Supplementary Materials to the Manuscript: Combining temperate fruit tree cultivars to fit spring phenology models

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Abstract

Phenological datasets for temperate fruit trees are often short , fragmented and geographically restricted, which hampers the development of cultivar-specific spring phenology models. To address this, we propose a novel calibration approach ("combined-fitting"), which pools observations from several cultivars of the same species, distinguishing between shared and cultivar-specific parameters. This method requires fewer observations per cultivar and allows jointly analyzing cultivars of the same species. We evaluate combined-fitting using the PhenoFlex framework, comparing it to a baseline model and to models that are fitted only with data for single cultivars ("cultivar-fit"). Our analysis is based on flowering data from nine almond, six apricot and six sweet cherry cultivars across Mediterranean (Spain, Morocco, Tunisia) and German climates. The combined-fit model failed to achieve higher prediction accuracy compared to the cultivar-fit and the baseline approach, as evidenced by similar root mean square errors across the data splits and calibration dataset sizes. When comparing the estimated parameters of the chill and heat accumulation submodels, we observed a large variation among cultivars of the same species in the cultivar-fit models. In contrast and by design, the combined-fit yielded only one parameter set for cultivars of the same species. Our findings demonstrate that integrating data from multiple cultivars can yield spring phenology models with high accuracy. Even though the combined-fit approach did not outperform the cultivar-fit approach, combined-fitting offers a practical solution for spring phenology modeling with limited datasets and facilitates comparison across cultivars of the same species.

1 Introduction

This document contains supplementary materials for the journal article: *Combining temperate fruit tree cultivar to fit spring phenology models*. It contains some extra tables and files that were not included in the main article. Also, it contains code snippets that help the reader to replicate parts of the analyses.

The phenology data that we analyse is part of a long-term phenology dataset (Luedeling, Caspersen, Delgado Delgado, et al., 2024) compiled by the *Adapting Mediterranean Orchards (AdaMedOr)* project. Of the more than 270 cultivars comprised by the dataset, a subset of 110 cultivars has been analyzed with the PhenoFlex framework (Luedeling et al., 2021), available via the R package *chillR* (Luedeling, Caspersen, & Fernandez, 2024). The analysis contains next to model calibration also climate change impact projections on future bloom dates (Caspersen et al., 2025).

More than 50% of the cultivars in the dataset were not analysed, because the bloom observations were deemed too short to be analysed with PhenoFlex. We propose an alternative calibration method called combine-fitting, that reduces the number of model parameters estimated per cultivar and may allow the joined analysis too short for conventional model calibration. We evaluate the method for three temperate fruit and nut trees (almond, apricot, sweet cherry) and compared the results with a baseline model and a common calibration approach where each cultivar is calibrated separately. We perform the analysis for the full dataset and an artificially shortened dataset.

Parts of the function that we present in this document are available via the R packages *evalpheno* (Caspersen, 2025a) and *LarsChill* (Caspersen, 2025b). Both packages are currently available via GitHub.

2 Preparing Bloom Data

This notebook shows the preparation of the phenology data. Performs calibration and validation data splits. Check out the notebook for more details:

Split data in calibration and validation

3 Model Calibration

These three notebooks perform the model calibration. The notebook for almond calibration has also some more comments on the different procedures. The notebooks for apricot and sweet cherry only contain the uncommented code.

- Almond calibration
- Apricot calibration
- Sweet Cherry calibration

4 Model Evaluation

This code shows how the calibrated models are evaluated. This script generates figures and tables for the manuscript.

Generate figures for the manuscript

References

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