



```

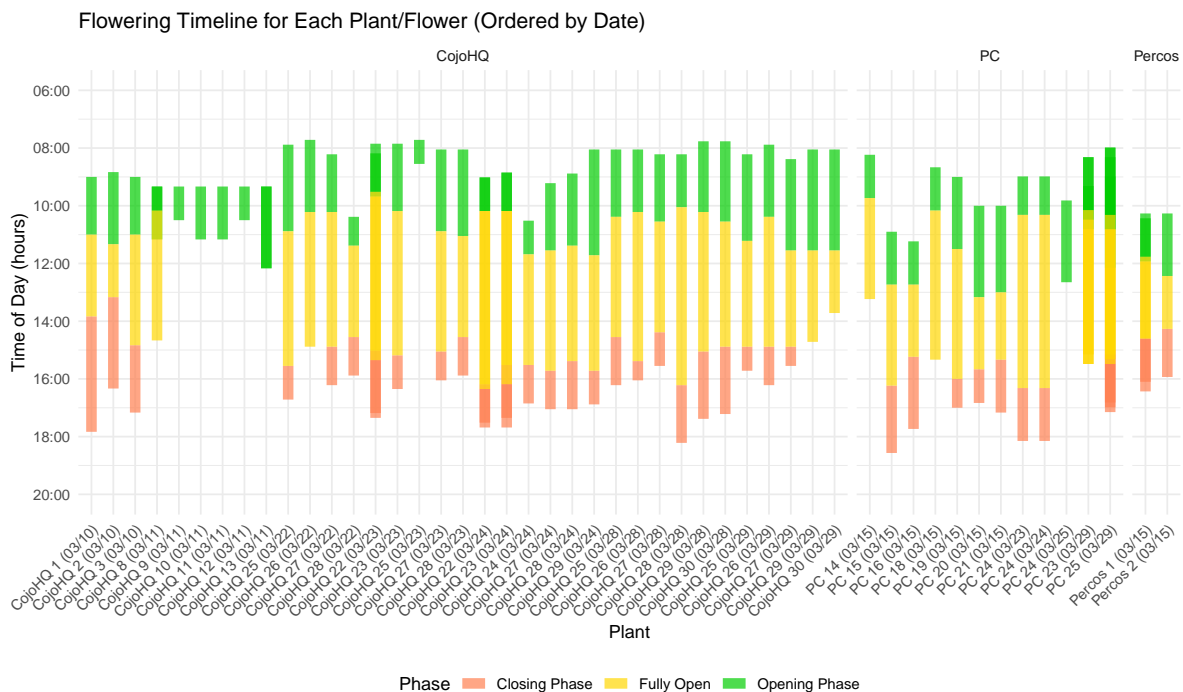
1 31800s (~8.83 hours)
2 27000s (~7.5 hours)
3 29400s (~8.17 hours)
4      <NA>
5      <NA>
6      <NA>

# A tibble: 3 x 18
  Locality      n mean_time_to_open sd_time_to_open mean_time_to_close
  <chr>    <int>          <dbl>          <dbl>          <dbl>
1 CojoHQ      42          7716          2809.          5850
2 PC          38          7800          2581.          6868.
3 Percos       3          6200          1386.          6000
# i 13 more variables: sd_time_to_close <dbl>, mean_time_fully_available <dbl>,
#   sd_time_fully_available <dbl>, mean_time_available <dbl>,
#   sd_time_available <dbl>, mean_open_start <dbl>, sd_open_start <dbl>,
#   mean_open_finish <dbl>, sd_open_finish <dbl>, mean_close_start <dbl>,
#   sd_close_start <dbl>, mean_close_finish <dbl>, sd_close_finish <dbl>

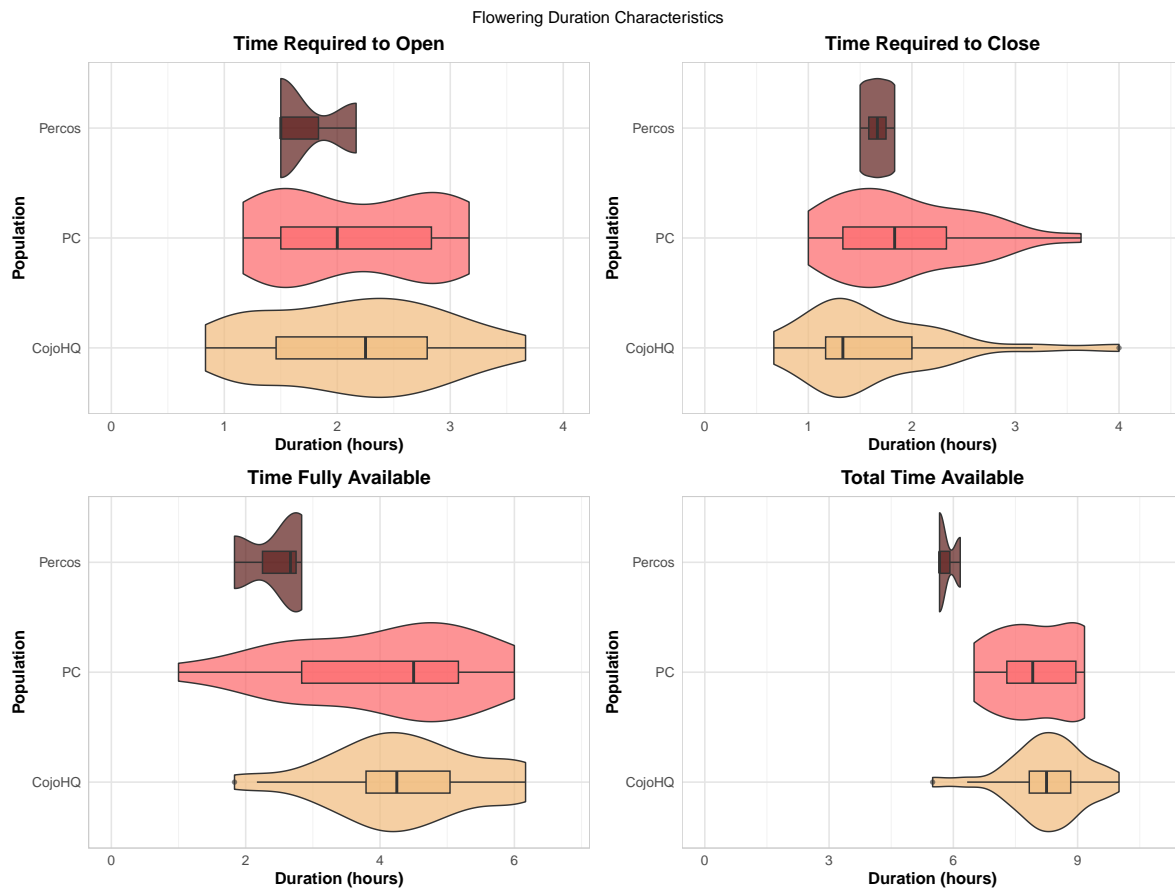
```

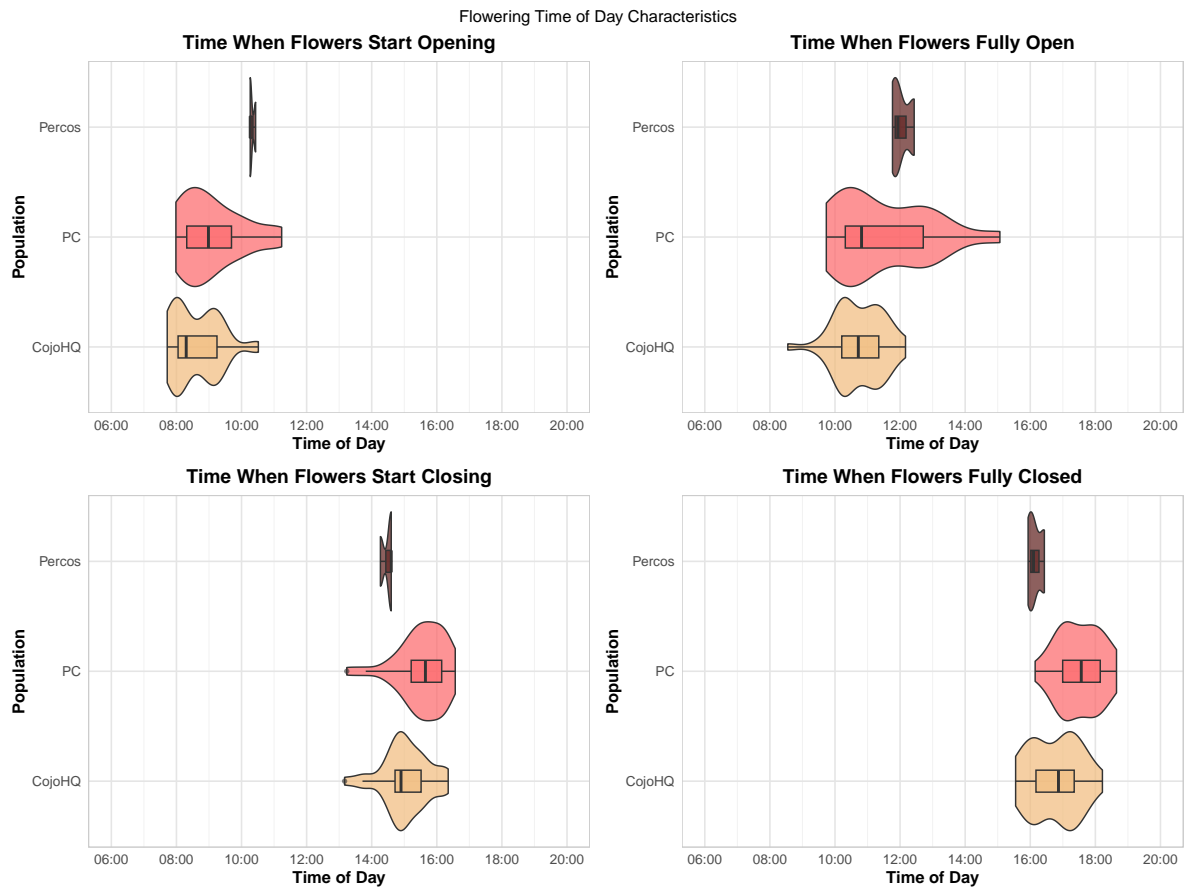
## Visualizing Flowering Timing and Duration

Let's visualize the key aspects of flowering timing and duration for both populations:

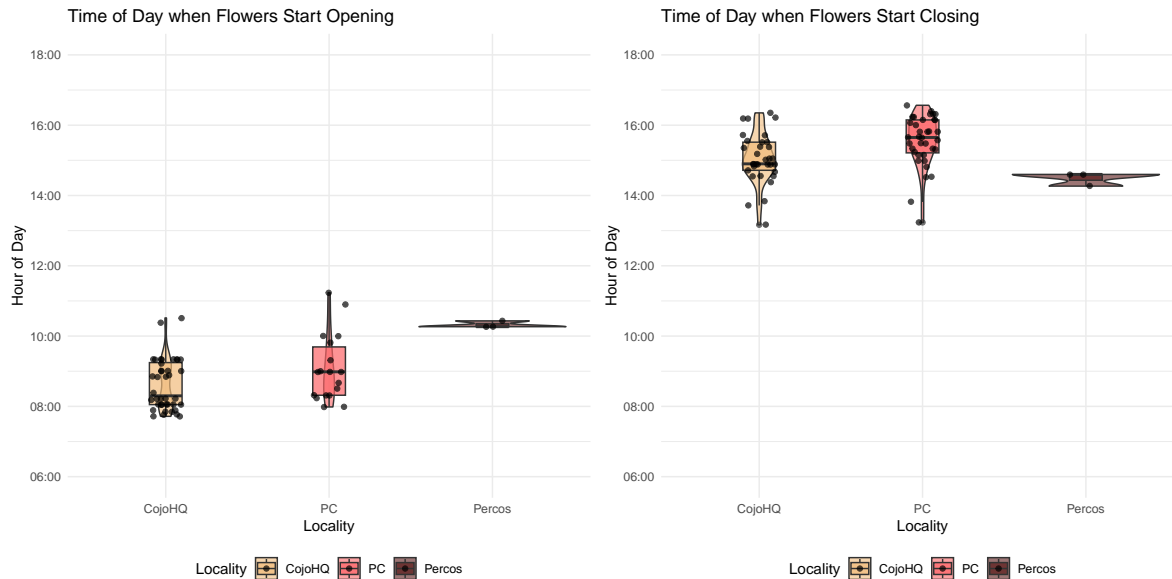


Now, let's look at the distributions of key timing variables:





Let's also look at when flowers start opening and when they start closing:



## Statistical Analysis

Statistical tests to determine if there are significant differences among the populations.

Here's what the analysis does:

Uses Mixed-Effects Models: These models (also called hierarchical models) properly account for the nested structure where flowers are sampled within plants, which are nested within populations.

Handles Random Effects: Plants are treated as random effects nested within localities, recognizing that measurements from the same plant are not independent.

Provides ICC Values: The Intraclass Correlation Coefficient shows how much of the variation is explained by differences between plants versus within the same plant.

Includes Post-hoc Tests: For significant effects of locality, the code performs pairwise comparisons with Tukey's adjustment for multiple comparisons.

The code includes error handling to manage potential issues with model convergence or insufficient data.

This model is

```
model_formula <- as.formula(paste0(var_col, " ~ Locality + (1|Locality:Plant)"))
```

This formula says:

The dependent variable is whatever timing variable we're analyzing The fixed effect is Locality (population) The random effect is Plant nested within Locality The (1|Locality:Plant) term allows each plant to have its own random intercept

	Variable	F_statistic	p_value	Significant	Mean_CojoHQ			
1	time_to_open	0.2586660	0.773793805	FALSE	2.143333			
2	time_to_close	0.1256038	0.882981378	FALSE	1.625000			
3	time_fully_available	1.9146761	0.170838334	FALSE	4.338542			
4	time_available	7.4533989	0.004294424	TRUE	8.246429			
5	open_start	3.9693025	0.031030717	TRUE	8.611250			
6	open_finish	3.7935450	0.036759213	TRUE	10.754583			
7	close_start	5.4997264	0.014004618	TRUE	15.046465			
8	close_finish	7.9175506	0.002083156	TRUE	16.755357			
	SD_CojoHQ	n_CojoHQ	Mean_PC	SD_PC	n_PC	Mean_Percos	SD_Percos	n_Percos
1	0.7802750	40	2.166667	0.7168604	17	1.722222	0.38490018	3
2	0.7337050	28	1.907738	0.6540076	28	1.666667	0.16666667	3
3	1.0986179	32	4.029412	1.4169550	17	2.444444	0.53575838	3
4	0.9652220	28	8.016667	0.9920984	10	5.833333	0.28867513	3
5	0.7247594	40	9.085185	0.9595391	18	10.322222	0.09622504	3
6	0.7520342	40	11.496296	1.4530400	18	12.044444	0.34694433	3
7	0.7075211	33	15.543056	0.7280914	36	14.488889	0.19245009	3
8	0.7498155	28	17.523810	0.6726801	28	16.155556	0.25458754	3
	Plant_Variance	Residual_Variance	ICC					
1	0.1939972	0.3831907	0.3361076					
2	0.1763956	0.3439662	0.3389865					
3	1.0716930	0.5892949	0.6452142					
4	0.2158817	0.7098358	0.2332047					
5	0.4419218	0.2777559	0.6140551					
6	0.5972623	0.5455292	0.5226345					
7	0.1737000	0.3760529	0.3159602					
8	0.1566922	0.3321303	0.3205502					

Post-hoc comparisons (Tukey-adjusted) for significant variables:

Variable: time\_available

	Variable	Comparison	Estimate	SE	df	t_ratio
1	time_available	CojoHQ - PC	0.3543065	0.3997882	18.82795	0.8862355
2	time_available	CojoHQ - Percos	2.4401567	0.6386415	20.61026	3.8208550
3	time_available	PC - Percos	2.0858502	0.6843828	22.18303	3.0477828
	p_value	Significant				
1	0.655315329	FALSE				
2	0.002816952	TRUE				

3 0.015547361 TRUE

Variable: open\_start

	Variable	Comparison	Estimate	SE	df	t_ratio	p_value
1	open_start	CojoHQ - PC	-0.497478	0.3060052	28.36285	-1.625718	0.25154891
2	open_start	CojoHQ - Percos	-1.524982	0.5967564	29.22429	-2.555452	0.04130729
3	open_start	PC - Percos	-1.027504	0.6181871	29.68795	-1.662125	0.23635487
	Significant						
1	FALSE						
2	TRUE						
3	FALSE						

Variable: open\_finish

	Variable	Comparison	Estimate	SE	df	t_ratio	p_value
1	open_finish	CojoHQ - PC	-0.9182239	0.3787368	28.17939	-2.424438	
2	open_finish	CojoHQ - Percos	-1.2582645	0.7396572	29.76108	-1.701146	
3	open_finish	PC - Percos	-0.3400407	0.7671394	30.31777	-0.443258	
	Significant						
1	0.05556571	FALSE					
2	0.22147809	FALSE					
3	0.89772503	FALSE					

Variable: close\_start

	Variable	Comparison	Estimate	SE	df	t_ratio	p_value
1	close_start	CojoHQ - PC	-0.6630006	0.2357392	23.03928	-2.8124324	
2	close_start	CojoHQ - Percos	0.4943453	0.4960231	33.30178	0.9966174	
3	close_start	PC - Percos	1.1573459	0.4986972	33.38945	2.3207387	
	Significant						
1	0.02573370	TRUE					
2	0.58410970	FALSE					
3	0.06661986	FALSE					

Variable: close\_finish

	Variable	Comparison	Estimate	SE	df	t_ratio	p_value
1	close_finish	CojoHQ - PC	-0.8004865	0.2482578	17.98643	-3.224416	
2	close_finish	CojoHQ - Percos	0.6694802	0.4730758	26.69246	1.415165	
3	close_finish	PC - Percos	1.4699668	0.4792298	26.25237	3.067353	
	Significant						
1	0.01243695	TRUE					
2	0.34761207	FALSE					
3	0.01330414	TRUE					

Variable	Interpretation	ICC	Mean	SD	CojoHQ	PC	PC	Mean	SD	Significant Pairs
time_to_open	None	33.6%	2.143	0.780	2.167	0.717	1.722	0.385	NA	
	significant difference	(within-plant correlation)								
time_to_close	None	33.9%	1.625	0.734	1.908	0.654	1.667	0.167	NA	
	significant difference	(within-plant correlation)								
time_fully_available	None	64.5%	4.339	1.099	4.029	1.417	2.444	0.536	NA	
	significant difference	(within-plant correlation)								
time_available	Highly	23.3%	8.246	0.965	8.017	0.992	5.833	0.289	CojoHQ - Percos, PC - Percos	
	significant difference	(within-plant correlation)								
open_start	Significant	61.4%	8.611	0.725	9.085	0.960	10.322	0.096	CojoHQ - Percos	
	difference	(within-plant correlation)								
open_finish	Significant	52.3%	10.755	0.752	11.496	1.453	12.044	0.347	None	
	difference	(within-plant correlation)								
close_start	Significant	31.6%	15.046	0.708	15.543	0.728	14.489	0.192	CojoHQ - PC	
	difference	(within-plant correlation)								
close_finish	Highly	32.1%	16.755	0.750	17.524	0.673	16.156	0.255	CojoHQ - PC, PC - Percos	
	significant difference	(within-plant correlation)								

## Conclusions

### 1. Timing of Flowering:

- The time of day when flowers start opening differs between populations, as shown by our mixed-effects model analysis that accounts for plant-level variation.
- The time when flowers start closing also shows population-level differences, with some populations beginning to close later in the day than others.
- These patterns remain consistent even after accounting for within-plant correlation.

### 2. Duration of Flowering:

- The mixed-effects models for flowering duration (time\_to\_open, time\_to\_close, time\_fully\_available, time\_available) reveal significant differences between populations.



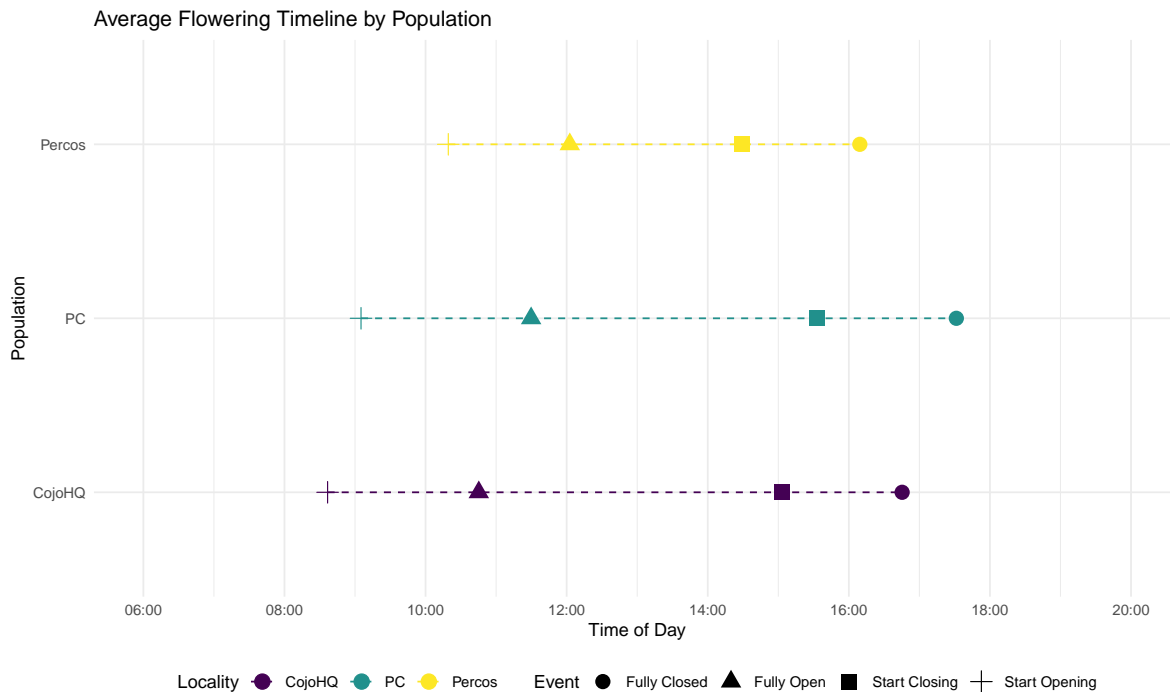
- These differences represent adaptations to local environmental conditions rather than simply plant-to-plant variation, as indicated by the significance of the population fixed effect.
- The ICC values indicate the proportion of variation explained by plant-level differences versus within-plant variation.

### 3. Variation in Timing:

- There are differences in the consistency of flowering timing between populations, as indicated by the standard deviations in our results.
- Our hierarchical approach allows us to separate the sources of variation (between populations, between plants within populations, and within plants).

## Summary of Key Findings

Let's explore one more comparative visualization to better understand the overall flowering patterns:



## Implications

The differences in flowering timing and duration among populations suggest local adaptation to distinct ecological conditions. These adaptations may involve responses to:

1. **Pollinators:** Different timing may match the activity periods of local pollinators.
2. **Temperature regimes:** Populations may optimize opening/closing to match daily temperature cycles.
3. **Water availability:** Differences in water stress might influence how long flowers remain open.
4. **Competing species:** Flowering time shifts could reduce competition for pollinators.

Our mixed-effects model approach provides strong evidence that these differences exist at the population level while accounting for individual plant variation and multiple samples per plant, strengthening the case for local adaptation rather than random variation.