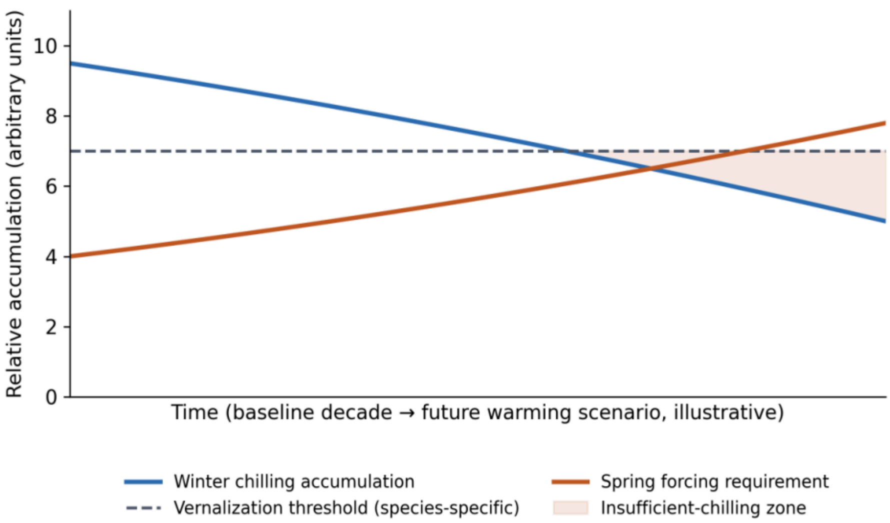

Figure 1. A conceptual picture of the chilling–forcing dilemma: when there is less winter chill due to global warming, more spring forcing will be needed before the vernalization requirement is fulfilled, and hence vernalization occurs later and less reliably (the curve shown here schematically is based on the dormancy-release model described in [2] and [3])

For spring-flowering bulbs, vernalization is better described as a dormancy-release process that is controlled by the accumulation of winter chilling units and that must then be followed by a warm spell (forcing) to finish flower development and induce stem extension [1]. And global mean surface temperature has risen by more than 1°C since the pre-industrial era. This warming is not uniform across the year: in many mid-latitude regions, winters have warmed disproportionately compared with other seasons. Therefore, the period available for sufficient chill accumulation is decreasing [2]. Since forcing and chilling act as opposing elements within the same dormancy-release system, reducing chilling will lead not to an earlier but to a later completion of vernalization, given that spring warming continues afterward; this is because plants that receive less chilling generally require more spring heat to emerge from dormancy [2]. This chilling–forcing trade-off (Figure 1) also explains why one cannot expect the phenological reaction of bulbous ornamentals to global warming simply to consist of an earlier onset of flowering everywhere; therefore, chilling needs as

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much consideration in predictions concerning possible changes in the flowering patterns of bulbous ornamentals under future climates as does spring warming.

3. Effects of climate change on spring-flowering bulbous plants

The most important commercial types of Tulipa, Narcissus, and Hyacinthus require about ten to sixteen weeks of chilling between approximately 1°C and 9°C in order to undergo the necessary processes of vernalization; otherwise, flower stalks will simply fail to grow out properly and blooms will never appear (or will develop abnormally small flowers). When this occurs, nurserymen say such plants have become "blind" [1]. There is also some observable evidence on this point from temperate trees. For sixteen tree species in Europe, reduced winter chilling between 1951 and 2014 appears to have erased approximately half of the phenological advancement that would have resulted from earlier springs alone [3]; modeling experiments show that models neglecting this chilling-forcing trade-off may therefore overestimate phenological advance later this century under a high-emissions pathway—by as much as several weeks [2]. There is also a comparable chilling-induced sensitivity reported for vegetation leaf-outs occurring at higher latitudes within China. Winter conditions affect leaf-out dates only indirectly in these regions, because they determine the relationship between the amount of warmth accumulated in the following spring and the timing of leaf appearance; thus, winter chill cannot independently alter the final date [4].

For spring-flowering bulbs, there seem likely to be three related consequences if they receive inadequate vernalization. One consequence will be delayed flowering or greater variability in its timing from one year to another as chill units accumulate differently each winter; consequently, it will also be harder to plan when displays will occur in home gardens or when cutting for market is to begin. Another consequence will appear when insufficient chilling causes scrawny flower stalks, small flowers, or even no flowers at all; thus, there will also be a loss of ornamental quality and of economic merit in cut-flower and potted bulb crops that need to have some degree of uniformity and dependability in their flowering. Thirdly, areas that now provide reliable natural chilling will likely gradually merge with warmer regions, where producers have increasingly relied on artificial pre-cooling in recent years. This shift will gradually redraw the map of the global bulb industry over the coming decades. Predictions for other temperate plants with chilling requirements also raise concern: when researchers modelled 21 commercial Japanese plum varieties in two Spanish regions based on their specific chilling needs, they found that the probability of meeting those needs would decline under both moderate and very high future greenhouse-gas scenarios. This probability declined especially rapidly after about 30 years in the warmer of the two regions, and also for plums requiring particularly long cold periods. Since some bulbs require similarly prolonged cold periods themselves, it is plausible that analogous effects may occur in bulbous crops.

4. Adaptation strategies (cultivation, conservation, and plant breeding)

4.1. Climate-oriented cultivation measures

However, there is good news on this front. Growers can partially compensate for inadequate natural chill in the short run through artificial precooling, generally referred to within the trade as "five-degree bulb" treatment, wherein harvested bulbs are held in storage under carefully regulated low temperatures, usually close to five degrees Celsius, for a determined period prior to planting or forcing. Such practice, which has permitted tulips, narcissi, hyacinths, and others to be cultivated profitably for decades in places lacking sufficiently severe winter conditions, will probably play an

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even larger role from now on—including in places that have had sufficient natural chill until recently—once that natural chill decreases further and begins fluctuating unpredictably from year to year. Other helpful steps include adjusting planting time so bulbs remain dormant at the coolest period, choosing higher-altitude locations or higher-latitude sites where sufficient natural cold persists, and purchasing cooling chambers if necessary for certain high-priced varieties that are susceptible to chill deficiency. Taken together, these operational measures are effective at addressing the immediate problem, although they entail considerable extra costs in electricity, space, labor, and other resources; thus, they do not eliminate the need for eventual genetic improvements.

4.2. Plant-oriented measures: conservation and breeding

If long-term adjustment is desired, greater genetic diversity for chill tolerance is needed and must be made available to plant breeders. Wild and landrace populations of some geophytes found in naturally warm regions, such as parts of the eastern Mediterranean, flower successfully even after little or no cold exposure; these populations offer a promising but largely untapped source of useful alleles for breeders seeking to reduce chilling requirements [1]. There is molecular evidence from other cold-responsive organisms that such breeding may succeed: in yellow lupin, a leguminous crop plant, natural deletions have occurred in the promoter region of one FLOWERING LOCUS T homologue; these deletions cause loss of vernalization responsiveness in that locus (so plants carrying them flower without having been chilled). Thus, again, quite modest genetic change appears sufficient, in principle, to reduce (or abolish) the chill requirement of a whole species [5]. New techniques such as marker-assisted selection (MAS) and CRISPR-based genome editing are being considered more frequently as tools by which breeders can quickly identify low-chill characteristics and incorporate them into breeding programs. MAS and CRISPR thus act alongside conventional crossing techniques, which take much longer [6]. There is also much to be gained from ex-situ conservation of wild geophyte germplasm in seed and bulb banks, because such measures help ensure that the genetic variation needed for future chilling-tolerant cultivars does not disappear before breeders have a chance to exploit it. In particular, they provide insurance that no useful low-chill alleles will be lost from wild populations before breeders have had a chance to utilize them.

5. Future research directions

There is still much to learn about how climate change affects spring-flowering bulbs. Chilling and forcing requirements have been worked out in detail for only some commercial varieties, so there is little basis for making predictions about most other types of ornamental geophytes now found in gardens worldwide. Flowering dates, flower quality, and failure rates need to be monitored over many years at several locations under various degrees of warming in order to test whether chilling–forcing relationships derived mainly from studies of trees can indeed apply equally well to bulbs. More molecular research is required if scientists hope to find out what genes determine vernalization needs for large groups of bulbous plants. Although progress has been made in yellow lupins [5], researchers do not yet know enough about the genetic mechanisms that govern the amount of winter cold required by tulips and daffodils. Lastly, economists will have to integrate all this information on plants with other economic and industrial models if growers, breeders, and governments are to anticipate where bulb growing may occur in the future, rather than discovering too late that it is no longer possible in their current production areas.

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6. Conclusion

This review has therefore addressed how climate change affects the amount of winter chill available for the vernalization of some spring-flowering bulbs (tulips, narcissi, and hyacinths) and what this means for their actual flowering. Possible measures of cultivation, conservation, and breeding that could help mitigate these problems were also discussed. This study shows that warmer winters will not merely cause earlier flowering, as one might assume at first glance; rather, because chilling and forcing are opposing aspects of the same dormancy-release process, reduced chilling will retard, reduce, or destabilize flowering despite rising spring temperatures. For now, artificial precooling and adjustments in growing practices (e.g., five-degree bulb treatment, site selection) can protect producers from insufficient natural chill. In the longer term, however, breeding for lower chilling requirements—based on molecular insights from studies of other vernalizing plants—combined with preservation of low-chill wild germplasm, appears to offer the best chance of ensuring that sufficient suitable genetic stock remains to secure continued bulb supplies, should climate change continue on its current trajectory.

There are also some shortcomings in this review that need to be noted. First, it depends largely on phenological evidence from temperate trees and shrubs, because detailed information on the chilling and forcing requirements of specific ornamental bulb cultivars is still too scarce to allow direct conclusions about those plants, necessitating inference. Second, most of the literature reviewed comes from a small subset of the world's major growing areas in Europe and China; elsewhere, such work has scarcely begun. Therefore, one cannot assume these places have typical climates. Thus, more direct measurements of the winter cold and spring warmth requirements of various bulbs are needed in many regions before researchers can determine whether their conclusions here hold true elsewhere. Only then will breeders and producers worldwide know better what to expect from their crops later on.

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