Traditional Chinese peonies investigated via means of data analytics: Morphological features and genetic connections in variety identification

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Chinese peony (*Paeonia lactiflora Pall.*), and its many cultivar varieties, are the most popular type of peonies in Finnish home gardens. Natural Resources Institute Finland (Luonnonvarakeskus, LUKE) conducted a study and collected samples of traditional peony species from Finnish home gardens. In the original study, goal was to collect samples of mainly natural peony species. However, due to their popularity and how easy it is to mistakenly identify peonies, many collected samples were in fact Chinese peonies, which became the core sample material for this thesis work.

A fairly large amount of morphological feature data was collected from the samples during their time of prime blooming. This work lists the methods used for measurement and assesses the usability of each measured feature for variety recognition.

This work is a MSc thesis work in data analytics. Core concepts of data analytics are applied and explored on self-measured feature data and genetic marker data of the samples. These concepts include dimension reduction, cluster analysis, correlation coefficients, statistical entropy and data visualization. Analysis was performed with custom Python programming code using free industry standard libraries. Written code is available alongside other materials for referencing (Appendix A).

Sample plants are compared and explored using the aforementioned means of data analytics. Main distinguishing features are listed for groupings of samples of the same assumed variety. Variety names are suggested for the main groups of samples using literature references. An extensive photographic documentation of the samples was done to aid analysis after the short time of flowering and for later referencing. (Appendix B)

Keywords: Chinese peonies, Paeonia lactiflora, Peony morphology, Data analytics, MSc thesis.

TURUN YLIOPISTO
Fysiikan ja tähtitieteen laitos

LEINO, ANTTI: Perinteisten kiinanpionien tutkimus data-analytiikan keinoin: Morfologisten mittausten ja genetiikan vertailu lajiketunnistuksessa
Pro gradu -tutkielma, 101 s., 12 liites.
Fysiikka: Data-analytiikka
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Kiinanpionit (*Paeonia lactiflora Pall.*) monine lajikkeineen ovat suosituimpia pioneja suomalaisissa kotipuutarhoissa. Luonnonvarakeskus (LUKE) keräsi tutkimuspellolle perinteisiä pionilajeja edustavia näytekasveja eri puolilta Suomea aiempaan tutkimukseensa liittyen. Aiemmassa tutkimuksessa keskityttiin pionien luonnonlajeihin. Kiinanpionien suosion ja pionilajien tunnistamisen vaikeuden takia useat kerätyistä näytteistä olivat kuitenkin kiinanpioneja, jotka muodostuivat tämän opinnäytetyön tutkimusmateriaaliksi.

Kukintakauden aikana pioneista kerättiin suuri määrä mittausdataa erinäisin menetelmin. Tässä työssä listataan käytetyt menetelmät ja arvioidaan niiden hyödyllisyyttä lajikkeiden tunnistamisessa.

Tämä työ on data-analytiikan linjan opinnäytetyö. Monia data-analyyttisia konsepteja sovelletaan ja tutkitaan itse kerätyllä mittausdatalla sekä geneettisellä merkkidatalla. Sovellettuja konsepteja ovat dimensioreduktio, klusterianalyysi, korrelaatiokertoimet, tilastollinen entropia ja datan visualisoinnit. Kaikki analyysi suoritettiin tarkoitusta varten kirjoitetulla Python-koodilla alalle tyypillisiä kirjastoja käyttäen. Kirjoitettu koodi on saatavilla muiden materiaalien ohella (Liite / Appendix A).

Näytekasveja tutkitaan ja vertaillaan toisiinsa edellämainittuja keinoja hyödyntäen. Oleellisimmat havaitut lajikkeita erottelevat ominaisuudet listataan ja niiden käyttökelpoisuutta arvioidaan lajiketunnistuksessa. Lajikenimiä ehdotetaan tutkituille kiinanpioneille kirjallisuuteen ja verkkolähteisiin viitaten. Näytteistä laadittiin kattava valokuvadokumentaatio lyhyen kukinta-ajan jälkeistä analyysia helpottamaan. (Liite / Appendix B)

Asiasanat: Kiinanpionit, Paeonia lactiflora, Pionien morfologia, Data-analytiikka, Pro gradu -tutkielma.

Contents

1 Introduction

Chinese peony (*Paeonia lactiflora Pall.*) is the most widely cultivated species of peonies in the whole world [1, p. 46]. Typical attractive features for many Chinese peony varieties are large double flowers, presence of side buds and a pleasant fragrance. It is also common for the large double flowered Chinese peonies to need mechanical support to stay in form. In Finland, Chinese peonies (Fin. 'kiinanpioni') also play a significant role in the gardening culture, as the most common and loved peonies in Finland are usually Chinese peonies. [2, p. 79]

Peonies are polymorphic by nature, which means that while species are possible to be recognized by eye, it is usually much more difficult to quantify the differences and formally describe them [1, p. 15]. Formalizing the differences as numerous categorical and numerical variables in this work is executed to a somewhat successful degree. The polymorphic nature of Chinese peonies became clear, as some samples could have plenty of variability even flower to flower within the same plant.

The Chinese peonies examined in this work were planted on a research field of The Natural Resources Institute Finland (Luonnonvarakeskus, LUKE) in Piikkiö. Plants were acquired from home gardens across Finland as explained in detail in section 2.1. Measurements were carried across multiple days in summer 2022. Planning and executing the measurements were done assisted by the team at LUKE, but overall everything was executed with the context of this data analytical work in mind. All measurements and methods used are explained in their appropriate subsections in section 3. My personal history on working with peonies made the task of performing this work on a short notice feasible. I have worked many summers at Pionien Koti, a Taivassalo based peony-focused plant nursery with a show garden of dozens of peony varieties. Taking care of, photographing and learning about different varieties of Chinese peonies had given me some insight on what features to focus on in this work.

Most of the measurements were done on site between the rows of blooming peonies. For some measurements, representative flower samples were chosen for further examination indoors. Every sample was explored individually out of all context in a fairly randomized order, where applicable, to eliminate biases. Connections to the genetic connections between the samples and the similarities of measured values were made much after the time of taking the measurements.

After taking all the measurements, began the data analytic phase of this work. Genetic data related to these samples was collected on the side of the other researched samples the earlier LUKE study. In this work, analyzing the genetic data included steps of feature reduction via means of principal component analysis and cluster analysis to form a dendrogram chart of genetic relations between the samples.

After having the genetic connections between the samples as a baseline, other data analytical means were applied to find similarities and differences between the genetically connected samples of Chinese peonies. Features of the sample sets were compared to each other using the industry standard Pearson correlation. These correlations are visualized with heat maps depicting the magnitudes and signs of correlation in colors for all feature pairings.

It was found out, that the Chinese peony samples genetically most alike each other tend to form groups of the same variety. With no reference samples present, variety names for the most prominent genetic groupings of samples are only suggested via literature and online references. Some suggested names are probably wrong, but the sample peonies do still represent a significant part in the Finnish gardening culture.

Relationships between the samples in the groupings of genetic closeness are explored by comparing the similarities of measured features across the sample groups. The similarity of numeric features is seen by comparing the coefficients of variation for the feature values within the sample group. Coefficients of variation are scale-independent values, which depict the relationship between the standard deviation and the mean of the examined feature.

For categorical variables, it is essential to know how many types of different values were assigned for the features within specific groupings of samples. Statistical entropy is a way to describe how disorganized a set of feature values is. A sample set with identical values for a feature in every sample will receive an entropy value of zero for that specific feature.

The similarities and differences between measured features are first explored for the genetically most identical peonies. Then, the broader sets of genetically close, but non-identical, samples are explored. These methods give insight to which features change the most between peonies of slightly different genetics and furthermore in case of different varieties. The measured features are evaluated by their usability in being a separating factor for the different Chinese peony varieties explored.

The appendices at the end of this work contain a link to all research materials available online (Appendix A) and a photographic listing of all the samples explored in this work (Appendix B). The online repository includes all custom written Python code used in the various analysis steps in this work as well as the recorded measurement values from the field. Also, additional photography from every sample is presented in the online repository. Adding all the $\tilde{1}000$ photos within this written document is just not reasonable. Not all the photos are as useful as the chosen ones present in this document, but they do offer some extra context about the samples.

2 Theory and background

2.1 *Dear old peonies* study and gathering of sample material

This thesis work focuses on peony samples and genetic data collected in the study *Dear old peonies–for gene banks and gardeners; microsatellite fingerprinting of herbaceous peonies in Fennoscandia* (Tanhuanpää et al. 2021 [3]). The study is briefly described below as it is an essential foundation under this thesis work.

In this study, the intention was to collect samples of natural peony species, which had been grown in Finland since the 1950s or earlier. Many of those peonies can nowadays be considered rare. After completing the necessary research on the peonies, some of these heritage peony samples were to be stored in a national gene bank to preserve the valuable peonies. These old natural species are prestigious and in danger of disappearing as houses change owners and old peonies are not recognized. They may also be replaced by more showy newer bred varieties, which often have more scent, bigger flowers or other desirable properties.

Gathering of plant material

Figure 1: Aerial view of the Research field in Piikkiö at the time of taking measurements. Chinese peonies are in their prime bloom, while other peonies have already bloomed. All external information in the below chapter is from the published research article of the study unless stated otherwise.

Plant material in the research field (Fig. 1) was collected from private gardeners, whose descriptions of their peonies matched closely to the properties of the old desired peony species. People were able to announce their peonies for the study at the LUKE Kasvikuulutus online form at `www.luke.fi/ilmoitakasvi`. This form is still used for other studies and for announcing other species. In addition to just the plants, oral history, photos and information of locations with decades old peonies were collected in the announcement form. This was done to achieve additional information on the samples, but also to filter out the falsely announced other species of peonies.

A total of 690 announcements of peonies were obtained, 335 of which were selected into the study. All the samples were given a research number with the 'LUKE' prefix and a positional identifier number. Both of these were signified beside every planted sample on the test field (Fig. 2). In this work, the research numbers are referred to as the LUKE code of the sample. Opposed to the way of the original study, here mainly the simpler and shorter code number of a sample's position in the field is used for referring to specific samples. In materials and plots related to specific samples, both the positional identifier as well as the LUKE code are stated.

Figure 2: Peony sample 226 (LUKE-42) on the test field with its identification plate. Referenced to as sample 42 in this work.

Every sample, for which there was slightest doubt that it may be one of the desired peony species, was taken into the study. Some of the announcements did not include images of the plants, but even a suitable descriptive text was enough for a peony to be accepted in. Plants were planted on the test field in the spring in groupings based on how they looked when starting to grow after being potted for the winter. Some of the samples unfortunately died during the winter, but new plants were obtained from gardens. Among the samples were three reference samples obtained from LUKE's *Wendlan puutarha* gardens in Jokioinen [4]. They had been recognized as Chinese peonies, and their primary use in this study was to test the genetic markers for peony species identification. As Chinese peonies were actually not originally sought for, these unwanted peonies could then be planted in their own part of the test field.

The originally sought after species of peonies were:

- *P. anomala* (kuolanpioni in Finnish)
- *P.* × *hybrida* (kartanopioni)
- *P. officinalis* 'Nordic Paradox' (juhannuspioni)
- *P. tenuifolia* (tillipioni)
- *P.* × *festiva* (tarhapioni)

This thesis work extends on the samples and genetic data collected in the *Dear old peonies* study. As is the case, many of the peonies mislabelled as sought after peonies, were in fact Chinese peonies, which were not a part of the original study. However, Chinese peonies do hold great value in the modern peony gardening culture. The Chinese peony varieties collected are mostly old varieties with some additional historical value. This research field provided unique grounds for doing data analytical work in relation to these peonies. Focus of this work became finding similarities and differences between different Chinese peony bred varieties.

The presence of the original *Dear old peonies* (Tanhuanpää et al. 2021 [3]) study echoes throughout this thesis work. Nowadays, the Chinese peony is the most cultivated species of peonies in the world with thousands of bred varieties produced [1, p. 46]. The Chinese peonies in this work, however, will look much like the originally sought after traditional peony species. This context must be noted as it puts a limit on applicability of some of the results in broader schemes.

Every plant, with genetic mapping done, had been given a LUKE code for identification. There were also some Chinese peonies, which were not included in the genetic mapping process. For those, it was not possible to have any information about the genetic connections between samples. The main focus of this work was on the plants with genetic data available, as it allows grouping samples based off of genetics. Other plants were left out partly due to this reason and partly due to the amount of potential additional work and less useful results. Some records and notes were originally made from the plants with no genetic data, which is the reason all plants here are mainly referred to primarily by their slot number on the field.

For peonies, the amount of shade plays an important role in defining plant composure, blooming time and many other morphological features. A 2022 study shows that shading does significantly decrease flower weight, stem diameter and strength (Tang et al. 2021 [5]). The LUKE test field is on an open field with full day natural sunlight. This most likely has an effect on the overall morphology of the peonies. Plants were irrigated using a drip irrigation system to ensure even conditions for all samples.

Genetic data collected from the peony samples

Genetic data was collected from leaf samples before planting the peonies at the test field. Leaf samples of Chinese peonies were collected on the side of collecting samples of the other peonies. An E.Z.N.A. ® SP Plant DNA kit (Omega Bio-tek, Norcross, GA, USA) was used to extract DNA from the peony leaves [3]. The whole exact process of turning DNA into genetic data and a visualization using microsatellites (simple sequence repeat markers, SSRs) and multiple pieces of software is outside the scope of this data analytical work.

For purposes this work, the research team at LUKE handed out a collection of genetic marker data in CSV format, where each row represented a different examined sample. For each sample, there was 304 variables with binary values of either ones or zeros representing the different pre-determined genetic markers. For two samples, having identical values across all variables, meant that the samples were genetic duplicates. From this dataset, a customized dendrogram was re-constructed in this work using data analytical principles and programming explained later in section 2.2. Focusing on the part of Chinese peonies in the dataset made it easier to customize the dendrogram for usefulness in per-variety analysis, where the differences are smaller than when comparing different species of peonies.

The original data of genetic markers is not available publicly. In the attached materials, the genetic data has already been modified via means of principal component analysis. It doesn't include the original genetic marker data, but a simplified two-dimensional version of it fit for figuring out the coarse relationships between samples. Personal details related to the gathering of peonies around Finland do not appear in the materials of this work.

2.2 Data analytical concepts

Goal of nearly all data analytic processes is to extract useful information from bulks of data. This work applies basic data analytical methods and concepts to extract information about how different varieties of Chinese peonies differ from one another and which morphological features are most important in distinguishing the varieties. The main data analytical concepts applied in this work are stated below. The same types of plots and graphs are presented for every sub-grouping of samples analyzed, but the concepts are explained in this section.

Programming as a tool in this work

All essential data, morphological and genetic, was handled with *Python* [6] programming language with code custom written for this purpose. Python is an industry standard flexible programming language with extension libraries suiting many needs. All libraries used in this work are standard for the data analytics industry.

Spreadsheet like **pandas** dataframes were used in handling of bulk data [7]. Common calculations were made simpler using imported functions from the **sklearn** library [8]. Data science focused library **scipy** was used for visualizing data clusters with the dendrogram function [9]. Heat maps of correlations were drawn using the statistical data visualization library **seaborn** [10]. Plots and visualizations were finalised to usable formats with the widely used **matplotlib** plotting library [11].

All code used in data analysis and visualization as well as and other materials related to this work are found in an online repository. See Appendix A for more information on code and material availability.

2.2.1 Genetic data dimension reduction (PCA)

Principal Component Analysis (PCA) is a linear technique for dimensionality reduction, that embeds a higher dimensional dataset into a linear subspace of lower dimensionality. As a method, PCA tries to conserve as much variation of the original higher dimensional data as possible. This is done by finding a linear basis of reduced dimensionality, for which the amount of variance is maximal. [12]

However, not all feature values can be represented in a lower amount of dimensions. This loss of original feature data leads to a direct loss of information. The loss of information might not always be harmful, and often the benefits outweigh the losses. The overall complexity of the data is reduced, which simplifies visualization and further analysis of the data set. The PCA algorithm can also eliminate noise and redundant features, which boosts the performance of chosen analysis algorithms. [13]

Applied to this work, PCA reduces the amount of genetic markers per every sample from over three hundred to just two principal components. Samples, which had all identical values for genetic markers in the original data set, will have identical values for the principal components in the dimension reduced data set. Differences in utilising original data and dimension reduced data are explored below in cluster analysis of the samples (section 2.2.2). The dimension reduced data of samples with values in only two dimensions can conventionally be visualized as a scatter plot (Fig. 3).

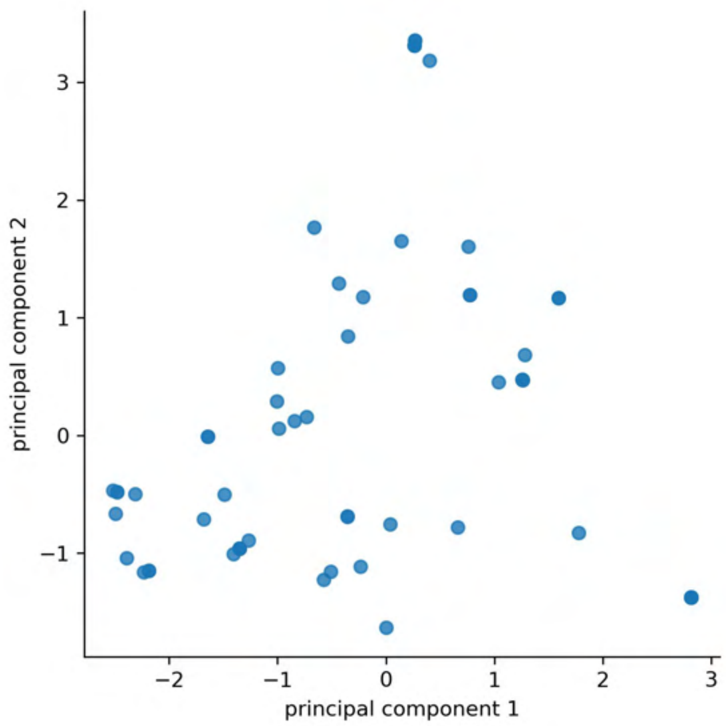


Figure 3: Genetic data mapped to two primary principal components. Every dot depicts a Chinese peony sample. Dots for identical samples are overlaid on top of each other. Distance between dots reflects the genetic difference between samples.

From the resulting principal components, euclidean distances between samples can be calculated. This is a way to approximate genetic similarities between any two samples. Based on how close the sample points are in this two dimensional representation, the likeness between the samples can be represented in multiple ways. One way is to create a heat map depicting genetic distance for every sample. The heat map on the next page (Fig. 4) shows the calculated distances on a 2D plane from every sample to every sample. Distances have been scaled 0 to 1 and visualized with shades of green. Values were inverted before plotting so that values closer to 1 depict the shortest genetic distance and vice versa.

Figure 4: Pairwise genetic similarities between samples scaled [0,1].

2.2.2 Cluster analysis - Genetic connections between samples

The earlier heat map of genetic similarity between samples (Fig. 4) shows the distances between samples, but it doesn't give visual info on the groupings of samples. A dendrogram is a visual plot of the sample set, which visualizes the hierarchy between clusters of samples. Samples closer, and therefore more alike, to each other are connected with a shorter link, than samples further away from each other. Dendrograms have been used as a suitable tool for visualizing hierarchy and genetic clustering of peonies. For example, a 2023 study (Fan et al.) used dendrograms for visualizing similar genetic data of peony cultivars. The study was focused on different cultivars of multiple species of peonies. Chinese peonies were included in the study among hybrids and peonies from the Itoh group. The dendrogram brought similar peonies close together into distinct groups. The older Chinese peony cultivars were genetically more alike each other than the peonies in groups consisting of newer hybrid varieties. [14]

Instead of relying on genetic markers alone, measured morphological features have also been used to create dendrograms depicting the similarity of different peony species and cultivars [15]. Creating dendrograms purely from measured features was also trialed in the process of this work. However, it proved difficult to obtain useful and informative dendrograms this way. Therefore, a dendrogram formed from the clustered genetic data is used as a baseline, on top of which measured features, correlations, values and varieties of the sample peonies are discussed.

All peony samples with genetic data recorded, which are the main substance of this work, are visualized in dendrograms below (Fig. 5a and Fig. 5b). Images of the samples are overlaid on the dendrograms to aid referencing. The dendrogram (Fig. 5a) acts as a baseline layout of all the samples for future referencing. Its order top-to-bottom is reflected in the order of analyzing the samples. The dendrograms are also included in the online repository along other materials.

Lines of the dendrogram visualize the closeness of samples in clusters on the 2D visualization of the PCA principal components (Fig. 3). Groupings of close samples are marked with unique colors, and the most prominent groups possibly consisting of same varieties have been labelled with letters (A - H). Samples connected closely with only a vertical line close to the images are identical based on the genetic data. Their values for all genetic markers have been identical, which made the principal component reduced values to also be duplicates.

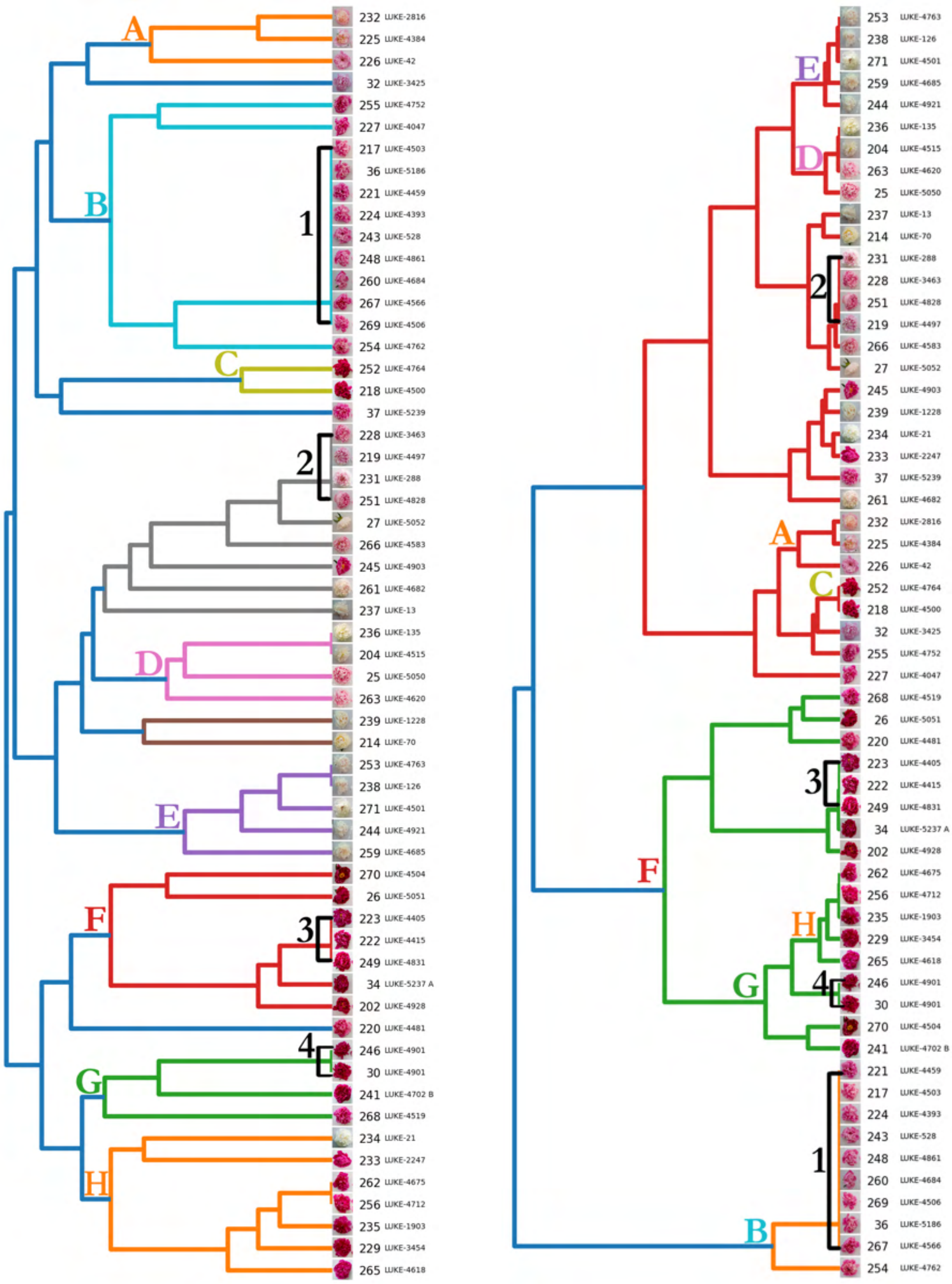
Multiple preprocessing steps were trialed for forming a dendrogram, which best depicts the whole sample set. Clusters of samples were calculated using an agglomerative clustering function with complete linkage criterion [16]. Other linkage criteria were trialed, but the clusters formed with complete linkage criterion best depicted the visually seen differences between the samples.

Dendrograms were formed on both all of the original genetic data markers (Fig. 5a) and the (PCA) dimension reduced genetic data (Fig. 5b). The analysis pipeline of performing principal component analysis leading into clustering has both advantages and disadvantages. Calculating clusters on a high dimensional data can be computationally intensive, which however was not an issue to a significant degree in this work. There is also a risk for misleading cluster assignments due to earlier information loss caused by the dimensionality reduction. Therefore, the distinct clusters must be confirmed to depict reasonable connections between samples via other measures. [17]

Both dendrograms are presented on the following page. There are some distinct differences between these two representations of the genetic connections. Samples with identical or near identical genetic data are plotted fairly similarly in both dendrograms. At higher levels of genetic distance, differences are more noticeable between the two dendrograms. The PCA dendrogram makes a greater difference between the main groups of samples, while the dendrogram from the original data has less genetic distance between the main groups.

The dendrogram of all genetic data (Fig. 5a) has fairly even branches of samples, which were easily labeled as analysis groups A to H. Magnitude of differences between these groups are not very large. The PCA dendrogram (Fig. 5b) has three main branches of samples, which are separated by a longer line: bottom-most is a branch with the pink peonies of duplicate group 1, in the middle are all the darker red samples of groups F, G and H and on the top is a diverse group consisting of light rose pink and white samples.

As further analysis shows, neither of these ways to group the samples is necessarily more correct than the other. When comparing the samples in groups F, G and H, it became clear that the samples are much more similar to each other than what the dendrogram of all data (Fig. 5a) visually shows. On the contrary, the difference between group B and the other samples might not necessarily be as stark as the PCA preprocessed dendrogram (Fig. 5b) suggests. In the end, the dendrogram calculated directly from the multidimensional genetic marker data was chosen to be used as the basis of further analysis. It provides a visually more balanced interpretation of the groupings within the dataset.



(a) All genetic marker data.

(b) PCA reduced genetic data.

Figure 5: (a): Dendrogram of cluster analysis from all genetic marker data . Groups of samples are labeled 1 - 4 for groups of duplicates and A - H for other sample groups. (b): Dendrogram of cluster analysis from the (PCA) dimension reduced data.

2.2.3 Heat maps of correlation between measured features

Similarly, as with the heat map of genetic relationships between all peony samples, the plot next page (Fig. 6) shows the pairwise correlations between all measured variables. This heat map is based on pairwise calculated Pearson correlation coefficients. The first 20 rows and columns were originally considered to be numerical variables. The following ones are dummy variables for all values of categorical variables. During analysis, two variables TIME (Blooming time) and UPRIGHTNESS (How well the peony stands on its own) were converted into categorical variables, since their values fall into discrete specific categories. Still, in these plots they have been treated as numerical variables as they were originally recorded as scales of time (values 1 to 3) and plant form (values 0 to 2).

In this work, correlations are calculated between all measured variables in the context of a chosen subgroup of samples. In the example below (Fig. 6), the presented samples are the first duplicate group, which is marked with number 1 in the earlier dendrograms (Fig. 5a). To account for different scales of value ranges for variables, the numeric variables in the dataset were standardized using `scipy.stats.zscore` function from the `scipy` library [9].

For categorical variables, *dummy* variables have to be used to make calculating Pearson correlations possible. This means creating a specific dummy variable for all the different values a categorical variable has received. These dummy variables receive binary values of either 1 or 0, which can then be incorporated in correlation calculations. For example, the categorical variable LEAF MARGIN has in the work received three different types of values BROWN, LIGHTGREEN and RED. After creating dummy variables (LEAF MARGIN_BROWN, LEAF MARGIN_LIGHTGREEN and LEAF MARGIN_RED), every sample will have a value of 1 for one of the dummy variables and 0 for the other dummy variables.

Pearson coefficient of variation for two features in a sample group is calculated as the relationship of the covariance between the two features and the product of the per-feature standard deviations. It formalizes as:

$$r_{XY} = \frac{\text{cov}(X,Y)}{\sigma_X \sigma_Y}$$

, where X and Y are the chosen features of the samples, σ is the standard deviation of that feature across the whole sample and cov is the covariance between the two samples. [18]

There is a potentially misleading issue in calculating the correlations, when all values for a feature are identical. When that is the case, there is no standard deviation for that feature either. This causes the correlation between the identical valued feature and every other feature to be undefined, which has to be noted! Technically, it is correct for the correlation value not to be defined, but here it is more useful and intuitive to visualize features with identical values differently than those with no values at all. In this work, features with all identical values were over-plotted with black bars to depict identicality (Fig. 6).

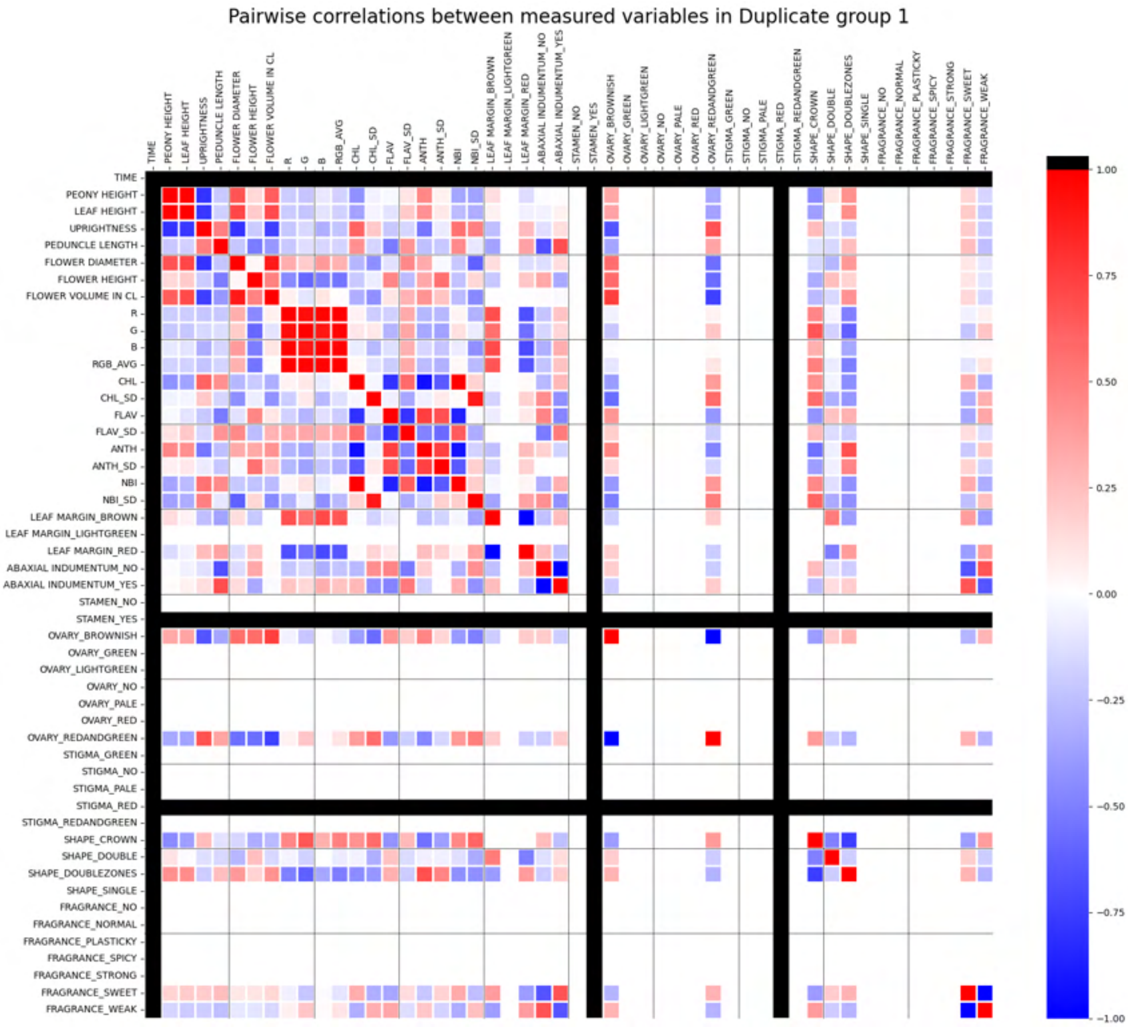


Figure 6: Example of a correlation heat map for the first duplicate group of peonies. Red depicts positive correlation, blue depicts negative correlation. Features with no color did not have any non-zero values present within the examined group. Features with all identical values are depicted with black color.

2.2.4 Coefficients of variation for analyzing numerical variables

Numerical measurements were done on multiple features of different scales. To usefully compare different measurements to each other in terms of amounts of variability, the method used must not depend on the scale used. Therefore, ordinary variance cannot be used in comparisons between features. Coefficient of variation, also known as Relative Standard Deviation (RSD), is a standardized measure that ignores different scales and can useful in comparing the measured features in this work. Coefficient of variation is defined as the standard deviation of a variable divided by its mean. It has been used as a measurement for variance in morphological variables earlier, for example in studying humulus plants [19].

A 2020 study (Mafakheri et al) compared coefficients of variance in measured plant features for a diverse group of wild humulus. It was proven, that some features had larger coefficients of variance across the whole sample set, while others had very little variation. Also, as in this work, Pearson correlation coefficients were used for comparing features in a heat map like arrangement. [19]

Here is an example of calculated coefficients of variation for a group of peonies. In the plot below (Fig. 7) and in other similar plots later in this work, blue bars represent the amount of variation in numerical variables within the specific group of samples. The values depict the pure relation between the standard deviation and mean of the numerical feature within the sample group. Often this value is then multiplied by 100 to achieve a percentage. This has not been done to achieve values of similar scale to the values of entropy for categorical variables.

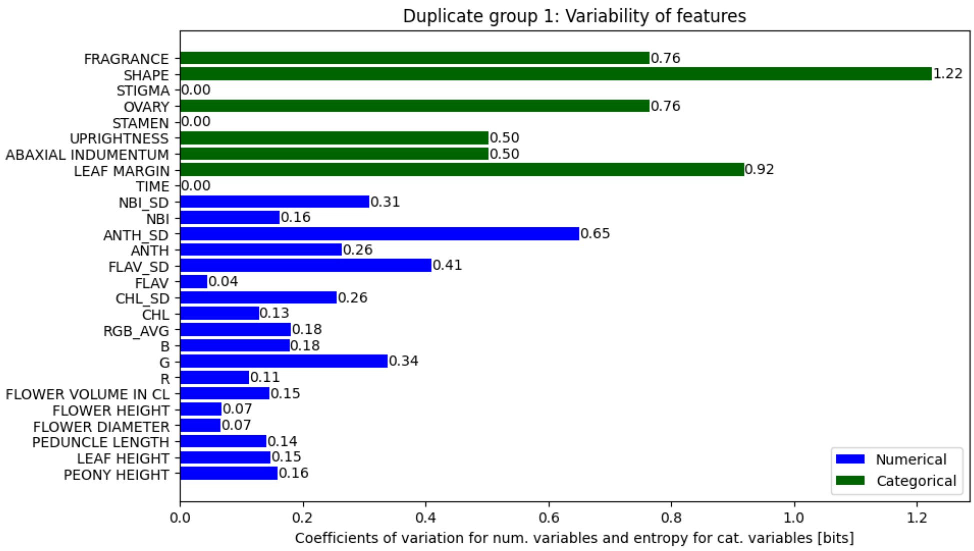


Figure 7: Example of variabilities of numerical and categorical features. Every row presents the amount of variation in that specific measured feature within the chosen group of samples. A lower value means that the feature is more uniform within the group.

2.2.5 Statistical entropy for analyzing categorical variables

Entropy describes the amount of order or disorder in a system in a pure fashion. Entropy is higher, when many states are present in a system, and lower when the system is very homogeneous. In its most simple form, entropy is completely determined by the different states a system has and the probabilities of these states [20, p. 51].

In information theory, the Shannon entropy quantifies the expected uncertainty of a discrete random variable. To calculate the entropies, the standard method from `scipy` Python module `scipy.stats.entropy` was used. Statistical entropy is calculated as:

```
H = -sum(pk * log(pk))
```

,where entropy `H` is given by the probabilities of different states (values) `pk`. The base of the logarithm used defines the unit. In this use case a base of 2 leads to units of bits. [21]

In this work, entropy is used to measure how similar categorical measurements are to each other. If entropy is low, fewer categories dominate, and measurements for chosen samples in this feature are nearly identical. If entropy is zero, all values for that categorical variable are identical. If entropy is high for a feature, there have been many different values assigned for that feature in the chosen sample group. The choice of unit here is irrelevant since entropy of a feature is only compared in scale to similarly calculated entropies of other features.

Amounts of entropy are visualized as green bars in plots such as the earlier plot (Fig. 7). The numbers on the side of the bars are the actual Shannon entropies of categorical features in the group. The plots are scaled to fit the bar with the highest value, hence the bars are not directly comparable plot to plot, and the values should also be noted.

3 Measurements on the test field

On the test field, various descriptors of morphology were measured across multiple days. Measured features were of both numerical and categorical types. These features are also referred to as 'variables' in the sample analysis part of this work. Higher case VARIABLE NAMES are used to refer directly to a feature as an analytical variable.

Some features were clear and quick to measure. Height measurements for example only required slight consideration and subjectivity on un-evenly shaped peony plants. Some features, on the other hand, were fairly subjective of nature. For example, recording values of FRAGRANCE required taking 60 scent measurements one after another on a field full of scents. For only a single person doing the evaluation, remaining subjective was a difficult task.

All the measured numerical features are presented here along with the units of measurement used (Table 1). Categorical features with their different values recorded are listed on the next page (Table 2). Features are listed here in the same order as they are presented in feature comparison heat maps.

Measured numerical feature	VARIABLE NAME	Unit / Values
Time of flowering (early to late)	TIME	1,2,3,4
Plant height from the flowers	PEONY HEIGHT	cm
Plant height from the leaves	LEAF HEIGHT	cm
Plant posture / need of support	UPRIGHTNESS	0,1,2
Length of the peduncle	PEDUNCLE LENGTH	cm
Diameter of a representative flower	FLOWER DIAMETER	mm
Height of a representative flower	FLOWER HEIGHT	mm
Estimated calculated flower volume	FLOWER VOLUME	cl
Color of the flower as luminance	RGB_AVG, R, G, B	[0,255]
Chlorophyll in the leaves	CHL, CHL_SD	µg/cm2
Flavonols in the leaves	FLAV, FLAV_SD	[0,3]
Anthocyanins in the leaves	ANTH, ANTH_SD	[0,1.5]
Nitrogen balanced index	NBI, NBI_SD	n/a

Table 1: Summary of measured numerical features.

EXAMPLE VARIABLE NAME - Description of categorical feature
POSSIBLE VALUES
LEAF MARGIN - Coarse color of the leaf margin
BROWN, LIGHTGREEN, RED
ABAXIAL INDUMENTUM - Can indumentum on the underside of leaves be felt
YES, NO
STAMEN - Are stamens present in the representative flower
YES, NO
OVARY - Main color or absence of ovaries / carpels
BROWNISH, GREEN, LIGHTGREEN, NO, PALE, RED, REDANDGREEN
STIGMA - Main color or absence of stigmas
GREEN, NO, PALE, RED, REDANDGREEN
SHAPE - Flower shape classification of the examined flower
CROWN, DOUBLE, DOUBLEWITHZONES, SINGLE
FRAGRANCE - Type or strength of the peony's fragrance
NO, WEAK, NORMAL, STRONG, PLASTICKY, SPICY, SWEET

Table 2: Summary of measured categorical features.

A few notes about the measurements

All measured data was collected either on the test field or close by near the cold storage, where flower samples were kept fresh for analysis. Without knowing what features would be the most important, it was acknowledged that redundant data would likely be collected. In fact, figuring out which features were of high or low significance was one of the most important goals for this work.

Original data records were manually written in Finnish, as the main language used in this work had not been decided at the point of taking measurements. The phase of data cleaning also included translating all recorded data into English, while also modifying the data sheet to be more intuitive and less redundant in ways described below.

As is often the case in field studies with natural plants, not all samples are in equally representative form. In general, most of these peonies were just mature enough at the time of taking the measurements to justifiably be called fully-grown. Some of the size and form differences between samples would probably level out during a few years.

There were a few samples that were not as independent from other samples. Samples 33 and 34, also known as LUKE-5237 B and LUKE-5237 A respectively, were two different peonies apparently originally dug up from the same place. There was only one value of recorded genetic data for leaf sample LUKE-5237, though. When referencing the genetic dendrogram to photographic and collected data, it became clear that the genetic data was much more likely collected from sample 34 (LUKE-5237 A). This peony seems very similar than the other samples which are genetically close to it. Sample 33 had to be removed from further analysis, but it is still included in the materials appendix. During this work it was also noted that the labels or plant material for samples LUKE 4501 and LUKE 4503 were accidentally swapped at some point. After making a correction swap, results made more sense.

Three of the samples proved to be in too unrepresentative condition for reliably studying their properties. These peonies were samples 230 (LUKE-3447), 250 (LUKE-4830) and 264 (LUKE-4619). All these samples had only a single flower blooming. Data was still collected for possible later research steps, but it is better to omit the samples altogether from primary analysis in this work. After some discussion, it was decided that actually all peonies without genetic data available were discarded from the main analysis of this work.

3.1 Dimension measurements of the sample plants

Heights of peonies

Heights of the samples were measured with a meter long ruler from the base at the middle of the peony plant. With non-uniform bush shapes and fallen down stems, some peonies were physically assisted to acquire the measurements needed. Two measurements were taken per peony: height of flowers and height of leaves.

Generally flowers were standing tall at the top of the peony plant. This height of the flowers is usually what is referred to as the height of the peony (Fig. 8a). However, distribution of leaves at the upper part of the peony seems to vary sample to sample. Therefore, a separate measurement was taken to see if leaf height (Fig. 8b) is something that can significantly differ from the height of the whole peony, and act as a defining factor in variety recognition.

(a) Measuring the (flower) height of a peony.

(b) Sample 37 (LUKE-5239), a case where most leaves are at a lower level than flowering height.

Figure 8: Height measurements for peonies.

Peduncle length

Peduncle length is a measurement taken from the receptacle of the flower to the first leaves along the stem. It has been noted as a differentiating factor between samples of different genotypes in the same species. For example, peduncle length has been recognized and used as an important descriptor in modern wheat breeding [22].

There often was lots of variability in peduncle lengths between different stems, even within the same sample peony. Therefore, three measurements per peony were taken for calculating average values for a sample's peduncle length. These measurements were rather quick to make compared to other types of measurements (Fig. 9).

Figure 9: Measuring the length of a peony peduncle.

Need of support

Many kinds of supportive structures are often used in home gardens to support large-flowering peonies from falling to the ground. However, not all peonies lie on the ground when blooming. This variable of a peony's need for support is a result of combined features of the plant like its flowers' weights and stems' rigidness.

For evaluating the need of support, three categories were used: Tall-standing peonies, peonies benefiting from support and peonies requiring artificial support. Peonies requiring support would often have their flowers touching ground due to rain or dew. Examples of both ends of the spectrum are presented below (Fig. 10). A peony benefitting from support was something in between. Maybe one or two stems only needed support, or generally the plant would have stood upright much better with slight support.

(a) Tall-standing peony

(b) Peony requiring support

Figure 10: Different amounts of need of support in peonies.

Originally, an idea was to try to measure the peony's need of support on a scale of many numbers. However, the shapes proved to be too non-uniform for reasonable categorization. Still, values were recorded as numbers rather than names of categories for later analysis. The way numeric values were assigned into the feature called UPRIGHTNESS is presented in the table below (Tab. 3).

Plant composure	Tall-standing	Benefits from support	Requires support
UPRIGHTNESS	2	1	0

Table 3: Labeling of the need of support as UPRIGHTNESS values used in the analysis phase in this work.

3.2 Leaves of peonies - Polyphenolic compounds, margin color and indumentum on abaxial surfaces

Flavonol, anthocyanin and chlorophyll contents of leaves

Concentrations of polyphenolic compounds were measured from the leaves of the peony samples with a Dualex instrument to see, whether or not the values for polyphenolic compounds were variety dependent. Dualex is a device with an optical sensor for measuring flavonol, anthocyanin, and chlorophyll contents and a NBI (Nitrogen Balance Index) value (Fig. 11b) [23]. When operating the device, a sample leaf is simply placed between the light source and the sensor (Fig. 11a). A single measurements takes all the previously mentioned values within a second. All data was saved in CSV format with a group of nine measurements per each sample plant for further analysis.

(a) Measuring the third leaflet of a peony stem

(b) Values from a single measurement

Figure 11: Single Dualex measurement of a Chinese peony leaf.

Leaves of the peonies go through a color shifting phase in the spring each year. There are essentially three phases to the colors of the leaves of Chinese peonies: Purple stage, Purple-green stage and Green stage. A peony goes through all these changes before blooming. Change of color is usually associated with an increase in chlorophyll amounts and a decrease in anthocyanins. [24]

This work focused on morphologic measurements at the time of blooming. Therefore, changes in leaf color over time were not measured. Polyphenolic compounds were measured from the leaves and compared peony to peony in the same time frame. For every plant, the most representative stem was chosen on the north-facing side of the peony. This was done to neglect possible differences between stems grown in sun or shade. On some peonies getting a 'good' measurement proved to be a difficult task, which resulted in some missing values due to imperfect measurements.

Nine measurements were taken per peony stem. Three at three different heights: top, middle and bottom part of the stem; one measure per every leaflet. Leaf position along the stem is important because the leaves are not fully comparable at different heights. De-Yuan Hong states in *Peonies of the World* regarding differences in leaves between different species of peonies: "- - character of leaves can not be precisely described without mentioning their position on a stem" ([25, p. 32]).

These differences might not be as notable between cultivars of Chinese peonies as it is for some other species of peonies. Nevertheless, more measurements lead to more reliable averages. Also, it was afterwards noted, that the values for flavonol, anthocyanin, and chlorophyll were often closest to one-another at the same height within the sample plant.

The Dualex device quickly produced a large amount of data. It had to be simplified to stay within a reasonable amount of data points. In simplifying the data, groupings for different height levels within the plant for each measurement were omitted and averages were calculated across measurements from all heights. Still, each sample had the same original amount of measurements from every height averaged to achieve these singular values representing the whole sample.

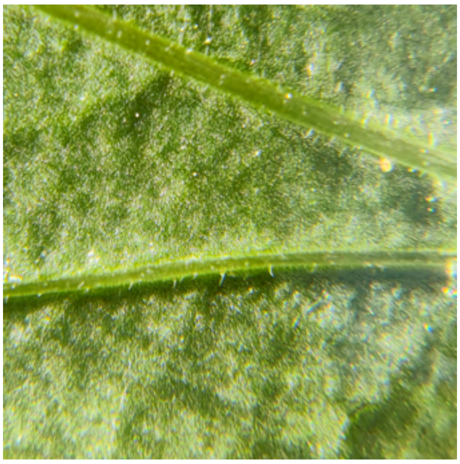
Leaf margin color

Leaf margins proved difficult to categorize, as there often was subtle shade differences to them. For means of reasonable analysis, margins were slotted into three main value categories: LIGHTGREEN, RED and BROWN. Differences between light green and the darker colored leaf margins were clear. For purposes of this work, only categorizing the colors as dark and light might have been simpler, as stating some samples either as purely red or brown felt difficult. However, a deeper look look into the shades and textures might have been interesting to conduct. As an afterthought, some leaf margins probably felt a bit sharper than others, but no values for the coarseness of leaf margins were recorded.

Figure 12: Dark red margin of a Chinese peony leaf.

Indumentum on abaxial sufaces of leaves

Some species of peonies can be recognised based on the presence or absence of indumentum in different parts of the plant. For all peonies, upper sides of the leaves are mainly glabrous, but some bristles can be found on the abaxial sides along the veins more or less frequently [25, p. 35]. Some abaxial surfaces of leaves of the peonies in the field did feel harsh to the touch, while some did not. Indeed, many samples did have some indumentum, which was barely visible to the eye, along the veins on the abaxial sides of the leaves. There probably were other variations or densities of indumentum than the two depicted in photos below (Fig. 13), but the binary value of either presence or absence of indumentum was chosen to be recorded for each plant. Values were recorded only by feeling a few leaves per sample by hand.



(a) Indumentum along veins

(b) No significant indumentum

Figure 13: Two distinctly different abaxial surfaces of *P. lactiflora* leaves.

3.3 Flowers: Size, shape, color and reproductive plant parts

This part of analysis was done only with a single flower sample depicting the whole sample plant. Most representative flower was chosen for each peony at the beginning of prime blooming. In general, these first flowers in a blooming peony tend to be larger than the flowers that opened near the end of the blooming season. The chosen flower was often likely not the most descriptive flower possible in terms of final variety recognition.

Each flower was kept in a cold storage room until examination. Measurements were done for one flower at a time. After making the other measurements, the flower was ripped apart for analyzing and photographing the reproductive plant parts within the flower (Fig. 14b). Before ripping the flower completely apart, some petals were ripped in a sequence from the center-most petal towards the outer petals. Then a photo was taken to record the types of petals present within each flower (Fig. 14a). All these photos are present in the photographic appendix (Appendix B).

(a) Sample 36 - Different types of petals within the flower.

(b) Sample 36 - Reproductive plant parts are visible after ripping some petals away.

Figure 14: Photos of sample 36 as an example.

Dimensions of flowers

For a general measurement of size, the widths and heights of sample flowers were measured with a digital caliper. Height was measured from the receptacle to the tips of petals (Fig. 15a). Sample flowers were of surprisingly many sizes and forms, which made this fairly trivial task a bit more challenging than expected.

Diameter of a flower was measured from the largest out-most petals (Fig. 15b). Petals were slightly pulled to achieve comparable diameter results for all flowers, as some were not completely open at the time of analysis. Some samples reacted faster than others to the warmth when being taken out of the cold storage room. For some samples, slight mechanical work was required to get the flower to open up.

(a) Height of a peony flower.

(b) Diameter of a peony flower.

Figure 15: Dimension measurements of a sample flower.

Calculating flower volumes

Diameters and heights were measured for only one flower of every sample. These dimensions of the flower would not stay identical between other flowers even in the same peony. Some flowers are flat and wide, while some are narrow and tall. To generalize the size of the flower into a single variable, one way is to think of the smallest container a flower can fit into. The more complex-shaped the container is along the edges of the flower, the closer the volume of the container is to the volume of the flower. In this case, a cylindrical approximation seems like a reasonable choice.

With the earlier two dimension measurements per sample, a peony flower's size can be approximated as a cylinder with a calculated volume V. These volumes are derived from diameter and height of the flower using the conventional formula for a cylinder's volume ($V = Ah = \pi(\frac{1}{2}d)^2h$) seen in figure below (Fig. 16).

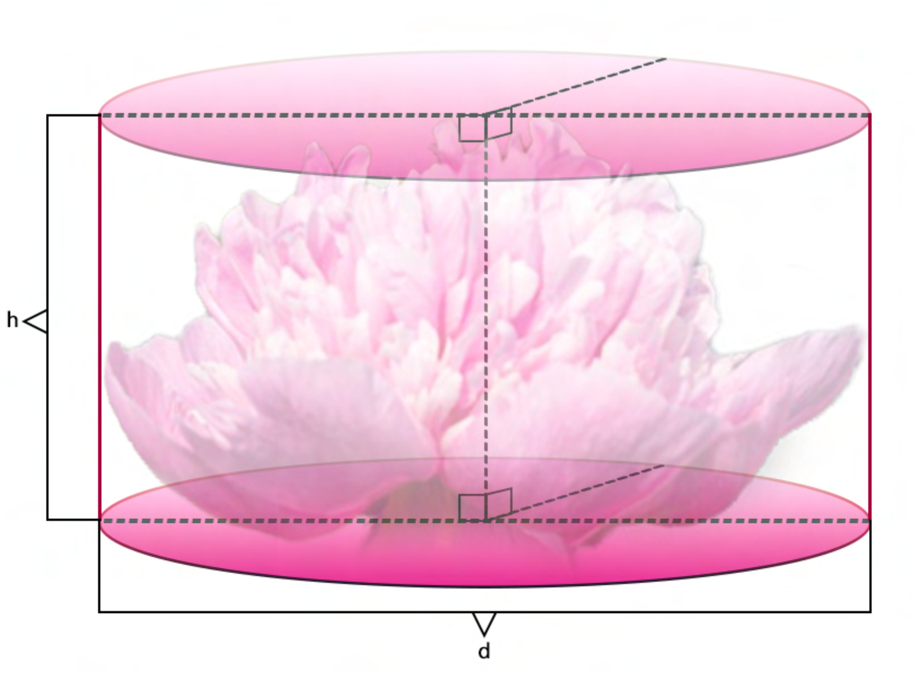


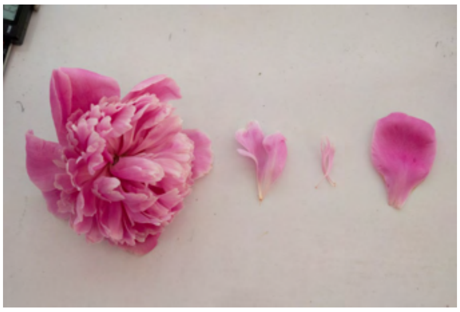
Figure 16: Calculating a descriptive value for a peony flower's volume. Note that this image of a peony inside the cylinder does not fully represent the configuration used while taking measurements. For example, flower diameter was measured while lightly stretching the outermost petals to a level plane.

Shape of flowers

There are generally considered to be five groups of blossom form in peonies: single, Japanese, anemone form, semi-double and full double. In addition, the full double form can be divided into more sub-groups: crown form, half-spherical form and rose form. Some variations to this classification exist, but this acts as a fair baseline. [26]

Evaluation of flower shapes was done subjectively, simultaneously with other flower related analyses, using the single flower chosen per plant. This work was not done on a wide selection of peonies, but rather on a fairly homogeneous group of Chinese peonies. Most of the flowers were of double form. Therefore, it was chosen to use the four types of flower shapes depicted in the figure below (Fig. 17) to classify these samples, instead of the more common classification.

(a) Full double form with fairly uniform petals (Sample 234)



(b) Crown form with distinctively large outer petals (Sample 217)

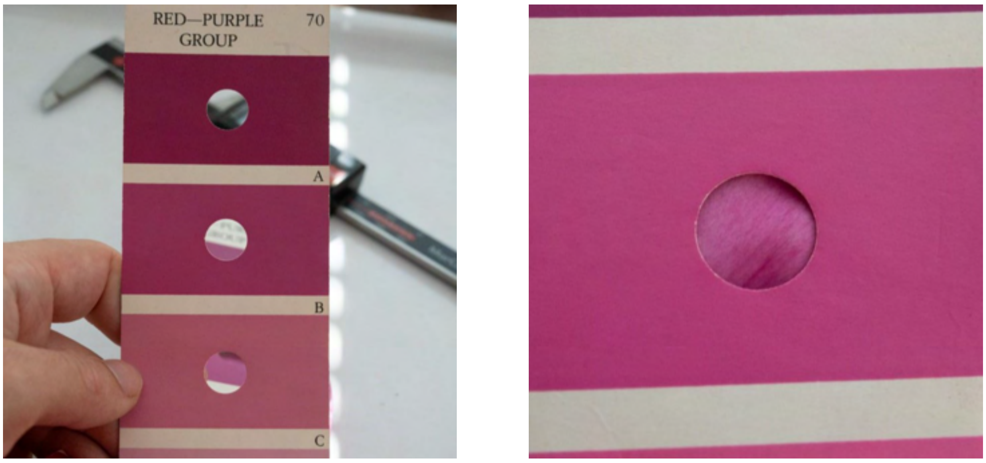
(c) Double form with zones of different sized petals (Sample 221)

(d) Single form (Sample 270)

Figure 17: Different types of peony blossom forms used in analysis of these Chinese peonies.

Color of petals

For determining colors of peony flowers, a Royal Hortonomical Society (RHS) color chart was used (Fig. 18). As there often are shade differences between the areas within a peony flower, color measurements were taken from two parts of each flower. One measurement from an outer petal, and another from a petal closer to the center of the flower.



(a) Single sheet of the RHS color chart (b) Determining peony's petal color

Figure 18: Two distinctly different abaxial surfaces of *P. lactiflora* leaves.

When preparing the data for analysis, labels of RHS color sheets were converted to RGB values to achieve numerical values of color for analysis. A conversion table provided by the Azalea Society of America was used to connect the values on the RHS sheets to corresponding RGB values [27]. Many studies have been conducted on RGB data and machine learning models. For example, a deep learning model can use RGB data to determine the quality of bananas within a picture [28]. Also, RHS colors have been combined with photographic data earlier for flower color analysis, for example in gerbera flowers [29].

Mapping color groups of flowers to luminance values

There have been presented various ways of converting measured RGB values to single values of luminance. For images and color captured with cameras, it is not a trivial task. For example, white balance, color space and other settings of the camera used affect this conversion. Although averaging purely the values of red, green and blue components is not technically most sophisticated, it is not a bad choice for achieving an estimate of luminance. [30]

As seen earlier in (Fig. 6), correlations to other measured variables were of similar magnitude among the numerical RGB color components. It seems like not very interesting separating results can be made from the singular converted components of color. This is why calculated value of luminance is fit for this task of analytically comparing colors and describing the "whiteness" of the sample. This might not be suitable for a more diverse group of peonies, where different types of colors would be present and the simplification of observed whiteness might not be enough to differentiate sample groups. For example, light green and light pink peonies might have similar calculated luminances, while having clearly different colors. In this example of converting RHS group codes to RGB values, the samples with the same color group end up with the same value for whiteness (RGB_AVG in 19).

SAMPLE	RHS GROUP	R	G	B	RGB_AVG	RGB
25	2F65B	228	150	196	191	
26	2F64A	147	26	73	82	
27	2F69B	231	189	238	219	
30	2F74A	149	0	99	83	
32	2F73C	235	139	216	197	
33	2F65C	238	167	206	204	
34	2F74A	149	0	99	83	
36	2F72C	172	58	143	124	
37	2F68B	219	87	174	160	
202	2F74A	149	0	99	83	
204	4F155B	246	234	227	236	
214	4F155A	233	221	207	220	
217	2F72C	172	58	143	124	
218	2F59B	96	12	35	48	

Figure 19: Analysis of the colors of peony samples. Colors originally referenced with RHS color leaflets have been transformed to values of RGB components.

Where to measure the color of a peony flower

As stated earlier, from each peony on the field, only one flower was taken inside for analysis, but two color samples were taken per flower. Some peonies have zones of different colors and types of petals within the flower. This makes overall categorizing peony flowers by a single color a difficult challenge. Obviously, the act of choosing the most representative petals plays a big part in this procedure.

However, when visually comparing the recorded color values for the petals (Like the colors above in Fig. 19) to the images of the flowers, it became apparent that the recorded values from the inner petals tend to represent the color of the whole flower a bit better. In most cases, the color for outer and inner petals were absolutely or near identical to each other. In the cases, where the colors were noticeably different, the color measurements from outer petals were generally slightly too dark when compared to images of the whole flower.

Edge color and features of petals

One other measured color related feature of the flowers was the color of the edges of the petals. This proved to be the most difficult feature to evaluate for these peonies. In general, the darker flowers had darker petals and petal edges, and whiter flowers had whiter ones. Distribution of color within petals proved to be very non-uniform. This was even more the case for edges of petals. Within the same pink flower, some petals can turn whiter towards the edges, while others stay pink throughout. Strong accent colors in white flowers are a sought after feature. The same applies to those too; by looking at only a few petals it is difficult to confidently state whether a peony has noticeable accent colors or not. Overall, declaring a simple petal edge color to represent a peony sample is not very useful.

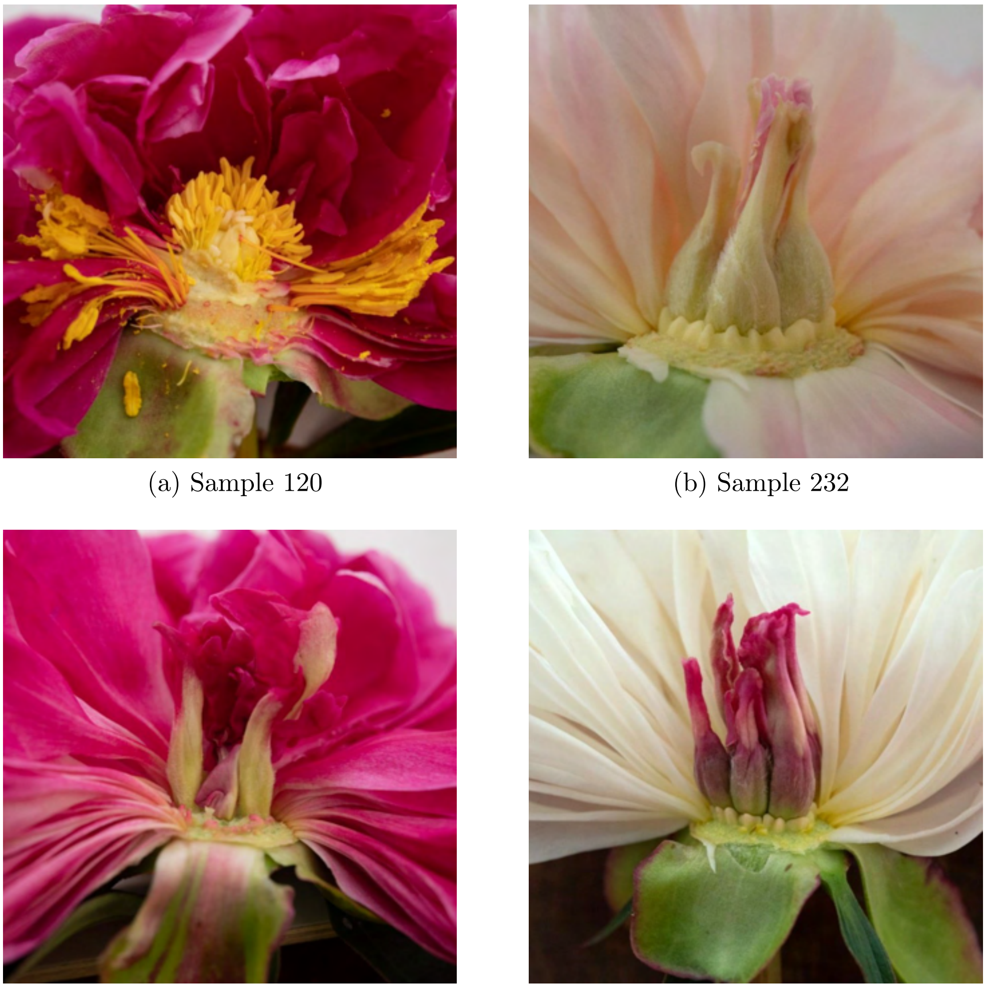
In this work only three simple categories were originally used for petal edges: red, white and a mix of red and white. This categorization was very subjective and often depended on the single petal chosen. This didn't feel useful in any case, which is why it is removed from the cleaned up version of the measurement data used in analysing sample groups.

The presence or absence of color features in some petals can still be used in variety recognition in the context of a whole flower. If one peony has some red dashes in petals among all its flowers and other has none, they probably are not of the same variety. If one were to only look at a few selected petals from these peonies or even one or two flowers, the comparison could not be relied on. Sometimes there are dashes of red in seemingly pure white peonies, and sometimes the red dashes are not to be seen in a peony, where the red dashes are usually a common feature. This applies to other features of peony petals too, like the sizes and shapes of petals in different parts of the flower. A simple looking flower can consist of many types of petals (Fig. 20).

Figure 20: Breakdown image of different types of petals in a single flower of peony sample 234. It is impossible for a single petal to represent this sample.

Reproductive plant parts

Reproductive plant parts saw a lot of variation between samples and in some cases even between flowers of the same sample peony. Some different configurations of stamens and carpels are shown in these four photos of different samples (Fig. 21).



(a) Sample 120

(b) Sample 232

(c) Sample 229

(d) Sample 27

Figure 21: Four examples of reproductive part configurations in Chinese peonies: (a) small carpels surrounded by short stamens with more longer stamens around (b) pale light green colored carpels with some indumentum on the surface, no stamens (c) green carpels have partly transformed into petals (carpelodes), no stamens (d) brownish carpels with tall red stigmas, no stamens

Stamens

During data collection, filaments and anthers were observed separately for each sample. Colors of these parts were written down when stamens were present. However, many samples didn't have stamens at all. During later analysis it became apparent that when present, all filaments and anthers were fairly similar and all were yellow. Therefore it made more sense to reduce this data to a binary value of stamens being present or not, as the additional details written down were redundant in every case. Further analysis of stamens between samples would have been outside the scope of this work.

Carpels

Only some samples were missing carpels completely, but for many they were not completely formed. Colors were recorded separately for stigmas and ovaries. Recorded values for stigmas were GREEN, NO, PALE, RED, REDANDGREEN. Values for ovaries included all the aforementioned ones and additional values of BROWNISH and LIGHTGREEN. Classification was done without preset categories, and in hindsight some broader categorization would have probably been useful.

Size of carpels also varied a lot. Some had indumentum on the surface and some had not. Some carpels were partly or fully developed into petal like carpelodes. These variations were not accounted for in this work, but they possibly act as ways to quantize variety properties.

3.4 Fragrance

Fragrance is a sought after attribute in garden peonies. There are clear differences between scents, although labeling the scents is somewhat subjective. Evaluation of the scents was done subjectively by walking peony to peony through the field. This was done two times. First at the time when most of the peonies were in their prime. Second time when the later varieties had begun to bloom. In addition, the second evaluation run was a chance to double-check the markings from the first run.

Even though I have no allergies, the amount of fragrance did nearly overwhelm my sense of smell after going through dozens of peonies. This is partly the reason my main focus was on the amount of fragrance per peony and rough categorization of scent, rather than going into details in the composition of the scents. Therefore, the types of fragrances used are probably not most fit for describing peonies, as their sole purpose was to create differences between groups of samples.

In the table below (Table 4) are listed all the categories used for my subjective measurements. In general, peonies with weak, normal or strong fragrance noted had a pleasant peony-like fragrance with no other special type of scent clearly present.

Amount of fragrance	Weak	Normal	Strong
Type of fragrance	Sweet	Plasticky	Spicy

Table 4: 6 main categories of fragrances observed on the field. Only one of these value was recorded for each sample. In addition, two samples had NO notable fragrance to them.

3.5 Time of blooming

For all peonies, blooming time is an important attribute of a cultivar in means of garden planning. Differences between different peony species' blooming times are generally larger than those between different cultivars of Chinese peonies. There are public records of blooming time differences between peony cultivars. For example, in *The Peony Bloom Date Project* by Michael Senny varieties have their blooming times presented as an offset in days from the blooming time of *Red Charm* variety [31].

In the research field, differences between different Chinese peonies were clearly noticeable. This also made the task of going through the flowers in their prime bloom a lot more feasible. Flower samples were taken at their prime, which meant that the most representative flower at the beginning of blooming was chosen for analysis. Date of taking the sample therefore to some degree represents the time of blooming for the whole plant sample. Collection of samples was performed on four different days (28.6.2022; 30.6.2022; 4.7.2022 and 6.7.2022), which gives a chronological order for the blooming time of all samples from 1 to 4. The scale is not evenly spread, as most samples were collected on day 1 or 2. The only sample collected on the last day ended up being discarded from most analysis due to its weak growth and small size as a plant, which might have affected other aspects of the plant as well. The photo below was taken on 6.7.2022 (Fig. 22).

Figure 22: Differences in bloom times between Chinese peonies were apparent on the field. The peony at the foreground was one of the first to bloom and has dropped its petals, while other Chinese peonies behind are still at their prime bloom.

4 Analysis of the peony samples

One of the main goals in this thesis work is to find the most suitable measured features to distinguish different Chinese peony varieties from each other. DNA of the samples were compared to one another using genetic markers, simple sequence repeats (SSRs), which was discussed earlier (section 2.1). Genetic duplicates offer a unique group of samples, where the premise is, that these peonies should be fairly similar in most measurements. Therefore, it is possible to explore, which feature variations are connected to inherited traits of Chinese peony varieties, and which are due to the natural variation of structures within the individual plants.

In this analysis section, the whole sample set and interesting subgroups are explored with the means of data analysis described earlier (section 2.2). First, the relations between features are explored for the whole dataset (section 4.1), then for genetic duplicate groups (4.2), and lastly for groups of genetically close but not identical samples (4.3).

Educated guesses are presented for the names of Chinese peony varieties in the main groups analyzed. No actual reference varieties were present at the test fields, which is why the variety naming is only based on literature and web sources. All the Chinese peony plants examined have been present in Finnish home gardens for decades. Knowing this about the background of the samples, allows to discard all new varieties from consideration.

Measurements and photography in this work are a solid foundation for recognizing the varieties, and selecting samples for gene banking purposes. As a starting point, probably the most famous Finnish book on peonies was used. Rea Peltola's and Vesa Koivu's book Pionit (2007) [2] lists many varieties popular in Finland during the first half of the 20th century. For example, a long list of peonies sold in a plant nursery, Ahtialan taimisto, in 1939 is presented [2, p. 142]. Other books and sources were also used for variety recognition. The likely variety names for groups of peonies are presented along the other analysis of the groups.

The genetic closeness of the peonies presented in the dendrogram below (Fig. 23) shows which samples are the most and least alike to one another. To achieve information about feature distributions, a deeper look per variable and the groupings of values needs to be incorporated. The dendrogram acts as the basis for labeling the groups of samples presented in separate sections below. Following the labeled dendrogram, the values of categorical values are overlaid on top of the dendrogram for sample value referencing (Fig. 24). Similarly, values for numerical variables can be presented overlaid on the dendrogram. In the third page of dendrograms (Fig. 25), the most essential numeric features are presented as per-feature scaled bars. Red bar for flowering height, orange bar for leaves height, green bar for peduncle length and pink bar for flower size. Exact numeric values and other records from the field are available in the online repository of this work (Appendix A).

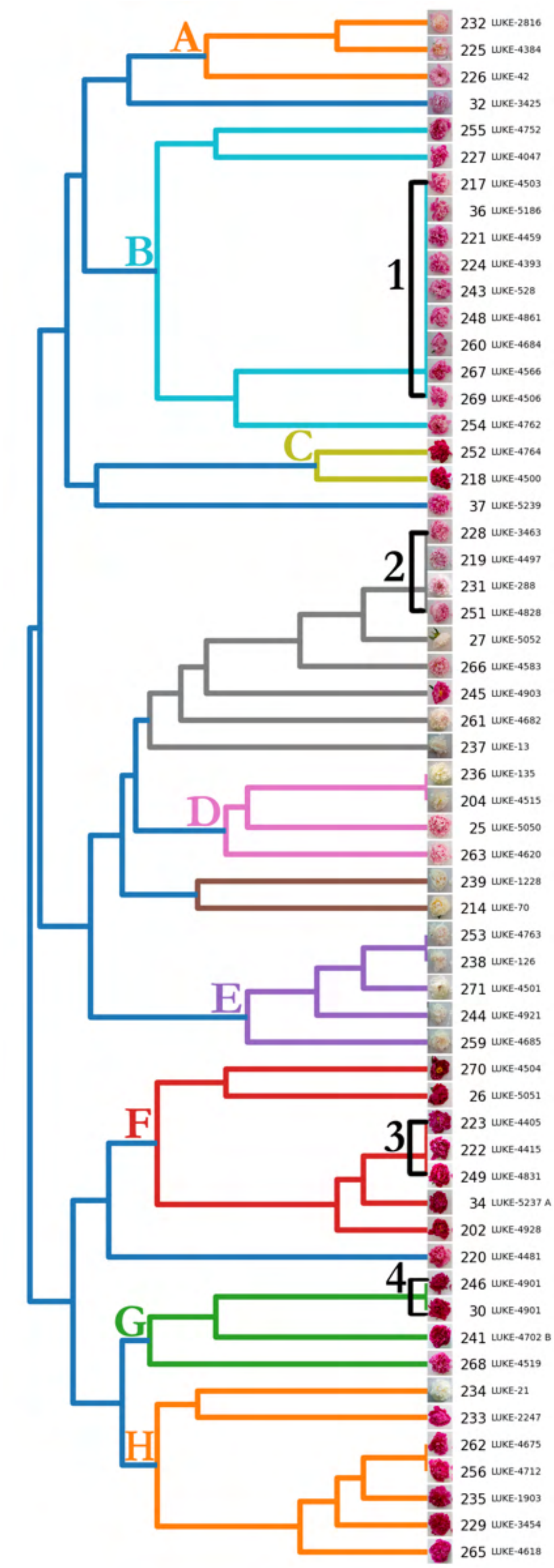


Figure 23: Visualizing the genetic data as a dendrogram of connections between all samples. Groups of samples discussed in the following sections are marked here with numbers 1 - 4 for groups of duplicates and A - H for other groups.

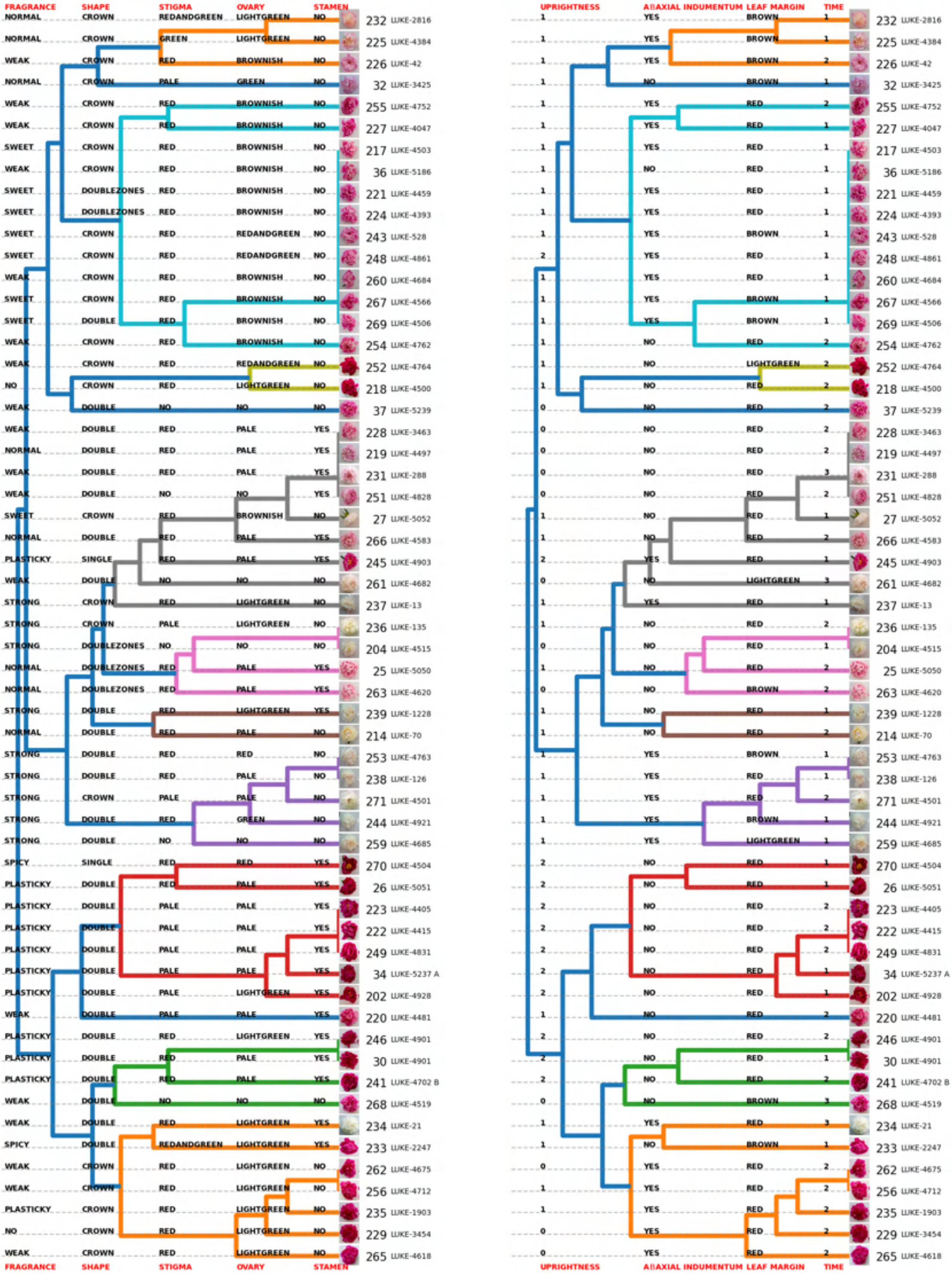


Figure 24: Values of categorical variables listed for all peony samples.

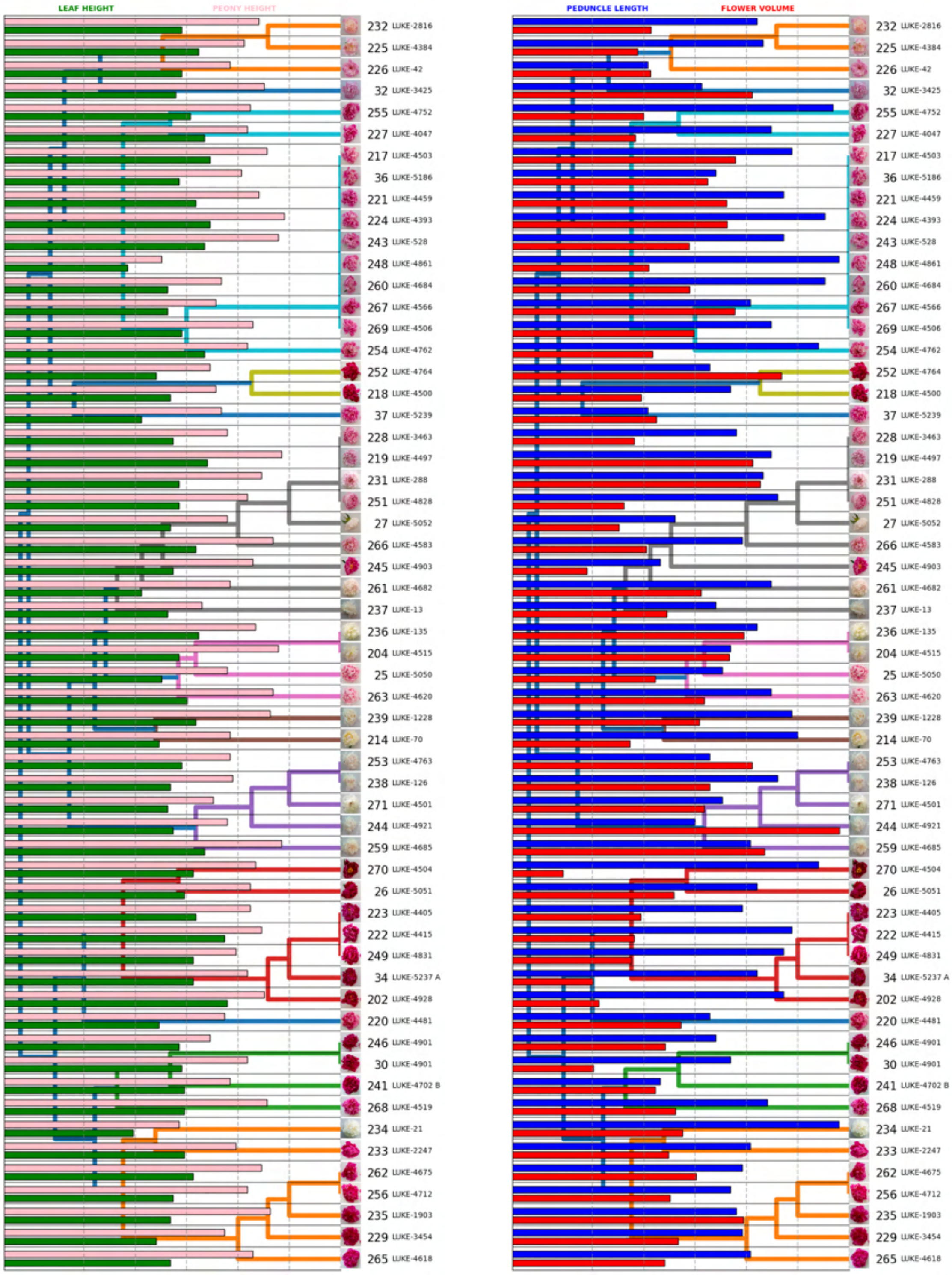


Figure 25: Values of numerical variables for all peony samples over the genetic dendrogram. Widths of bars on peony height and leaf height (green and pink) are on the same scale. Otherwise the scales are only comparable within the same feature as the bars are scaled to overlay the dendrogram nicely.

4.1 All samples

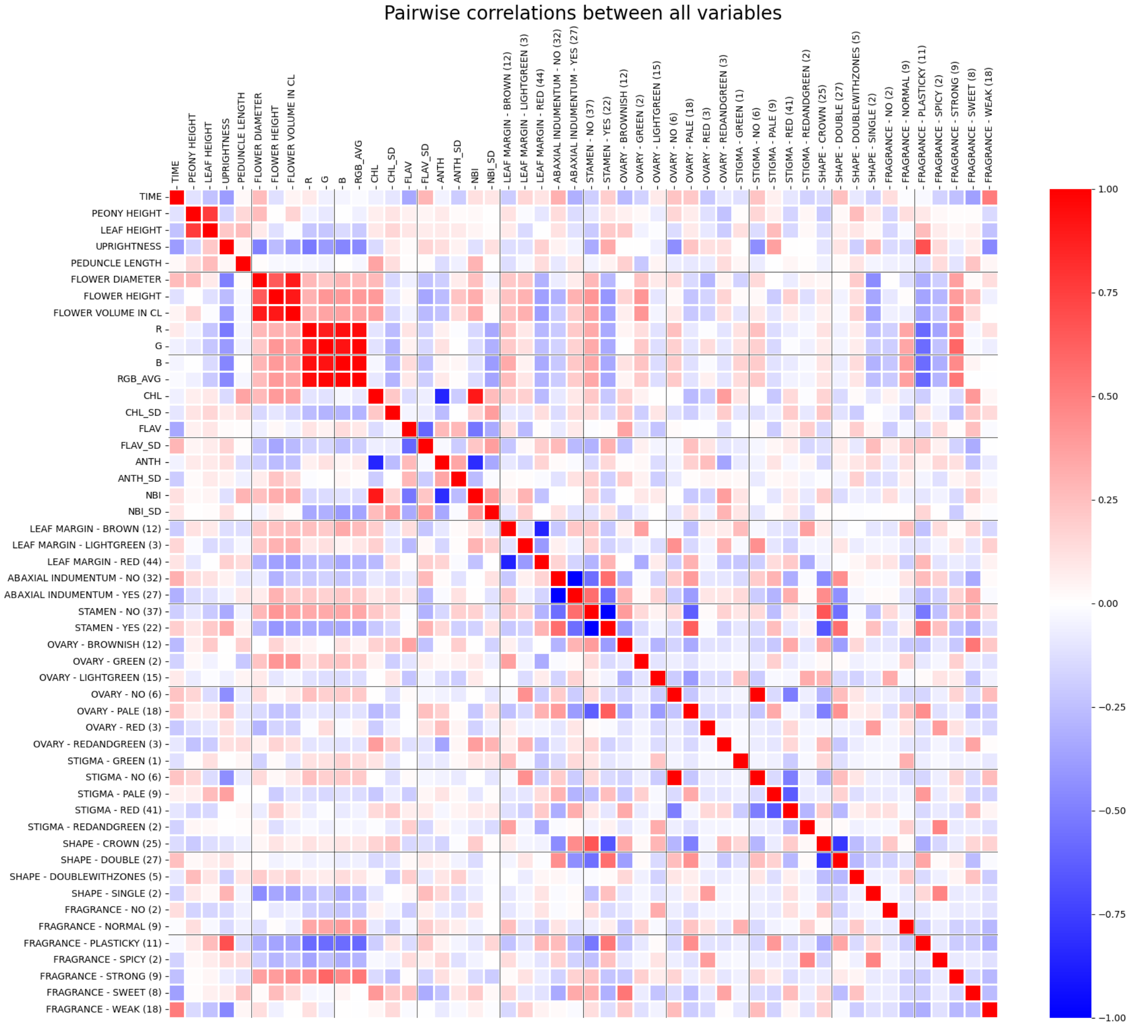


Figure 26: Heat map of correlations between measured and calculated variables in all samples in this work.

This heat map above (Fig. 26) shows Pearson correlations between all measurements on the whole sample set. Methods and calculations in forming these sort of correlation heat maps were discussed earlier (section 2.2.3).

The heat map is useful for finding general tendencies of feature connections in the whole sample set. For categorical dummy variables, the number of samples with the value in question in stated in parenthesis. Below are some notes on the information that this heat map provides. The heat map is mirrored and all features are listed both vertically and horizontally. This creates a red diagonal axis of complete correlation for features with themselves.

Notably, there are two variables with only binary values: ABAXIAL INDUMENTUM and STAMEN with values of only YES or NO, which essentially splits the whole sample set between these two values. This is why they show identical strengths of opposite shades of correlation for numerical variables. These variables could have been represented without the dummy variables for both plausible values.

One of the strongest and most intuitive correlations is between variables PEONY HEIGHT and LEAF HEIGHT. This means that the peonies with flowers reaching higher tend to also have their leaves reach higher. Vice versa also applies; it is not usual for the general leaf mass to reach higher than the flowers. This is of course natural for Chinese peonies as the flowers are at the ends of stems and therefore reach higher than the leaves.

TIME is the first listed variable, which states the time of prime bloom for each sample. Larger value means later bloom time and vice versa. Correlation with UPRIGHTNESS is negative. For UPRIGHTNESS, plants that stood up better received a higher score, and the ones fallen near the ground got a lower score. This negative correlation generally means that the earlier bloomed varieties had their flowers on a stronger support, and the peonies, which bloomed later, had their form more fallen apart. This can not be generalized to all Chinese peonies, but only for this sample set.

For UPRIGHTNESS, there is clear negative correlation with flower sizes, color values, not having reproductive plant parts and a weak fragrance. Only definitive positive correlation is for the distinctive PLASTICKY fragrance. In the context of this data set, this means that peonies with larger and brighter colored flowers tend to fall closer to the ground. The lack of reproductive plant parts seems to be connected to this tendency. The transformation of carpels into petals might be a common feature in adding weight to the flower. The distinctive plasticky scent was present mostly in dark red flowered peonies that stood well upright.

PEONY HEIGHT and LEAF HEIGHT don't seem to have strong correlations to any other variable. Some slight tendencies can be mentioned. There are negative correlations between both measured aspects of peony height and the RGB values for color. Hence, the higher peonies had darker colored flowers in this dataset. There is also very slight correlation between heights and all measured polyphenolic (Dualex) values.

PEDUNCLE LENGTH has slight positive correlation with measured peony heights as well as with CHL and NBI Dualex values. It also seems natural, that generally the taller peonies also had longer peduncles.

FLOWER DIAMETER, HEIGHT and VOLUME have strong positive correlations with each others, which is expected as they essentially are very similar measurements. In a broad sense, this means that it is fairly irrelevant which way or combination of measuring the size of the flower is used to describe the size of the flowers. Actually, the size of the flowers seems to divide correlations on multiple measured variables. Having large flowers correlates here with lighter flower colors, having indumentum on abaxial leaf surfaces, not having stamens, having green ovaries and having a strong fragrance. Flower size correlates notably negatively with plant uprightness, having a red leaf margin, having stamens and a plasticky scent. Single flower form also has strong negative correlation with the size of the flower, which is an expected result.

The method used for RGB color values were discussed earlier (section 3.3). The idea of changing the specific labeled color groups to values of RGB and calculated luminance values seems to have yielded some interesting correlations. However, separated color components R, G and B don't seem to differ from each other much at all. There is only very slight differences in these components. For example, having a larger value for R (darker red component) has slight positive correlation with FRAGRANCE - WEAK, while G has slight negative correlation for the same variable. This shows that the method can in some situations separate the color into situationally useful components.

RGB_AVG shows correlations in the heat map as averages of the components. The differences in per-component correlations were so small, that at the scale of this whole sample set, using only the averages would yield the same results. Treating the RGB values as de facto luminance gives some interesting insights into the dataset compared to just grouping the peonies by similarity of color. In addition to other notes stated above, light color (large RGB values) correlates strongly with FRAGRANCE - STRONG and NORMAL, and clearly negatively with FRAGRANCE - NO, PLASTICKY and SPICY. This means that pleasant and strong scents are associated with peony flowers of lighter colors. The less definitive fragrance categories of WEAK and SWEET don't show correlations with color in either way. Other notable features are abaxial leaf indumentum and the presence of stamens. STAMEN - YES in this dataset seems to correlate with darker colors, while lighter colored peonies much less likely have stamens present in the flowers.

LEAF MARGIN was one of the more difficult categorical variables to assign to samples. LIGHTGREEN was assigned to only three samples with large majority of samples having RED margins (44) and a decent amount had BROWN margins (12). Mostly, the samples with BROWN and LIGHTGREEN features correlate similarly to other features. Notably LIGHTGREEN seems to correlate with other not as prominent categorical features: OVARY - NO (6) and STIGMA - NO (6). BROWN margin seems more prominent with larger and lighter colored peony flowers, while RED margin correlates with smaller flowers and darker flower shades. Otherwise, the leaf margin colors don't show definitive correlations in the whole sample set.

ABAXIAL INDUMENTUM is a categorical variable that splits the whole dataset into two, as stated earlier. Abaxial indumentum was noted as an important feature for peony species recognition [25, p. 35], and it seems to have correlations with other features within these Chinese peonies. Having abaxial leaf indumentum has positive correlation with flower sizes and lighter flower shades. Peonies with abaxial leaf indumentum tend to not have stamens present within the flower. For peonies with abaxial leaf indumentum, CROWN flower shape has clear positive correlation, while the regular DOUBLE shape has clear negative correlation. A pale OVARY also seems to correlate fairly strong for the sample not having abaxial indumentum and vice versa.

STAMEN was another binary variable. Having stamens here correlates slightly negatively with flower size and larger RGB values. Strongest positive correlations for having stamens are for ABAXIAL INDUMENTUM - NO, OVARY - PALE, SHAPE - DOUBLE and FRAGRANCE - PLASTICKY. Strongest negative correlation is for SHAPE - CROWN.

OVARY and STIGMA color classifications don't show many strong correlations. As earlier stated, pale shade correlates with the presence of stamens. STIGMA is a part of the ovary. There is very strong correlation between OVARY - NO and STIGMA - NO, which is expected as a stigma cannot exist without a proper ovary. OVARY - PALE is another feature that separates the DOUBLE (positive correlation) and CROWN (negative correlation) flower types from each other. As a single note, OVARY - BROWNISH shows strong correlation with FRAGRANCE - SWEET.

Flower SHAPE has two more common categories CROWN (25) and DOUBLE (27). DOUBLEWITHZONES (5) shows no strong correlations and SINGLE (2) consists of only two samples, which means the correlations are not general enough to be useful. As stated earlier, these two main categories show strong correlations with some other features; mainly ABAXIAL INDUMENTUM and STAMEN, while naturally having strong negative correlations with each other.

FRAGRANCE is the final feature in the heat map. Values are spread fairly constantly between different categories, apart from SPICY having only two samples for it. Fairly many of these categories correlate with blooming TIME. SWEET and STRONG correlate negatively, which means they bloomed earlier, while WEAK has strong correlation depicting later blooming. As stated above, there are some correlations to flower sizes and colors in PLASTICKY and STRONG categories. FRAGRANCE - PLASTICKY was very distinctive feature for a specific group of samples. All these notes are discussed with appropriate context below in analyzing specific sample groups.

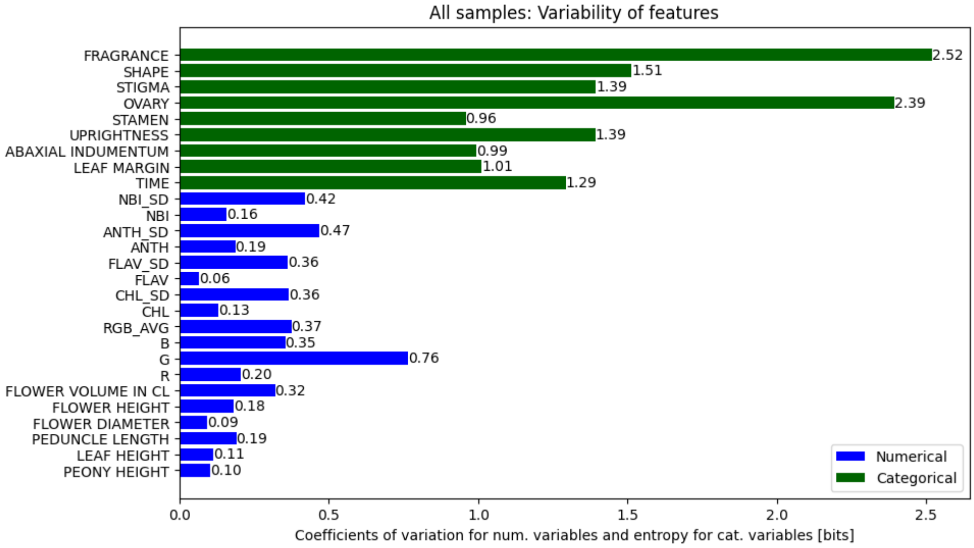


Figure 27: Variability of features in all samples.

The bar chart above (Fig. 27) and the ones in following sections are based on the methods discussed earlier in section 2.2.4. This plot shows the variabilities of numerical and categorical features for all samples in this work. The following plots of groupings of samples provide more useful sample related information. This only offers general insight into how much variability there is among every feature.

Entropies for categorical variables here depict the general distribution of samples in the subcategories. Lowest entropies (< 1) are for the binary features STAMEN and ABAXIAL INDUMENTUM, which had only two types of values to them, and the samples were spread fairly evenly between the values. Largest entropies are found in features FRAGRANCE and OVARY, which both had many value types to them, and samples were spread unevenly into these value groups.

For numerical variables represented with blue bars, this chart depicts the overall scale of variation for every measured feature. Top most eight bars are values from the Dualex measurements and the per value standard deviations. Generally, there is more variability for standard deviations of a samples measurements than for the actual features themselves. This is due to the actual values of Dualex measurements consisting of nine samples per plant, which evens out the differences between single measurements. The amount of the original measurement deviations show in the variabilities of SD features.

For RGB values, the values for green component G have clearly most variability. This might be due to the green component being very low for dark red colored peonies and very high for the white ones with very little values in between. There are no mainly green colored peonies studied in this work.

Interestingly for flower dimension measurements, there is more variation in FLOWER HEIGHT than in FLOWER DIAMETER.

All samples with genetic duplicates removed

This subgroup is explored to see how large of an effect the inclusion or exclusion of the most similar samples have at the scale of the whole dataset. There are a couple larger groups of genetically duplicate samples. For example, the nine genetically identical samples in duplicate group 1 might boost the importance of some features, that would otherwise not be as prominent in the types of peonies examined.

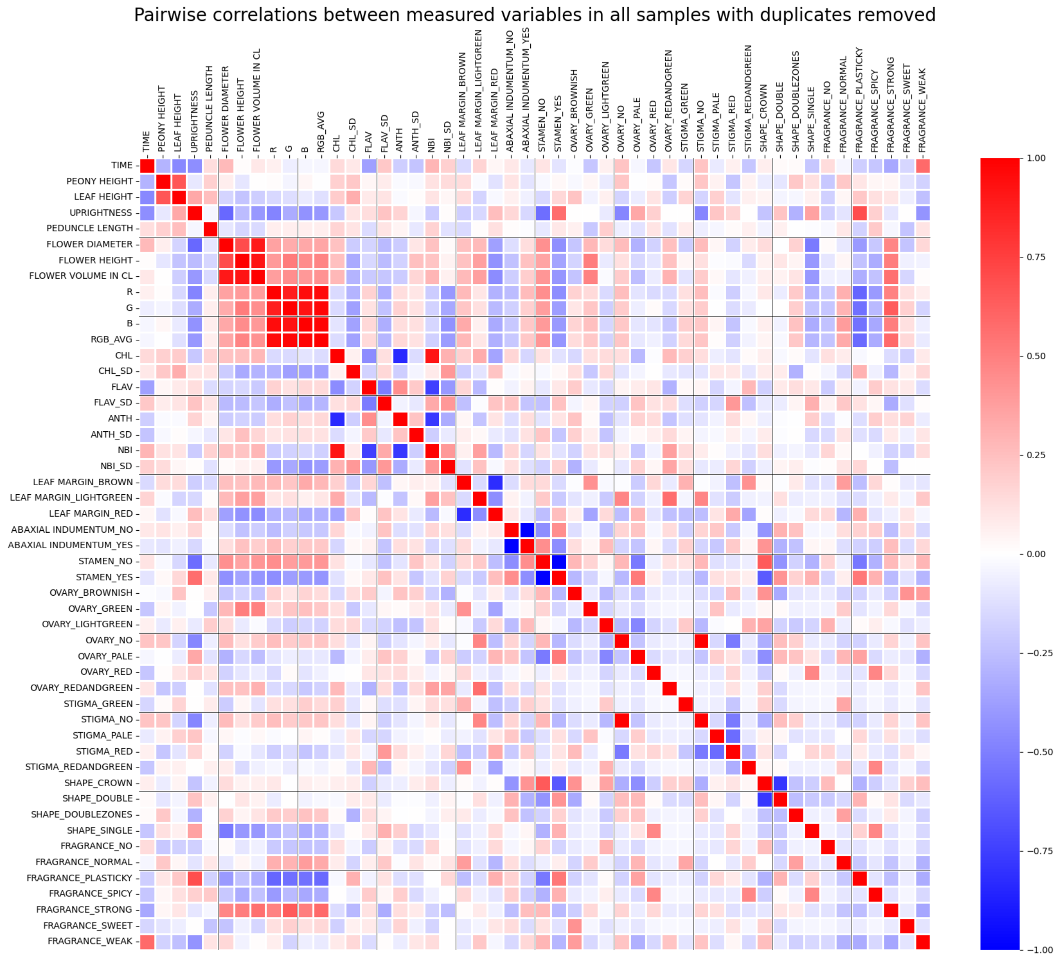


Figure 28: Heat map of correlations between measured and calculated variables in all samples, but removing the genetic duplicate groups of more than two samples (Duplicate groups 1, 2 and 3.)

The correlation heat map above (Fig. 28) does however show only slight difference to the earlier heat map of all samples (Fig. 26). At a quick glance, there are no large magnitude differences. On a closer look some cells have a slightly stronger or lighter shade, which depicts slight change in the broad scale of the dataset. Stronger changes are only seen for dummy variables of those categorical features, which were prominent specifically in the duplicate groups.

For example, the fragrance was described as SWEET for 7 out of 9 samples in the duplicate group 1. Outside the duplicate group 1, only one sample's fragrance was described as SWEET (27 LUKE-5052). Removing the duplicate groups hereby has most effect on such variables. In this dummy variable FRAGRANCE_SWEET, there are great differences between correlations to other variables.

It is essential to note that with the dummy categorical variables, the amount of samples per variable might be very low. In smaller groups of samples, these heat maps essentially only show what values for categorical variables are present in the group, and how they correlate to other recorded values in that specific group.

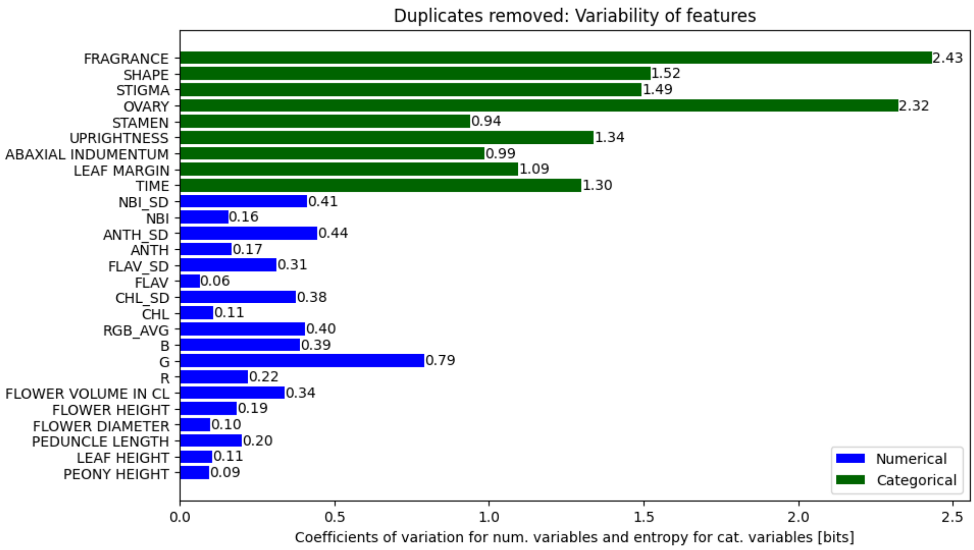


Figure 29: Variability of features in all samples with duplicates removed.

The chart of variabilities above with duplicates removed (Fig. 29) is very similar to the earlier chart with all samples (Fig. 27). Both the coefficients of variation for numerical variables and entropies for categorical variables are very much alike in these charts. Most differences are within 10 % of each other and none show differences of truly meaningful magnitudes.

4.2 Genetic duplicate groups

These groups of samples had identical values for genetic data recorded for them in the original genetic analysis (section 2.1). For the samples analyzed in this work, there are three duplicate groups with more than two samples. These groups are easy to visually spot from the dendrogram of all samples. They referred to as duplicate groups 1, 2 and 3. Duplicate group 4 acts as an example of analyzing a group consisting of only two samples. Similar pairs of duplicates are found among the other sample groups analyzed later. Samples in the prominent duplicate groups are:

Duplicate group 1:
36 (LUKE-4861); 217 (LUKE-4503); 221 (LUKE-4459); 224 (LUKE-4393); 243 (LUKE-528); 248 (LUKE-4861); 260 (LUKE-4684); 267 (LUKE-4566); 269 (LUKE-4506)

Duplicate group 2:
219 (LUKE-4497); 228 (LUKE-3463); 231 (LUKE-288); 251 (LUKE-4828)

Duplicate group 3:
222 (LUKE-4415); 223 (LUKE-4405); 249 (LUKE-4831)

Duplicate group 4:
30 (LUKE-4901); 246 (LUKE-4901)

4.2.1 Duplicate group 1 - Assumed variety 'Edulis Superba'

Figure 30: Imagery of samples in duplicate group 1.

Duplicate group 1 is the largest group of duplicate samples in this work. It consists of samples 36, 217, 221, 224, 243, 248, 260, 267 and 269.

Based on visual inspection of the plotted bars for numerical variables over the dendrogram (Fig. 25), the values seem to not be very close to one another, in this sample group. Sample 248 is much smaller in every dimension, which explains the shorter value for its measured heights as well. Interestingly, it also had the smallest measured flower size in the duplicate group, while on the contrary having the longest peduncle length measured. It might very well be, that the original root was of smaller size or quality than the roots of other samples within this group.

The variabilities of features in the bar chart below (Fig. 31) can be compared with the earlier chart of variabilities of all variables (Fig. 27). It has to be noted, when comparing plots, that the visual length of the bars are scaled based on the longest bar in each plot. The actual values have to therefore be noted when making comparisons

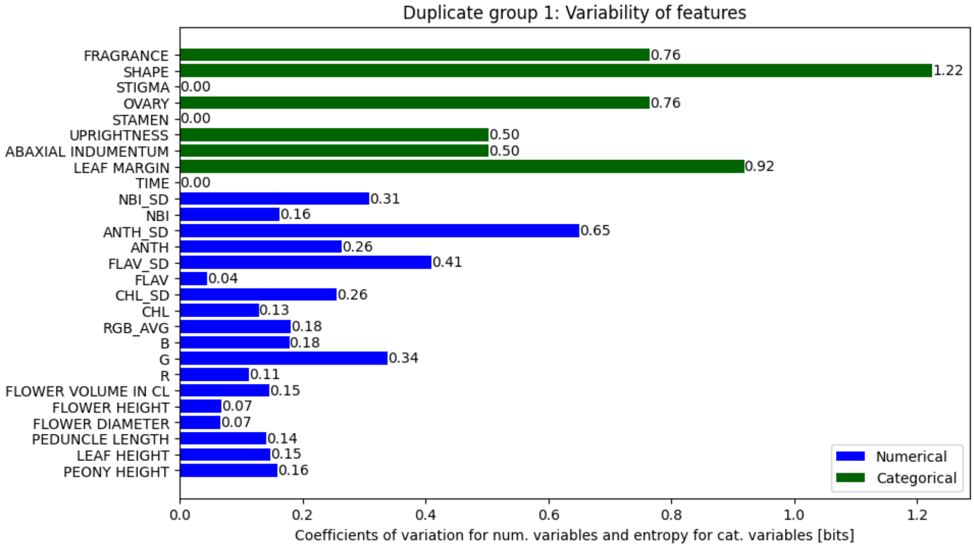


Figure 31: Variability of features in duplicate group 1.

between plots and not just trust on the visual presentation. All measured values for categorical variables are much more similar to each other in this duplicate group than in all samples.

In general, the measured numerical features (blue bars in Fig. 31) are slightly more similar between this group of duplicates, than for all samples in this work. Clearest differences are for the color value averages, flower volumes and peduncle lengths. In contrast, the coefficients for variation are actually larger for this duplicate group for both plant height measurements, G component of flower color and the anthocyanin (ANTH) measurement.

Comparing categorical variables (green bars in Fig. 31) to those of all samples, yields more intuitive and interesting results. In fact, values recorded for STIGMA, STAMEN and TIME were identical for all nine samples in this duplicate group. Roughly said, other categorical variables in this duplicate group have half the entropy that was measured between all samples. It is useful to look deeper into the specific values in these categorical variables using the listed values over the dendrogram (Fig. 24) or the data in the online repository (Appendix A).

Values for flowering time was recorded as 1 for all these genetically identical samples. They were all among the earliest blooming Chinese peonies on the test field. Stigmas were all red colored and stamens were missing completely from all of these samples.

Fragrance values are a mix of values SWEET (7) and WEAK (2). This does not necessarily mean the scents were much different for the two types of values, but the fragrance might not just have been present in the two differently categorized representative flowers. Leaf margins were a mix of RED (6) and BROWN (3) values. Values for Ovaries are a mix of BROWNISH (7) and REDANDGREEN (2, samples 243 and 248) values. Photography shows that the ovaries in sample 243 were not as present as in other samples, and the ovary of the significantly smaller sized flower 248 probably should have been categorized as similar to the other samples.

Flower shapes were a mix of mostly CROWN values, two values of DOUBLEWITH-ZONES (221, 224) and a single value of DOUBLE (269). From the flowers analyzed, sample 269 had a comparatively small out-most petal, which is the reason for different flower shape classification. Samples 221 and 224 had a zone of very small petals between the outermost petals and larger inside petals. Looking back at it, this classification method seems too specific, as all samples probably should have been actually assigned the same identifier for flower shape.

Abaxial indumentum was recorded present on the leaves of all samples in duplicate group 1, except for sample 36. UPRIGHTNESS values were recorded as benefiting from support (1) for all other samples than sample 248 (2). This again seems reasonable as sample 248 was so much smaller in size than the other peonies, which aided in keeping stems upright. The heat map below (Fig. 32) also shows this negative correlation between the heights of peonies and their uprightness values.

Another interesting note is that the color of the leaf margin somewhat correlates slightly with the measured color (luminance, RGB_AVG) of the samples. Samples with a red margin seem to have slightly darker toned flowers than peonies with brown margins. Leaf margin color was a difficult feature to assess overall, and this note might very well be irrelevant.

The strengths of many correlations might seem very strong compared to earlier plots with all samples. Although, at this smaller size of the sample set, it is easy to jump into too quick assumptions. A slightly different value in a single sample can make a fairly large impact on the plot.

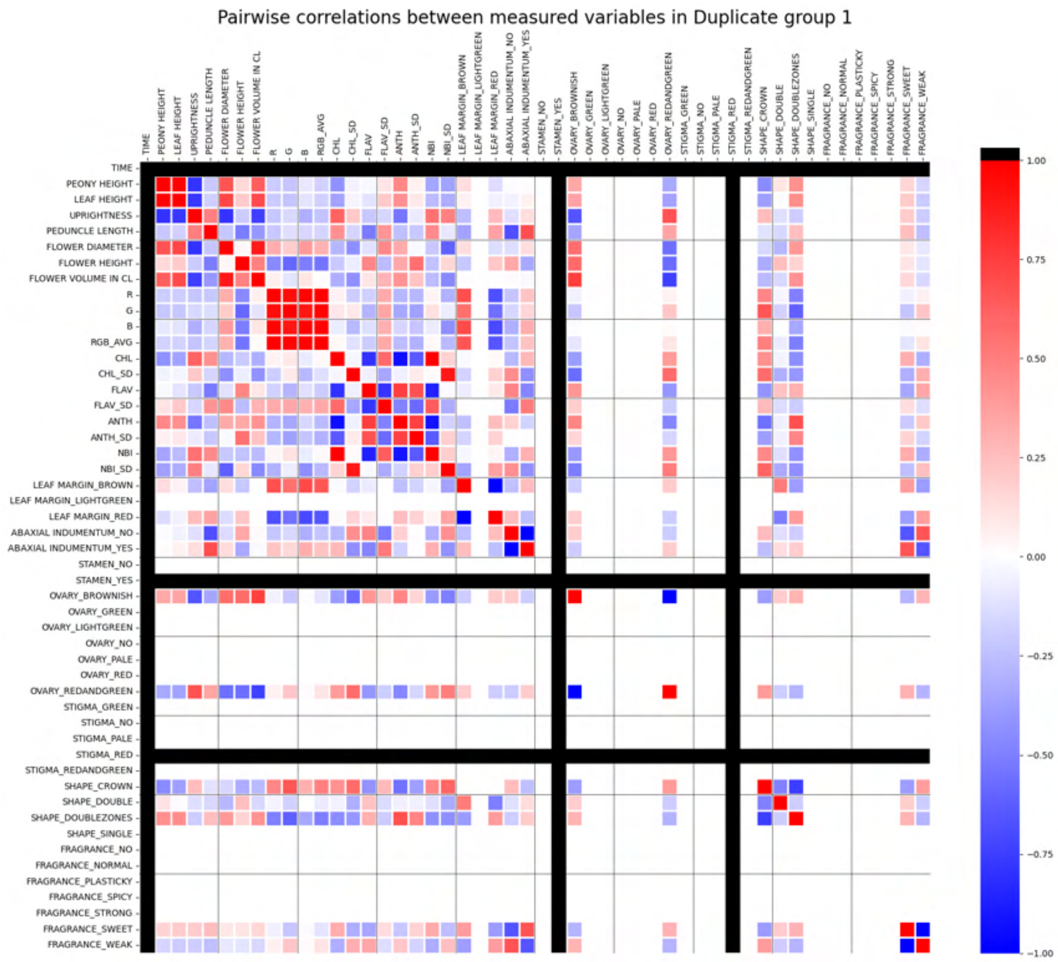


Figure 32: Heat map of correlations between measured and calculated variables in duplicate group 1.

Recognizing the variety

The sheer amount of identical samples of this specific type of Chinese peony gathered in the study states that it has most likely been a very popular variety in the Finnish garden culture. Most descriptions of the Chinese peony variety 'Edulis Superba' (Lémon, 1824) fit the observation done in this work. 'Edulis Superba' is an old variety that has been listed for sale in Finland already in the 1930s [2, p.142].

American Peony Society's registry gives many matching criteria. All of the samples had the earliest value for time of flowering, which matches the description of blooming time 'Very early' perfectly. These peonies were among the first to bloom in the whole Chinese peony part of the test field. In the image below, most other Chinese peonies are still opening their buds (Fig. 33). Also a collar of lighter and shorter petals is mentioned, which aligns with the flower shape DOUBLEWITHZONES recorded for some of the samples, even though it might not have been a good value of classification. [32]

Many other features of these peonies do synchronize with the general depictions of 'Edulis Superba', too. Flower shape of 'Edulis Superba' develops to a full crown in mature plants with silver edges on inner petals and a sweet rose-fragrance [1, p. 92]. These are all aspects that well suit the recorded values in this work.

'Edulis Superba' is highlighted as the most common peony variety in Estonia [33, p. 77]. Estonia's and Finland's peony cultures probably share many of the same varieties. However, this variety recognition is only approximate as many of the old varieties listed for sale in Finland share very similar features. Other fairly similar old varieties are 'Madame Geissler', 'Philomèle' and 'Noemi Demay' [2, p. 142]. However, 'Noemi Demay' should not have any carpels present [34], which is a definitive difference to the peonies in this duplicate group. Sources about the old peony varieties do sometimes differ greatly for descriptions of the same varieties.

Figure 33: Sample 203 - likely variety 'Edulis Superba'.

4.2.2 Duplicate group 2 - Assumed variety 'Sarah Bernhardt'

219 (LUKE-4497) 228 (LUKE-3463) 231 (LUKE-288) 251 (LUKE-4828)

Figure 34: Duplicate group 2: Samples 219, 228, 231 and 251.

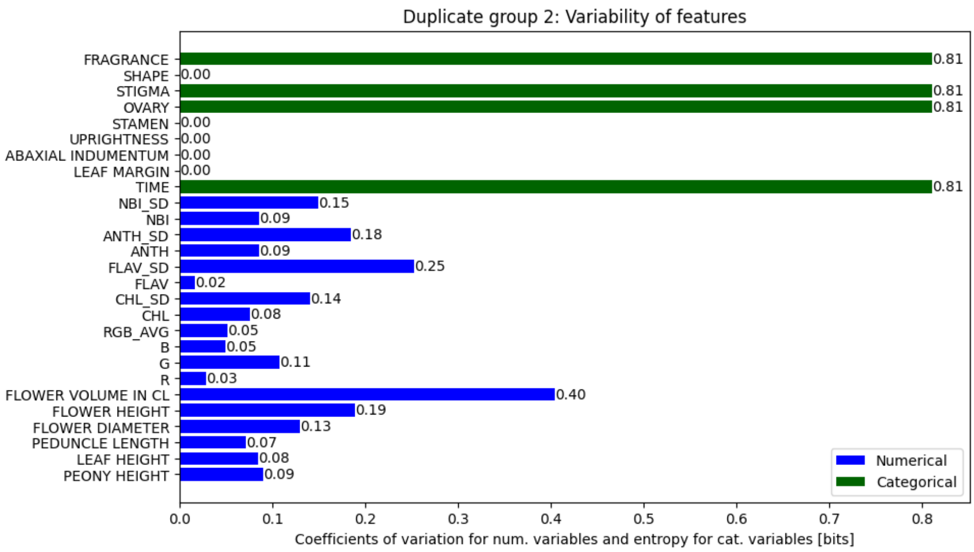


Figure 35: Variability of features in duplicate group 2.

Duplicate group 2 consists of four duplicate samples. The other peonies genetically closest to these peonies show a lot of variance in appearance. It is clearly seen in the photos of this group (Fig. 34), that the sample 231 is visually a lot paler then the other three samples. Other three samples seems fairly similar to each other.

Looking at the variability within these duplicates in the bar chart of variabilities (Fig. 35), all categorical features are identical to each other except FRAGRANCE, TIME and reproductive plant parts depicted by variables STIGMA and OVARY. Equal entropy value of 0.81 in all of these states that in all of those groups the values differed by the same amount. Numerical variables show much less variance in this duplicate group than in the scope of all samples earlier (Fig. 27), except for flower dimension measurements, which show a lot of variance. All the polyphenolic variables and color values show significantly lower variation in this sample group. These results are somewhat expected with such identical seeming peonies.

Numerical measurements (Fig. 25) show that most size measurements from these samples were fairly uniform, with the exception of flower size. It is seen clearly that the flowers examined for samples 228 and 251 had only around half of the flower volume of the other two samples (Fig. 25).

Looking at the values of categorical variables in the samples of this duplicate group (Fig. 24), it is seen that of the four samples, only one sample had a different value than the others in these four variables. Variable TIME had value of 3 for only sample 231 and value of 2 for all others. As TIME states the date of collecting the flower sample, this date difference might largely be causing the earlier noted difference in the color shades of the samples.

FRAGRANCE was recorded as NORMAL for one sample and WEAK for all others. There might very well have been no significant difference in scents. OVARY was recorded as PALE for all except sample 251, which received value of NO. Same goes for the measurement of variable of STIGMA (3 YES, 1 NO). Ovaries are hard to recognize in the photos above (Fig. 34). The ovaries, which are seen in other samples, are very small. Ignoring them for sample 251 might be due a measurement error or due to an atypical sample flower. The image below (Fig. 36) is taken of the same sample in the end of the summer on 18.8.2022 and it shows that carpels had been present within the flower.

The heat map between features in a sample group this small doesn't provide much useful evidence (Fig. 37). Though it is quick to see which variables were identical for the whole group.

Figure 36: Sample 251 shows some remains of the ovaries at the end of the summer.

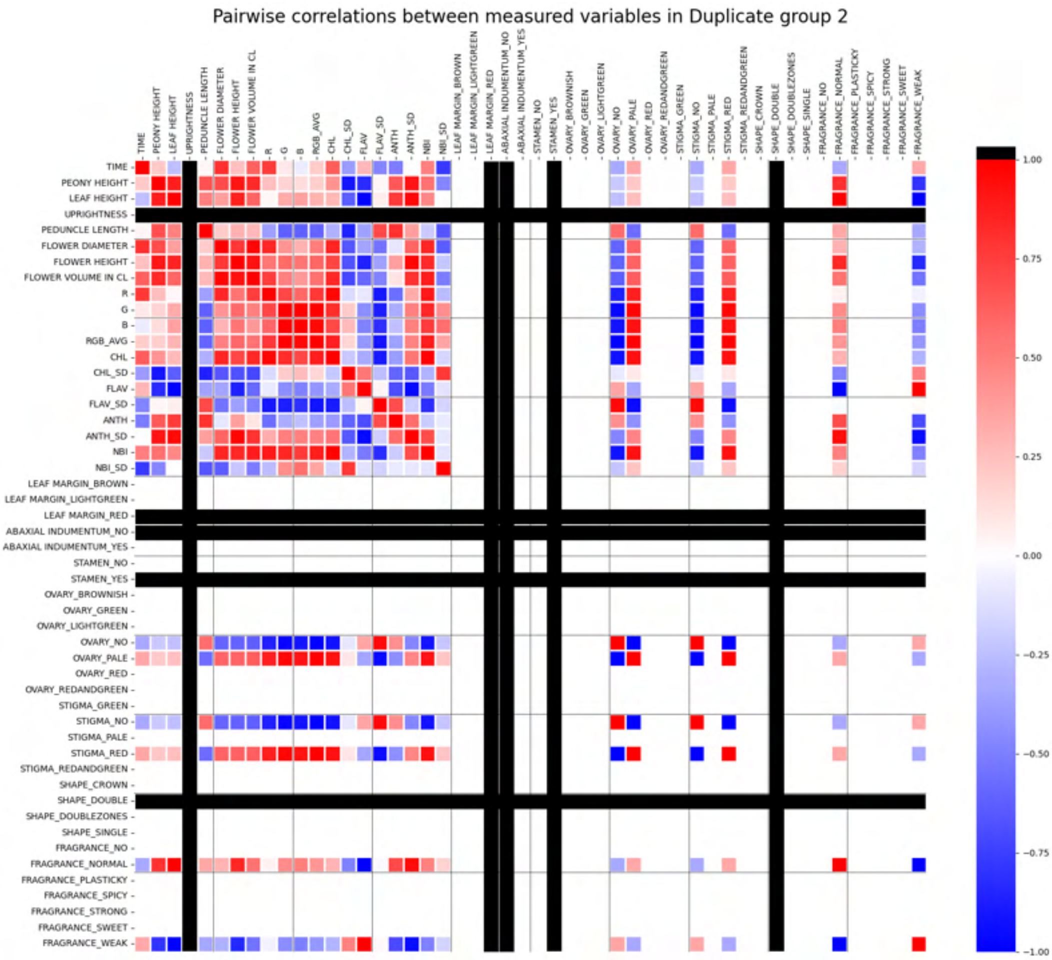


Figure 37: Heat map of correlations between measured and calculated variables in duplicate group 2.

Recognizing the variety

For attempting to recognize the variety, some cohesive notes of the samples have to be made by referring to the photos of the samples (Fig. 34) and the recorded features of the samples (Fig. 24). All of these samples were similar of color. They were fully light rose pink when the flowers opened and lightened towards the end of the flowering time.

All samples had well defined stamens and very small pale ovaries with red stigmas, which were not initially noted for one of the samples. Flower shape was double for all samples and the scent was of weak to normal strength of a peony like scent. Time of blooming was middle of all samples of Chinese peonies. Leaf margins were red for all, and none of the leaves had abaxial indumentum. While blooming the posture of all samples would have greatly benefited from added support. A typical sight is seen in the picture below taken on the field (Fig. 38), where the fully blooming flower had been laying on the ground.

'Sarah Bernhardt' (Lemoine, 1906) is a Chinese peony variety that is probably the most common and well known peony in the whole world [35]. In Finland, too, it is one of the most common and oldest peony varieties of its type. 'Sarah Bernhardt' has been sold in Finland confirmedly for at least nearly a century. It was sold in Harviala in 1929 and in other confirmed sources in the 1930s. The edges of the petals are lighter in shade. The middle petals are a bit shorter. The scent is described as slightly sweet, but not very special. [2, p. 187]

All these features presented match the notes and photographic evidence taken of the samples. It has to be noted that this type of peony is very common and there are multiple varieties that are very similar.

Figure 38: Flower of sample 251 - assumed variety Sarah Bernhardt picked up after it had been laying on the ground due to its weight and fairly weak stems.

4.2.3 Duplicate group 3 - Assumed variety 'Karl Rosenfield'

Figure 39: Images of duplicate group 3.

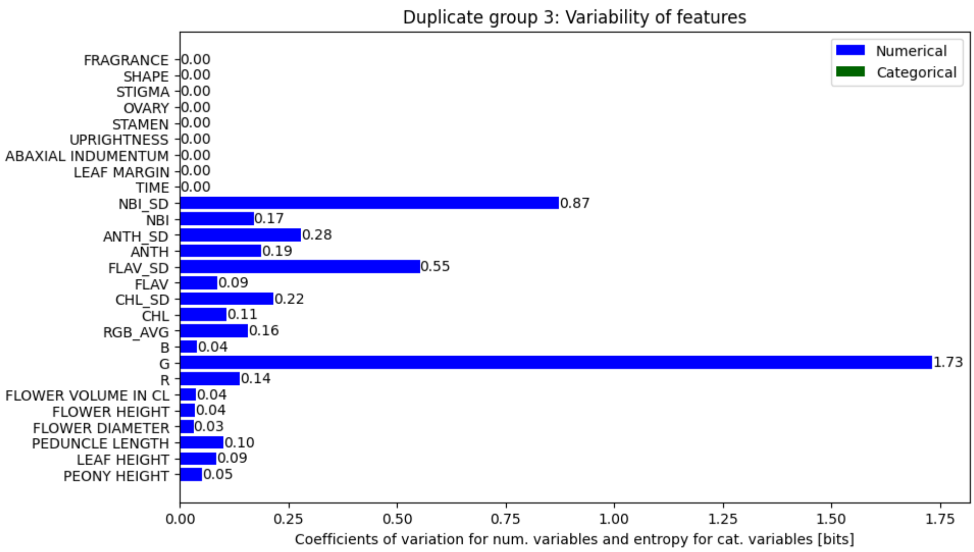


Figure 40: Variability of features in duplicate group 3.

Duplicate group 3 consists of only three samples. However, as the bar chart above (Fig. 40) shows, the recorded categorical values were identical for all three. For numerical features, there is a big spike for color component feature G. The color of sample 249 was classified in a slightly different color category than the other two samples. Converting the color groups to color component values resulted in a large relative difference for the G component, as its value is 30 for sample 249 and 0 for the two others. B and R color components had much lesser amounts of difference to them. Apart from this anomaly, all other numerical variables are much more alike in the duplicate group than in the reference of all samples (Fig. 27).

The heat map of features (Fig. 41) shows the large amount of identical values visually. Difference between numeric and categorical features is clearly visible, as every categorical feature is represented by a black bar depicting equal values.

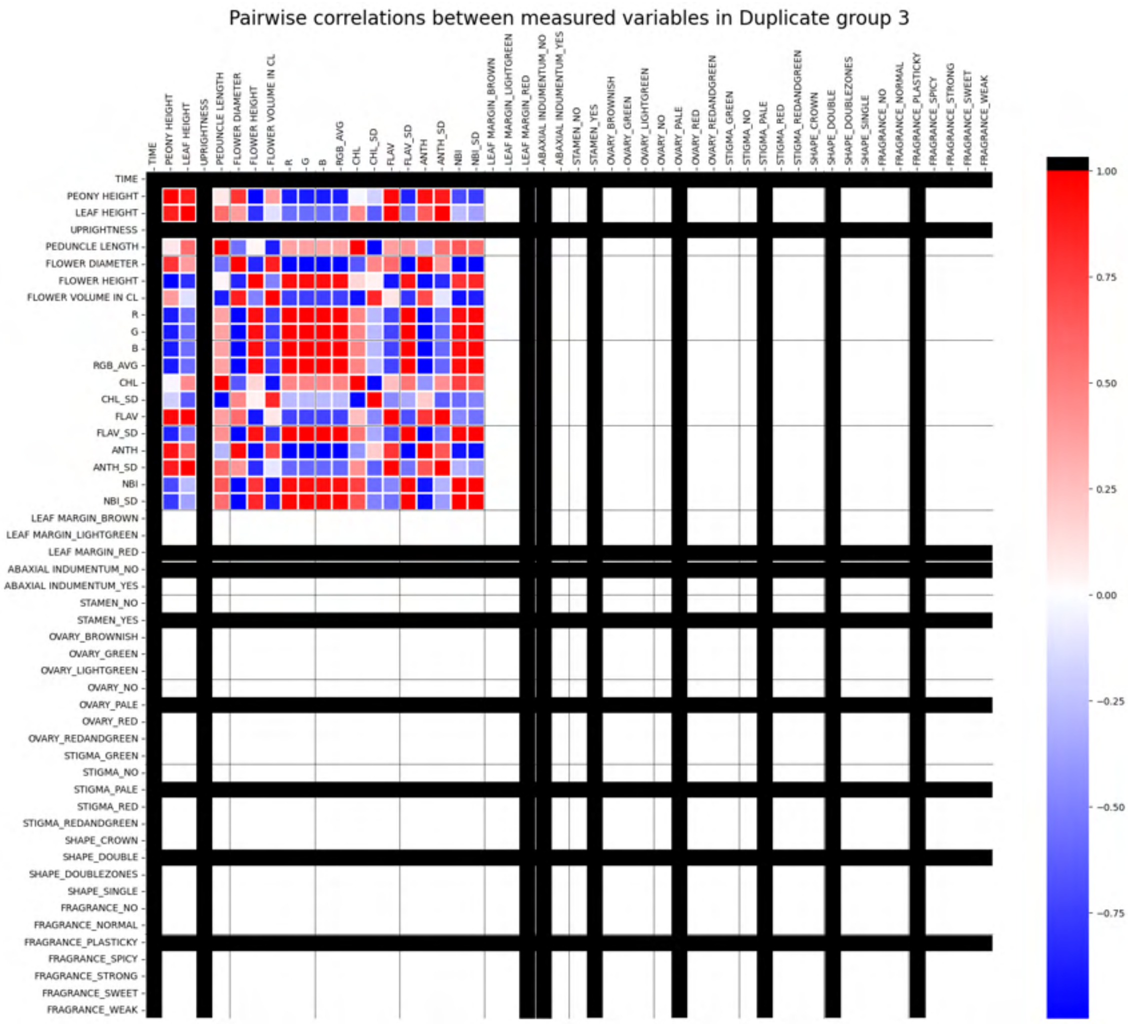


Figure 41: Heat map of correlations between measured and calculated variables in duplicate group 3.

Recognizing the variety

All of these peonies had the same distinct 'plasticky' smell to them, which is very special compared to the general scents of other samples. All flowers were double shaped with pale ovaries and stigmas. Stamens were clearly present. Every plant stood well upright with no additional support required.

'Karl Rosenfield' (Rosenfield, 1908 [36]) is one of the most common red peonies in the Estonian (and Finnish) peony scenes, which some sources mention to have an unpleasant smell [33, p. 97]. All these peonies within the duplicate group had very good posture and they held the flower well upright. The fairly slender but strong stems are a known property of 'Karl Rosenfield' [37, p. 61], which is seen in the image below on the field (Fig. 42). The color of 'Karl Rosenfield' peonies sold at Athialan taimisto in 1939 was described as "dark wine red" [2, p. 124]. These are signs that point towards this peony being the famous 'Karl Rosenfield'.

Figure 42: Sample 249 - likely variety 'Karl Rosenfield' held its flowers well pointed towards the sky, unaided.

However, as one of the oldest and widely spread varieties, there seems to be at least two different types of 'Karl Rosenfield' sold globally. Some sources describe 'Karl Rosenfield' as bright crimson red ([1, p. 103] and [36]) / blood red colored [37, p. 61], while some sellers describe it to have a purplish red [33, p. 97] or blue-purple glow ([38] and [39]).

In the Finnish scene, there are multiple online shops selling 'Karl Rosenfield'. For example, Mustila Puutarha [40], Hankkija [41] and Pionien Koti [42] have multiple images of 'Karl Rosenfield' on their websites. Many of these images show great resemblance to the peonies examined in this duplicate group. However, the exact shade of color seems to be highly connected to the surrounding lighting environment of taking the picture.

An American peony grower Adelman Peony Gardens, is selling 'Karl Rosenfield' on their website, claiming it to be of the true original variety [43]. Based purely on the pictures, it seems to be of brighter red color than the peonies explored here. After all, 'Karl Rosenfield' is originally a variety registered in the United States [44, p. 176]. As it seems to be the original variety, what should the variety sold very widely across Europe then be called? The issue seems to be of global scale and to have originated early in the 1900s.

Anyway, the test field examined in this work didn't have proper reference samples for any peonies. Which ever the proper variety name is, these peonies play a valuable part in the Finnish gardening culture. Exploring the connections to the different types of variety 'Karl Rosenfield' would need proper references samples. As seen later in analyzing other groups, it is not very clear if the many other red peonies in the test field were variations of this peony variety, or if they represented other similar varieties.

Figure 43: Sample 249 - likely of variety known as 'Karl Rosenfield', even though it may not be the original 'Karl Rosenfield'

4.2.4 Duplicate group 4 - Suggested variety 'Monsieur Martin Cahuzac'

30 (LUKE-4901) 246 (LUKE-4901)

Figure 44: Images of duplicate group 4.

Duplicate group 4 is a special one. It consists only of two samples (30 and 246). These samples were originally a single plant before moving to the test field. Genetic data is of the same single leaf sample collected. This pairing acts as a solid basis for exploring which features have been changed only due to environmental reasons. Peonies in other duplicates, while having identical values of genetic data, might still differ in a manner that was not recognized by the genetic markers. There are also a couple other pairs of genetic data, but this is the only case separately discussed due to its speciality of being from the same original plant.

The bar chart below (Fig. 45) shows the great degree of similarity in categorical variables. For only two samples, the amount of statistical entropy as it is calculated in this work is always either one or zero. The difference in variable TIME was of the least significant magnitude possible (Fig. 24). Sample 30 was among the earliest group of examined samples, while sample 246 was in the second group of flower analysis. The other difference was found in variable OVARY, which was recorded as PALE for sample 30 and LIGHTGREEN for sample 246 (Fig. 24). This slight shade difference can also be seen in the photos above (Fig. 44), however it is still a fairly small difference. Otherwise, the insides of the flowers are very much alike for the two samples.

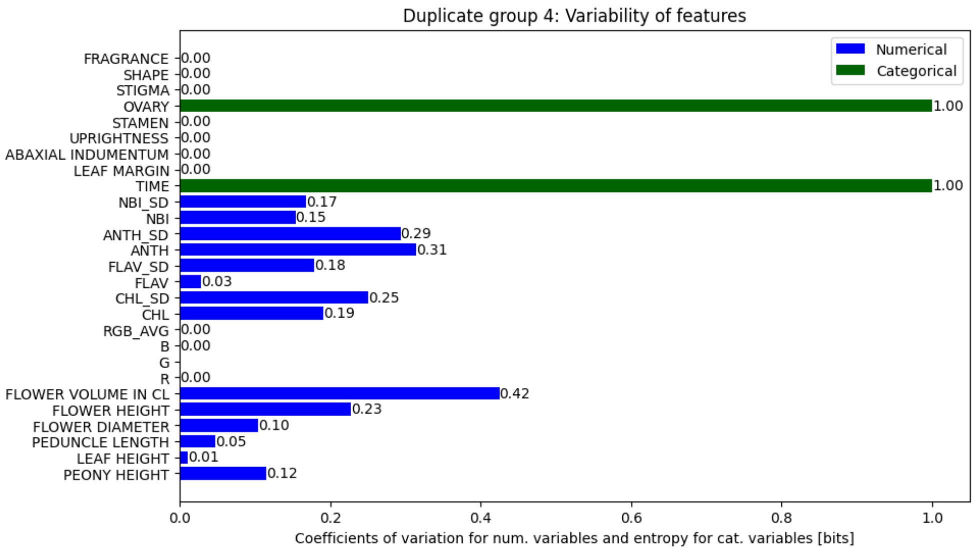


Figure 45: Variability of features in duplicate group 4.

For numeric variables, the coefficients of variation don't yield very useful information for only two samples. Same applies for comparing correlations between the variables of only two variables (Fig. 46). The heat map is not very useful for other than recognizing what the values for identical values.

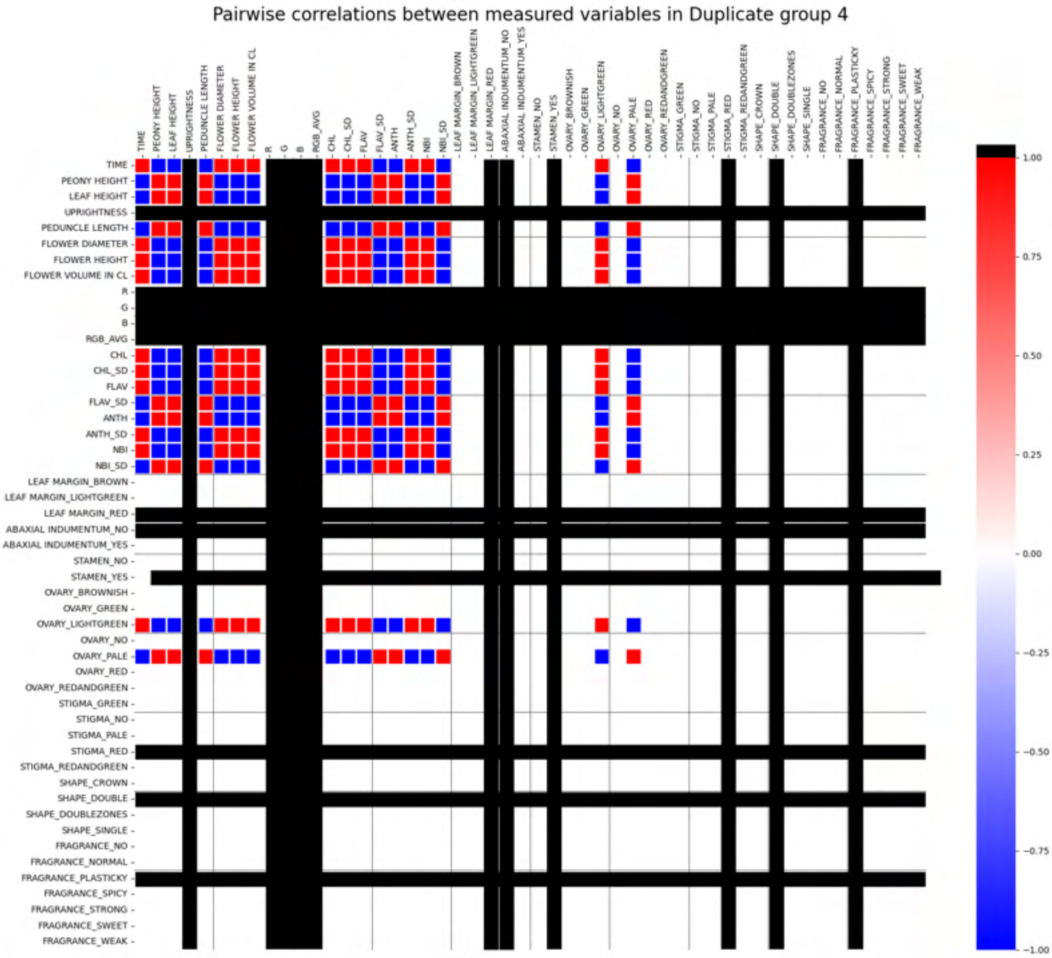


Figure 46: Heat map of correlations between measured and calculated variables in duplicate group 4.

Recognizing the variety

Below are two photos of these peonies' flowers on the test field (Fig. 47). Photos were taken before acknowledging the fact that the peonies were of the same origin. On the field their the similarity is outstanding. They share most features: red leaf margins, no indumentum on the abaxial sides of leaves, both would benefit from mechanical support, PALE/LIGHTGREEN ovaries with RED stigmas, both flowers were of DOUBLE form and had a PLASTICKY fragrance.

These peonies might look similar to the previous group (3) at a quick glance, but there are some clear differences present. These peonies have well formed ovaries, which the previous duplicate group lacked nearly completely. These larger carpels have red stigmas, while the ones in duplicate group 3 were pale. Sample 30 bloomed slightly earlier than sample 246 and all of the samples in duplicate group 3. These samples seem to be a bit darker in color and to have less magenta tint in the color, as the samples in duplicate group 3. However, the differences are fairly minimal.

This means finding features to differentiate these two groups is very difficult. Focus has to be in the carpels, as only real differences were found in ovaries and stigmas. These features are often neglected, when listing features of peonies as they do not make a great difference to the garden use of the variety. 'Monsieur Martin Cahuzac' (Dessert, 1899) is one of the darkest red Chinese peonies, which doesn't have a notable scent, has stiff stems and stamens present within the flower [45]. Those descriptions fit close to the samples explored here.

Still, without actual references the connection cannot be confirmed. These samples might also be just another slightly different variation of the 'Karl Rosenfield' case discussed earlier (section 4.2.3). After all, duplicate groups 3 and 4 are genetically fairly close to each other as well (Fig. 23).

(a) Sample 30

(b) Sample 246

Figure 47: Flowers of the two peonies, that were divided from a single peony, when moving the peony to the test field. - Suggested variety 'Monsieur Martin Cahuzac'

4.3 Groups of genetically close and similar appearing peonies

These groups of samples are not identical genetically, but they are still fairly close to each other. Groups were formed based on the dendrogram depicting genetic relationships between all samples (Fig. 23). Groups consist mostly of samples, which are reasonable for an observer to quickly view them as the same peony cultivar. Some groups may consist of a few different varieties. Some clearly different appearing samples are excluded from the analysis groups despite being within the same section of the dendrogram. Exploring these groups gives insight on which features are most similar among the very closely related groups of peonies, and also how diverse a specific named variety can be in terms of genetics and morphology. Some of these groups include an earlier discussed duplicate group within themselves. In these situations, only one sample from the genetic duplicate groups is picked to represent the whole duplicate group and to not over saturate the broader group with the values from the duplicate group.

Group A:
232 (LUKE-2816); 225 (LUKE-4384); 226 (LUKE-42); 32 (LUKE-3425)

Group B:
255 (LUKE-4752); 227 (LUKE-4047); 217 (LUKE-4503); 254 (LUKE-4762)

Group C:
252 (LUKE-4764); 218 (LUKE-4500)

Group D:
236 (LUKE-135); 204 (LUKE-4515); 25 (LUKE-5050); 63 (LUKE-4620)

Group E:
253 (LUKE-4763); 238 (LUKE-126); 271 (LUKE-4501); 244 (LUKE-4921); 259 (LUKE-4685)

Group F:
26 (LUKE-5051); 223 (LUKE-4405); 34 (LUKE-5237 A); 202 (LUKE-4928)

Group G:
246 (LUKE-4901); 241 (LUKE-4702 B); 268 (LUKE-4519)

Group H:
233 (LUKE-2247); 262 (LUKE-4675); 256 (LUKE-4712); 235 (LUKE-1903); 229 (LUKE-3454; 265 (LUKE-4618)

4.3.1 Group A - Assumed main variety 'Mons. Jules Elie'

232 (LUKE-2816) 225 (LUKE-4384) 226 (LUKE-42) 32 (LUKE-3425)

Figure 48: Group A: Samples 232, 225, 226 and 32.

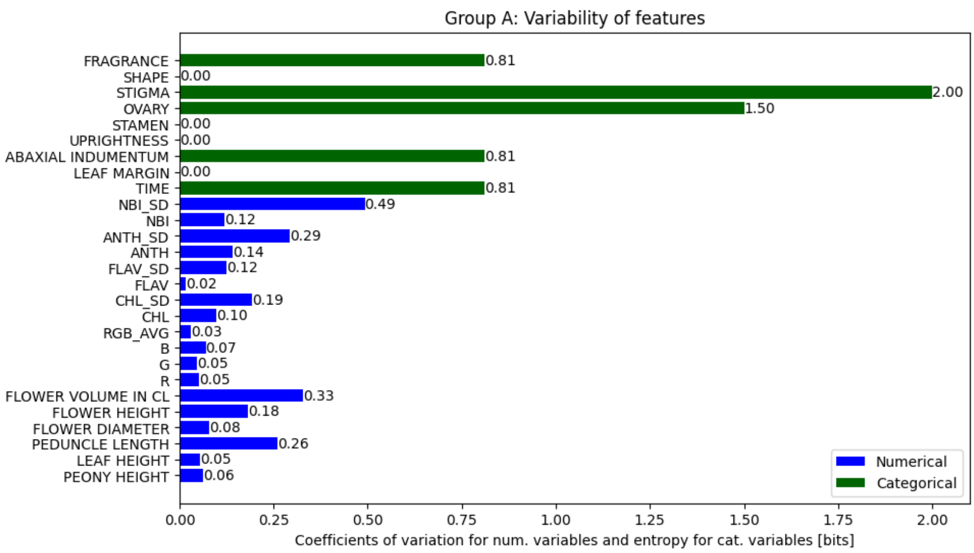


Figure 49: Variability of features in peony group A.

Group A consists of samples 232, 225, 226 and 32 (Fig. 23). Genetic distance to sample 32 is just above the color grouping threshold of the dendrogram. Since it is closest to this group of more closely related samples, and looks fairly similar to the other samples, it is discussed as a part of this group. Imagery of this group immediately shows more variation in the samples than what was present in any duplicate group (Fig. 48).

The bar chart of feature variabilities (Fig. 49) shows more variation, than what was present within a duplicate group consisting of four genetically identical samples (Fig. 35). Color values show very little variance, which is visibly seen in the photos as well. All other numerical values show smaller variability than the values for the whole dataset, except PEDUNCLE LENGTH (0.26), which was more than the value for all samples (0.19, Fig. 27).

Categorical variables have identical values for SHAPE, STAMEN, UPRIGHTNESS and LEAF MARGIN. STIGMA had the most variability with every sample having a different shade of STIGMA, also OVARY was identical only for two samples (232, 225) (Fig. 24). In ABAXIAL INDUMENTUM, TIME and FRAGRANCE only one sample had a different value than the other three. For only four samples, the heat map of variable correlation (Fig. 50) doesn't yield much useful information. It can be used as a quick reference to see, which values were identical for all samples.

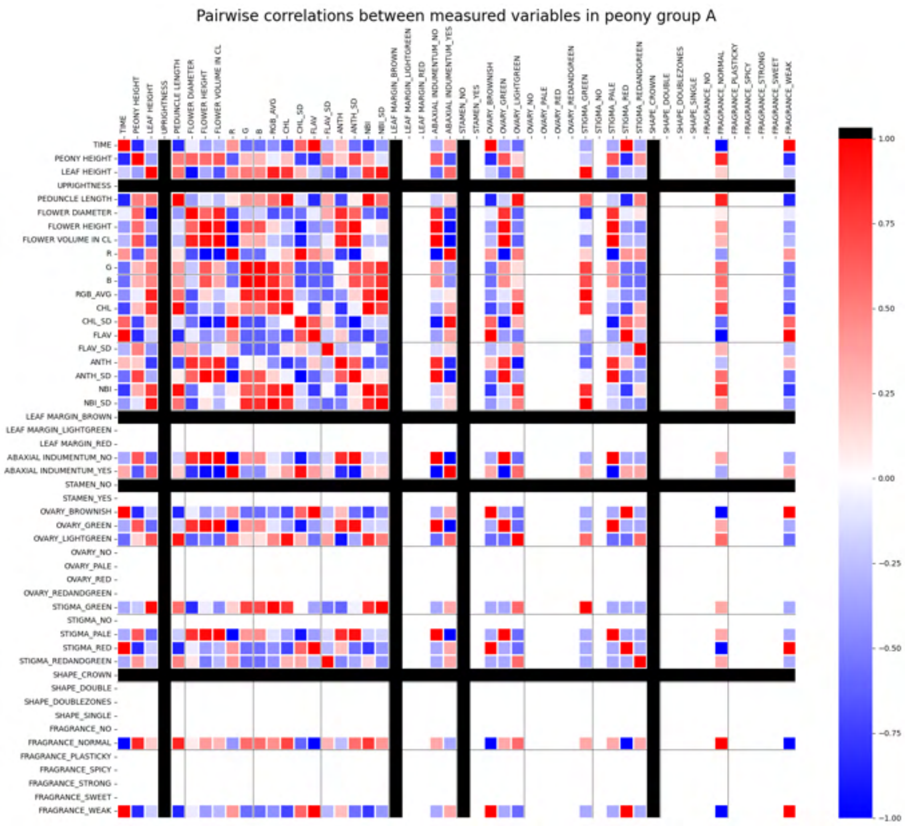


Figure 50: Heat map of correlations between measured and calculated variables in peony sample group A.

Recognizing the variety

Samples 232 and 225 are more close genetically than the other two samples in this group. To aid recognition, some general notes on the features are useful. For those two samples, heights of the plants, flower volumes and peduncle lengths were very similar, sample 32 had a much larger flower, and sample 226 had shorter peduncles (Fig. 25).

Other 3 peonies bloomed in the first phase of collecting samples, except sample 226, which bloomed in the second phase. The most genetically different sample, 32, is the only one without abaxial indumentum. All peonies would have benefited from mechanical support. Fragrance was classified as WEAK for sample 226 and NORMAL for the other three. All flowers are CROWN shaped and no stamens are present. Biggest differences are found in the carpels. Samples 232 and 225 are most identical, with only a slight shade difference in the stigmas (Fig. 51). Carpels seem to be slightly transformed to petals in sample 232. Comparing carpels across multiple flowers in these samples might be useful.

(a) Sample 232 (b) Sample 225

Figure 51: Tips of the carpels (stigmas) have a slight shade difference in genetically closely related samples.

'Mons. Jules Elie' (Crousse, 1888) is a famous early flowering variety, which has no stamens and for which the stems have difficulty to keep the flowers upright [33, p. 119]. The flowers are moderately fragrant and change shape during flowering, they always finish in the crown type [46]. These descriptions fit the plants of this group rather well.

However, 'Mons Jules Elie's carpels are stated as absent in some sources [1, p. 96], which is not a good fit for any of these samples. Could the sample 32 still possibly be 'Mons. Jules Elie'? Maybe the small carpels evolve into carpelodes, when the plant grows larger. In any ways the flower looked fairly different in natural environment (Fig. 52 (a)). Towards the end of flowering, the petals fade towards white . Also, for some flowers carpels were very small, which raises more questions for variety recognition (Fig. 52 (b)).

'Claire Dubois' is another variety that fits the aesthetics of samples 232 and 225 [1, [p. 80] rather well. 'Claire Dubois' has been listed for sale in Finland a long time ago [2, p. 142]. However, the signature dark foliage and late flowering time of 'Claire Dubois' make it an unlikely candidate for the actual variety [47].

(a) Sample 225 in its prime bloom.

(b) Sample 225 fades to full white.

Figure 52: Sample 225 in natural light at prime bloom (a) and at the end of blooming (b).

Figure 53: Sample 232 - assumed variety 'Mons Jules Elie' showing different sizes and shapes of flowers.

4.3.2 Group B - Assumed variety 'Edulis Superba'

255 (LUKE-4752) 227 (LUKE-4047) 217 (LUKE-4503) 254 (LUKE-4762)

Figure 54: Images of peonies in group B.

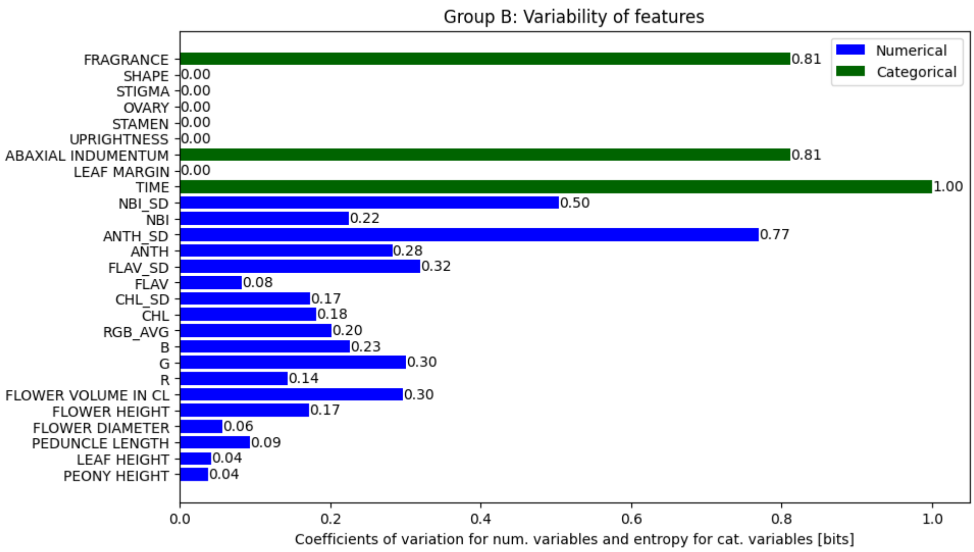


Figure 55: Variability of features in peony group B.

Group B includes the largest duplicate group (1) within itself. To possibly see, which differences appear with slight genetic difference, only sample 217 is chosen here to represent the earlier discussed duplicate group. Photos above (Fig. 54) shows that the sample group seems fairly homogeneous. It has to be noted, that for some reason sample 254 bloomed with very few flowers, despite of the good foliage growth.

The bar chart for variabilities of features in this group (Fig. 55) shows that TIME is the only feature, which now has variability, that didn't have variability for analysis of duplicate group 1 (Fig. 31). In fact, the only sample with TIME value of 2 (instead of 1), was the poorly blooming sample 254. Numerical measurements for this group don't show clear difference to the measurements of duplicate group 1. By going through the values of categorical values (Fig. 24), it is seen that all the values present for these samples, were already found in duplicate group 1.

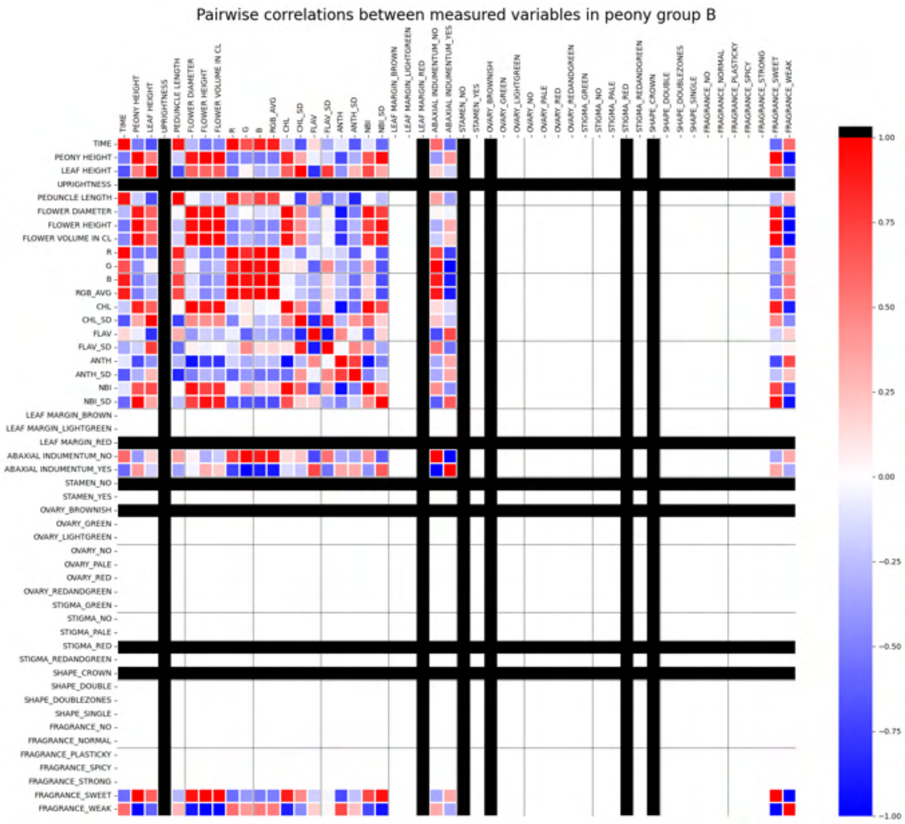


Figure 56: Heat map of correlations between variables in peony sample group B.

Recognizing the variety

Duplicate group 1 forms the largest part of this sample group. Variety recognition was already discussed for purely the duplicate group. None of these samples show any drastic difference to the peonies in the duplicate group, despite not being identical in terms of the genetic analysis. They are in no way differentiable from the peonies in duplicate group 1. There is no reason for additional analysis to what was stated earlier(section 4.2.1). These samples also represent the same variety, assumedly 'Edulis Superba' (Lémon, 1824).

This group confirms that there might be slight variation in the genetic marker values, with no great effects to the peony's morphology. This might be indicative of the fact that this specific variety has a long history in Finland. Variation in genetics might be a summary of slight genetic mutations over time.

4.3.3 Group C - Assumed variety 'Inspecteur Lavergne'

252 (LUKE-4764) | 218 (LUKE-4500)

Figure 57: Images of samples in group C. Two very similar looking flowers with slight genetic difference.

Group C consists of only two samples; 252 and 218 (Fig. 57). In the genetic dendrogram (Fig. 23), sample 37 is fairly close to these two, but based on photographic evidence, it is of distinctively different variety. These two samples are in many aspects different than any other sample in the whole scope of this work. The variability bar chart (Fig. 58) and the feature correlation heat map (Fig. 59) below are practically useful only for seeing, which measured features were identical for these two peonies.

It is essential to note that on the contrary to duplicate group 4 (section 4.2.4), these two samples were not identical based on the genetic analysis. Still, there were only some differences between recorded values. The measured flower from sample 252 was significantly larger (Fig. 25). Sample 252 had weak scent, while 218 had none. Last notable difference is in the colors of the OVARY. Once again, the specific forms of the carpels might vary within the same peony flower to flower.

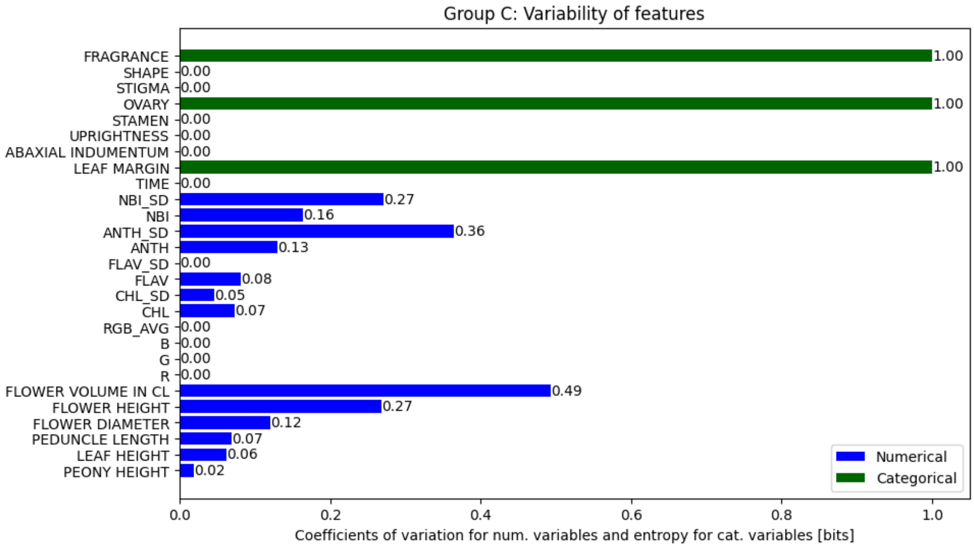


Figure 58: Variability of features in peony group C.

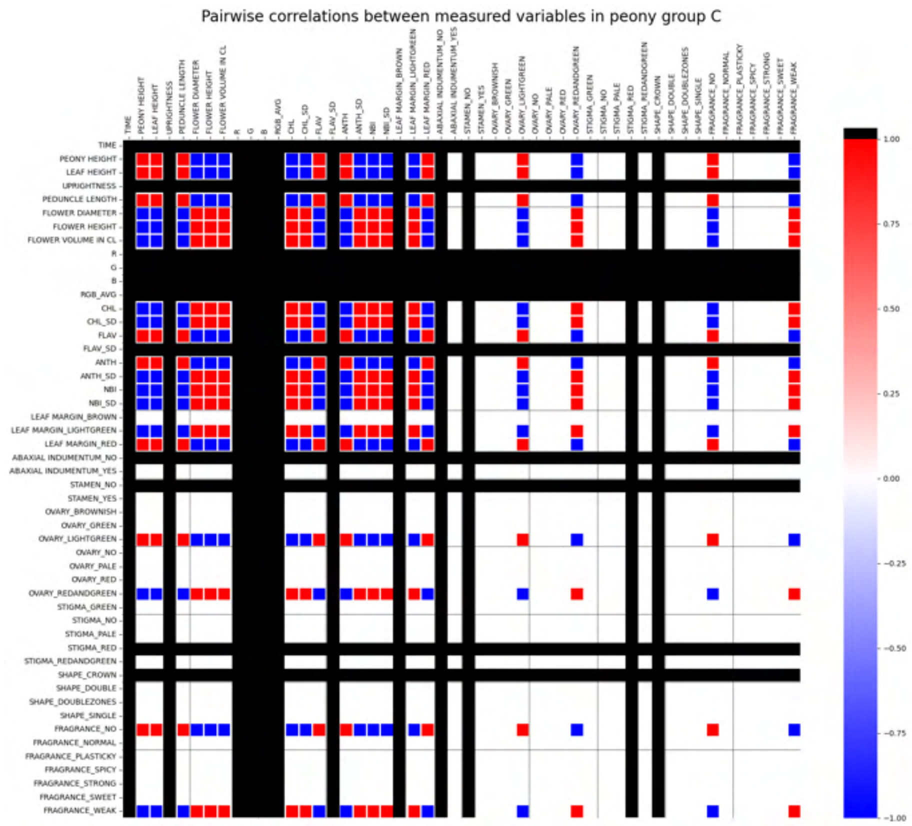


Figure 59: Heat map of correlations between variables in peony sample group C.

Below are photos of these two samples taken at the end of the flowering season (Fig. 60). After all, no significant differences can be seen between the carpels of the two samples, even though in the images earlier (Fig. 57), and in analysis the ovaries were clearly different. This is one of many cases in this work, where carpels of Chinese peonies present variation of features within the same plant.

(a) Sample 218

(b) Sample 252

Figure 60: Carpels of the peonies in group C after the petals were dropped.

Recognizing the variety

’Inspecteur Lavergne’ (Doriat, 1924) is one of the oldest red Chinese peonies in Finland. It has deep carmine red outer petals and a fluffy center. There is a little bit of white detail on the tips of the narrow center petals. Fragrance is very mild. ’Inspecteur Lavergne’ was sold in Finnish plant nurseries already in 1937, 1944 and 1954. [2, p. 194]

American Peony Society’s peony registry states the flowering time of ’Inspecteur Lavergne’ as early [48]. Both of these samples bloomed in the second out of four days of collecting peony samples. It is also a known feature for carpels of ’Inspecteur Lavergne’ to transform in to green and purple carpelodes [1, p. 88]. There is solid evidence to suspect these samples are true variety of ’Inspecteur Lavergne’.

Figure 61: Sample 252 - ’Inspecteur Lavergne’ blooming on the test field.

4.3.4 Group D - Assumed varieties 'Duchesse de Nemours' and 'Sarah Bernhardt'

236 (LUKE-135) 204 (LUKE-4515) 25 (LUKE-5050) 263 (LUKE-4620)

Figure 62: Images of peonies in group D.

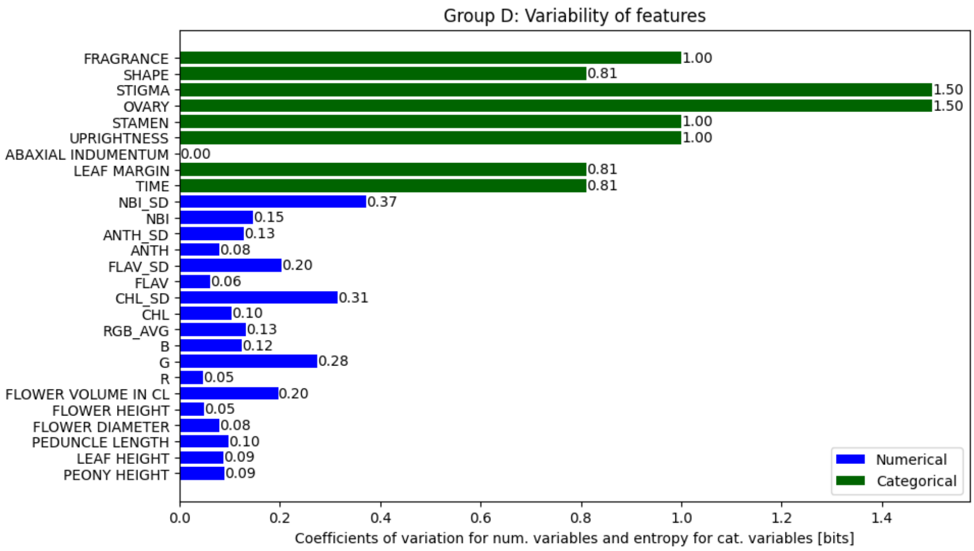


Figure 63: Variability of features in peony group D.

Group D consists of four samples (236, 204, 25 and 263). On a quick look, it seems there are two different varieties of Chinese peonies here, two each (Fig. 62). Based on genetic analysis, the two white samples, 236 and 204, are genetic duplicates. However, the genetic difference between the two pink samples (25 and 263) is roughly of the same magnitude as it is between the pink and the white samples. It is clear that all peonies do not represent the same variety. Therefore, this group differs greatly from the others. These white and pink samples are discussed separately below. They could have been split into their own sample groups, but as noticed earlier, groups of only two samples are not very meaningful for exploring the data of the samples' features.

Collectively as a group, there is great variance in measured variables (Fig. 63), and the heat map of feature correlations (Fig. 64) is probably of no significance in a group this diverse. Only categorical feature with identical values for all four samples is ABAXIAL INDUMENTUM. Scents are fairly similar with two values of STRONG and two NORMAL. Values for blooming TIME and UPRIGHTNESS differ by one at most (Fig. 24). Heights of the plants are fairly uniform across the group with sample 25 being slightly shorter and having smaller flowers than the others (Fig. 25).

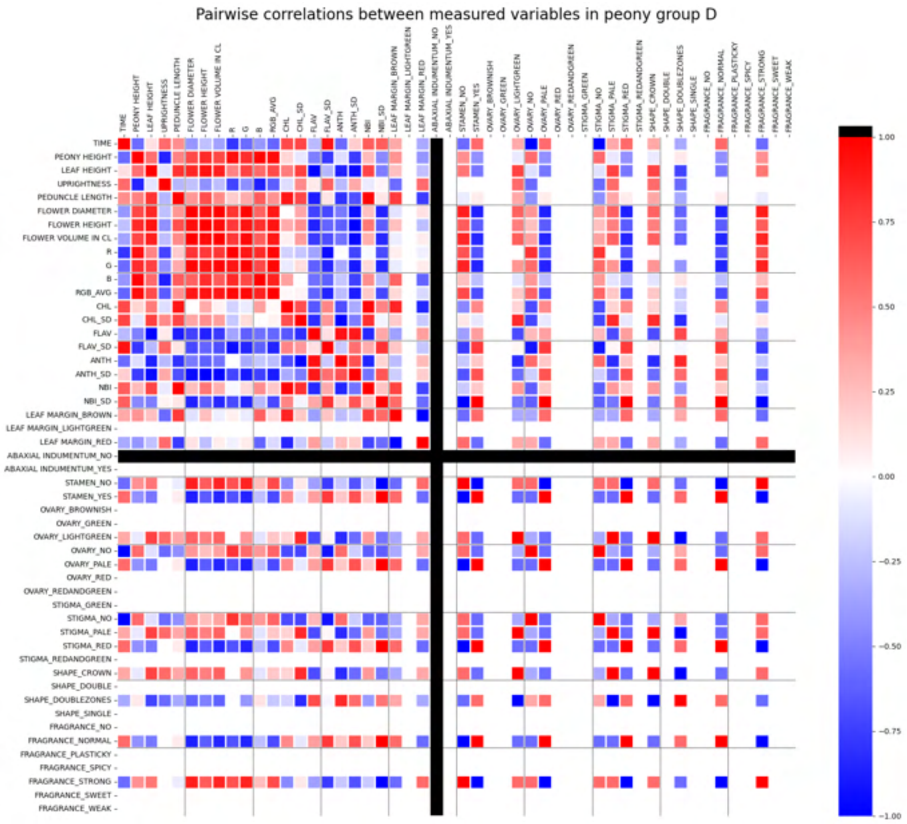


Figure 64: Heat map of correlations between measured and calculated variables in peony sample group D.

Recognizing the varieties

First discussing the genetically identical white samples 236 and 204. The peonies were among the tallest ones in the whole sample set, they were among the first peonies to bloom and both had their flowers lying close to the ground, sample 204 even more so. FRAGRANCE was STRONG for both samples. Neither had stamens, and sample 204 was stated to not have ovaries. Looking at the photos again closely shows, that sample 236 very barely had any to speak of.

Photographic evidence taken at the test field shows that in the same plant, some flowers on had developed carpels, while some had not. This makes the difference between the carpels in the examined flowers fairly irrelevant.

(a) Sample 204 without carpels.

(b) Sample 204 with carpels

Figure 65: Two photos of sample 204 after the bloom of first flowers. Both taken 8.7.2022.

'Duchesse de Nemours' (Calot, 1856) is described as a widely available old Chinese peony variety with crown shaped creamy white flowers. The large outer petals have notches in the middle of them. Carpels are absent or rudimentary. Scent is delicious and the foliage is attractive. [1, p. 82]

All these features match the notes made from these flowers. The notches are seen present in the outer petal of sample 236 (Fig. 62). 'Duchesse de Nemours' is stated as one of the peonies sold in Finnish nurseries by its name already in 1919. It is also typical for the flowers, which open with slight shade of green, to fade into pure white color. Scent is distinctively strong. [2, p. 163]

The pink samples (25 and 263), on the other hand, are more difficult to assess. On a quick look, they seem fairly similar with samples in duplicate group 2. Despite of the genetic differrence between these two samples, they have very similar morphological values recorded for both of them (Fig. 24). Both have stamens present surrounding PALE ovaries. Flowers are double with zones of different sized petals. A NORMAL scent with flowers requiring or benefitting from mechanical support.

The values are very similar to those of duplicate group 2. Group D and duplicate group 2 are in fact in the same broader branch of the genetic dendrogram (23). Even though there are other different peonies genetically closer to these pink peonies, it seems they do represent the same variety of 'Sarah Bernhardt' (Lemoine, 1906). Without actual reference samples, it is impossible to find clear distinctive differences.

'Sarah Bernhardt' is the most common peony in the world [35]. As was with group C earlier, it seems these old varieties might have some genetic variation to them, which is picked up by the genetic markers, but which doesn't affect the morphology in a distinctive way. All in all, these samples represent two of the most iconic peonies in the Finnish garden culture (Fig. 66).

(a) Sample 236 - 'Duchesse de Nemours'

(b) Sample 25 - 'Sarah Bernhardt'

Figure 66: 'Duchesse de Nemours' and 'Sarah Bernhardt' are fairly close genetically.

4.3.5 Group E - Assumed variety ’Festiva Maxima’

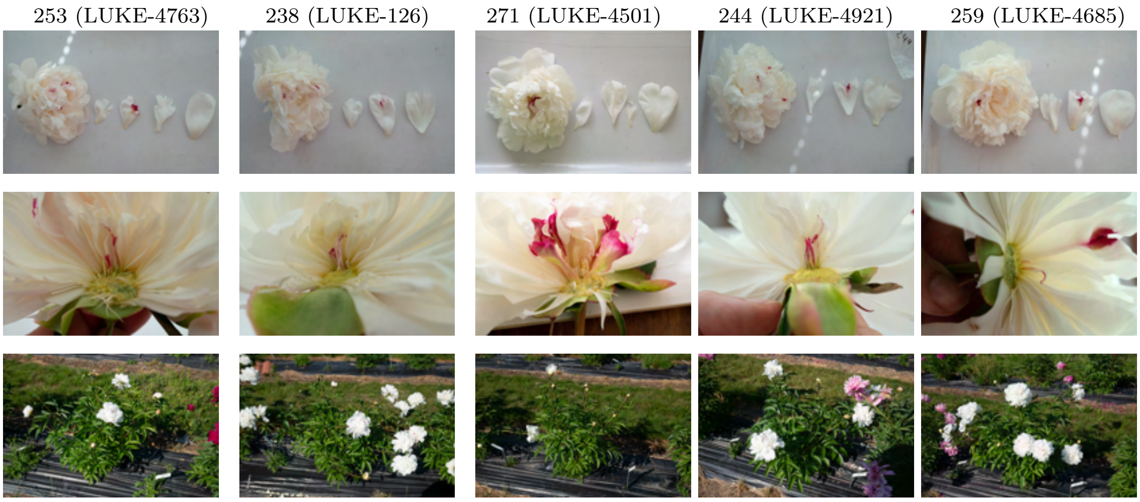


Figure 67: Images of peonies in group E.

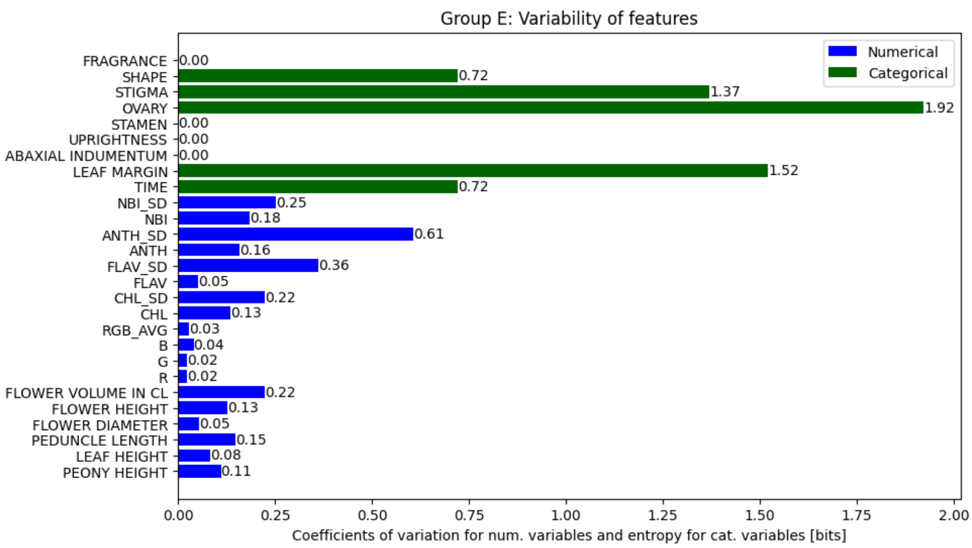


Figure 68: Variability of features in peony group E.

Group E consists of five white flowering samples (253, 238, 271, 244 and 259). Samples 253 and 238 are duplicates by the genetic analysis (Fig. 23). Other samples get more genetically distant from the identical ones, left to right in the sequence of photos above (Fig. 67).

Analysis of feature variability (Fig. 68) shows, that in this group categorical features with identical values are FRAGRANCE, STAMEN, UPRIGHTNESS and ABAXIAL INDUMENTUM. Variability in SHAPE is caused by sample 271 being categorized as CROWN shaped, while others were recorded as DOUBLE. OVARY and STIGMA had a lot of variability; values are a mix of RED, PALE, GREEN and NO (Fig. 24). Carpels of these samples were difficult to asses due to their small size and irregular forms, which is seen in photos above (Fig. 67). Based on visual analysis, sample 271 seems to be slightly different than the other samples.

Most of the numerical values also show less variance than what is the baseline of the whole sample set (Fig. 23). As is usual in these fairly small sample sets, presenting feature correlations in a heat map (Fig. 69) is mostly useful for seeing which values were present in the sample group.

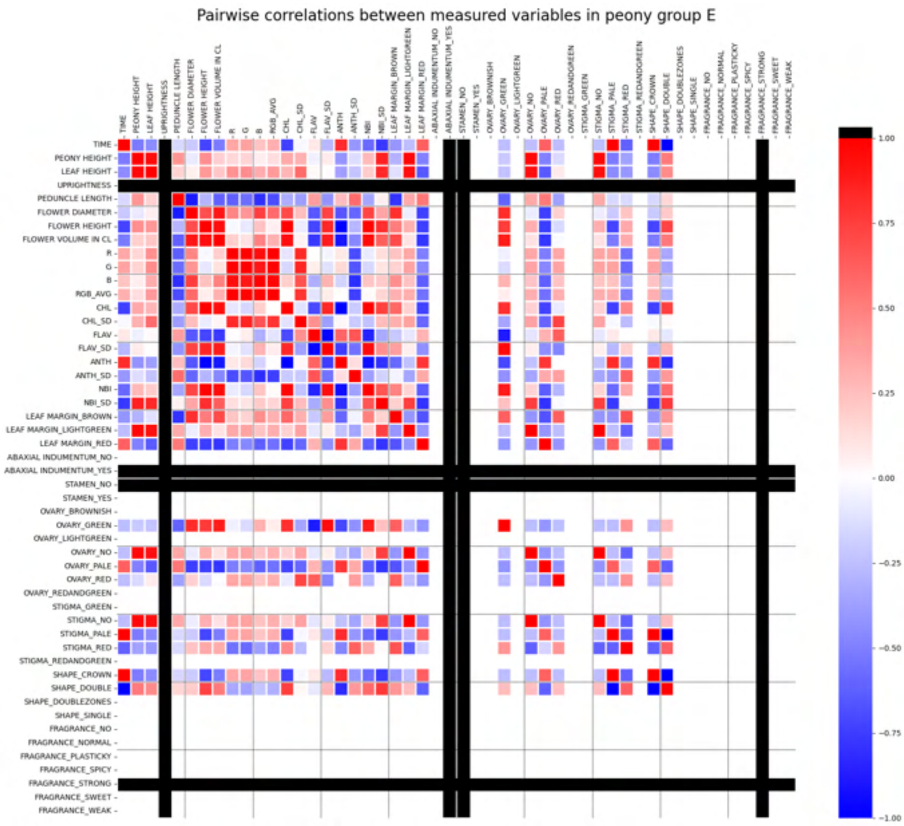


Figure 69: Heat map of correlations between measured and calculated variables in peony sample group E.

Recognizing the variety

There are many uniform features in this group of samples. Each sample has a strong fragrance, all require mechanical support to keep flowers upright and all had indumentum on abaxial leaf surfaces. All bloomed in the earlier half of blooming on the test field. Color is pure white on all samples. There are distinctive red color spots on the tips of petals in every sample, other than sample 271, where the transformed carpels are the only source of red color. Other samples also have red tips on the carpels, but the carpels are much smaller in size and visibility. However, in other peonies, there have been drastic differences in carpels within the flowers of the same peony (Fig. 65). Therefore, the difference is not necessarily a variety defining factor.

From the list of peonies sold in Ahtialan taimisto in 1939 [2, p. 142], only 'Festiva Maxima' (Miellez, 1851) matches these descriptions well. Although, it has to be noted that many other white peonies could have been labelled falsely as 'Festiva Maxima' [2, p. 164]. Other matching features are the early blooming time, good fragrance, prominent crimson red flakes on a few central petals and strong, but rather spreading stems [49].

Sample 259 was the one sample, for which no ovaries were noted to be present in the flower analysis (Fig. 24). As seen below, some of its flowers did still end up developing carpels (Fig. 70).

(a) Sample 259 - 8.7.2022

(b) Sample 259 - 18.8.2022

Figure 70: Two photos of sample 259 that show presence of carpels.

It seems that the varying types of flowers are carpels are seen in all these samples within group E. Below are the two main types of flowers that could be seen in all of these samples (Fig. 71). Fig. 71 (a) shows the most recognizable type of flowers with red dots scattered around the center. Fig. 71 (b) is the less developed type of flower, where the color red is still seen only in the carpels. This photo 71 (b) is from a sample, that had also produced a more recognizable flower (Fig. 67).

(a) Sample 244 - Typical flower of 'Festiva Maxima'

(b) Sample 238 - Flower on the field that doesn't show red spots on the petals.

Figure 71: Two looks of flowers present within same peonies of sample group E. - Assumed variety 'Festiva Maxima'

4.3.6 Group F - Assumed variety 'Karl Rosenfield'

26 (LUKE-5051) 223 (LUKE-4405) 34 (LUKE-5237 A) 202 (LUKE-4928)

Figure 72: Images of peonies in group F.

Sample group F is an extension to the earlier discussed duplicate group 3. In this group and the above photos (Fig. 72), sample 223 was chosen to represent the samples of duplicate group 3 in the analysis of this broader group. Referring to the genetic dendrogram (Fig. 23), samples 34 and 202 are genetically closest to the samples of duplicate group 3. Sample 26 is fairly similar looking than the other samples, even though there is quite a big of a difference genetics wise. Sample 270 (Fig. 73) was chosen not to be included in the analysis group as it is clearly of different flower shape than all the other samples in the same branch of the dendrogram.

(a) Sample 270 (b) Sample 270

Figure 73: Sample 270's flower form differed from the others greatly.

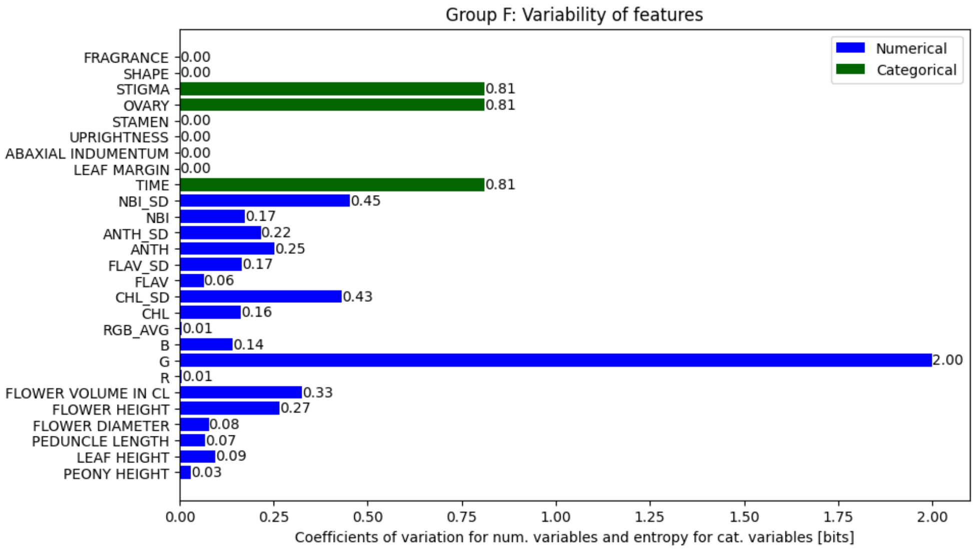


Figure 74: Variability of features in peony group F.

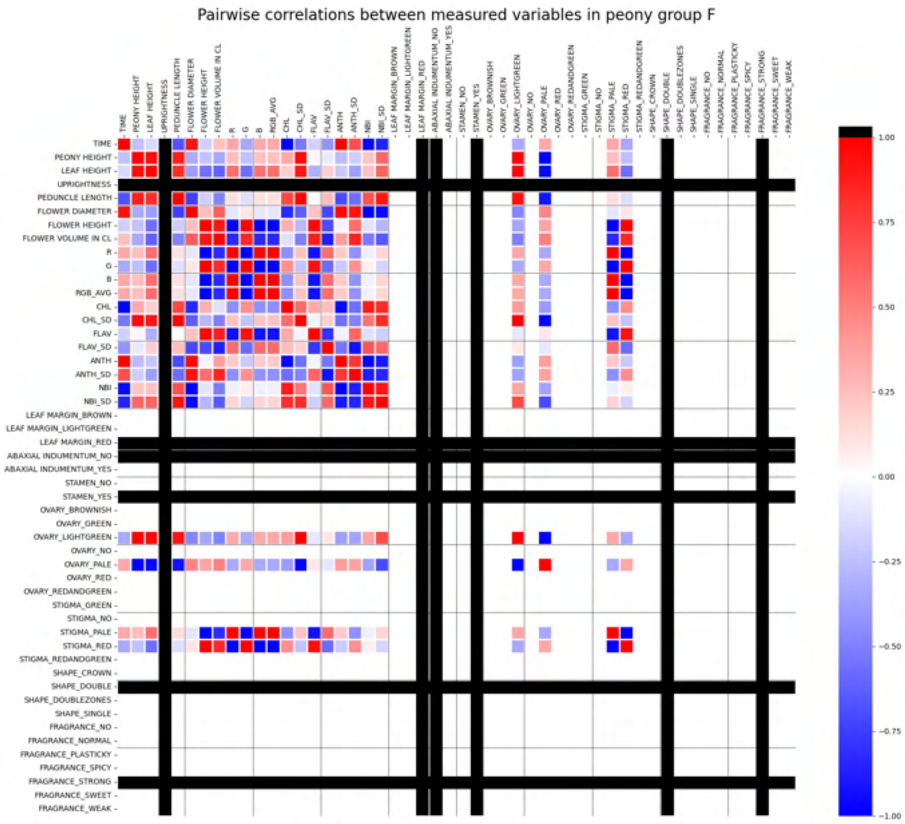


Figure 75: Heat map of correlations between measured and calculated variables in peony sample group F.

Looking at the variabilities of features (Fig. 74) shows that despite the slight differences in genetics, these peonies were very much a like each other. Only categorical variables with slight differences were STIGMA, OVARY and TIME. As was the case earlier with duplicate group 3 (Fig. 40), there is a large amount in variation of G color component, which is mostly due to the conversion from classified colors to components of color. Flower and height measurements are fairly uniform across the group. Again with a group this small, comparing feature correlations (Fig. 75) does not yield very useful results.

Recognizing the variety

In the scheme of the whole genetic dendrogram (Fig. 23), this group is very close to the other groups of fairly similar red flowering peonies in groups G and H. Notes about the samples in Duplicate group 3 still hold true for these slight genetically varied samples. There is no reason to count these samples as a different variety than those of duplicate group 3, which were determined to be representing the named variety known mainly as 'Karl Rosenfield' (Fig. 76).

Figure 76: Sample 34 - another assumed type of 'Karl Rosenfield' blooming on the test field.

4.3.7 Group G - Assumed varieties 'Felix Crousse' and 'Monsieur Martin Cahuzac'

246 (LUKE-4901) 241 (LUKE-4702 B) 268 (LUKE-4519)

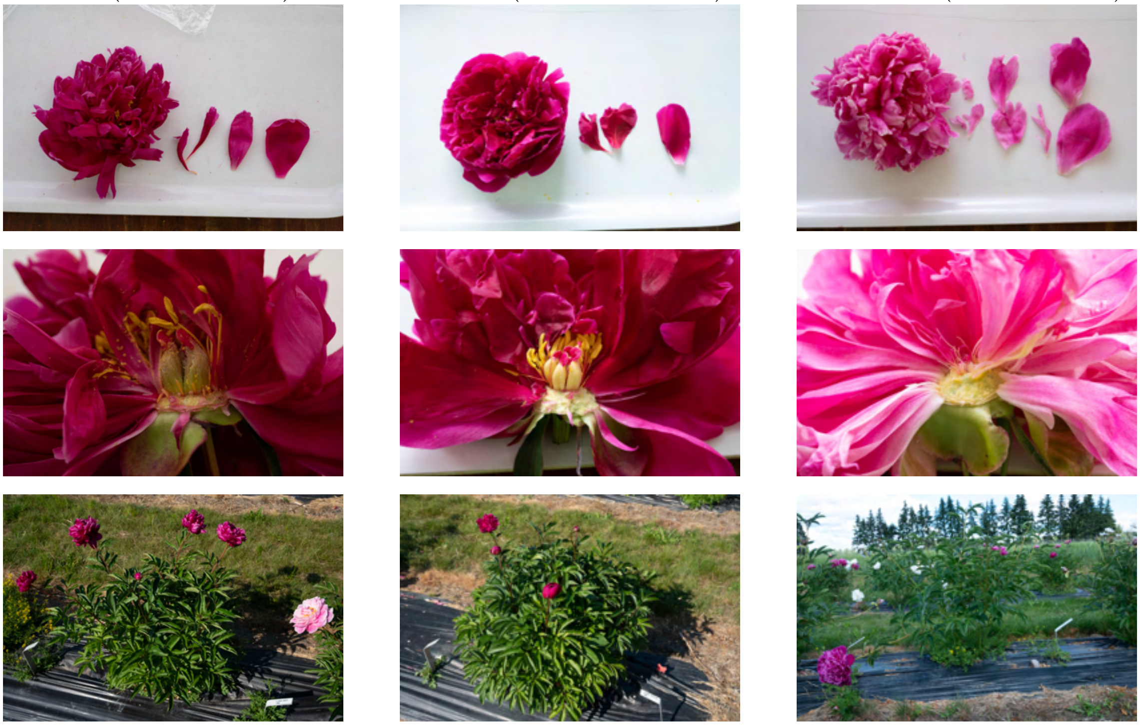


Figure 77: Images of group G.

Group G consists of samples 246, 241 and 268. It includes the earlier discussed duplicate group 4, which here is represented by sample 246, within itself (Fig. 23). Shade of sample 268 is visually clearly different from the other two samples (Fig. 77). Heat map of feature correlations (Fig. 79) also shows the large amount of different values the categorical values had received, despite the group only consisting of three samples.

The visual differences are backed up with the bar chart of variabilities (Fig. 78). Only common categorical values for all three samples are ABAXIAL INDUMENTUM (NO) and SHAPE (DOUBLE). Most variation is in the OVARY variable. The drastic differences in ovaries are also seen in the photos above (Fig. 77).

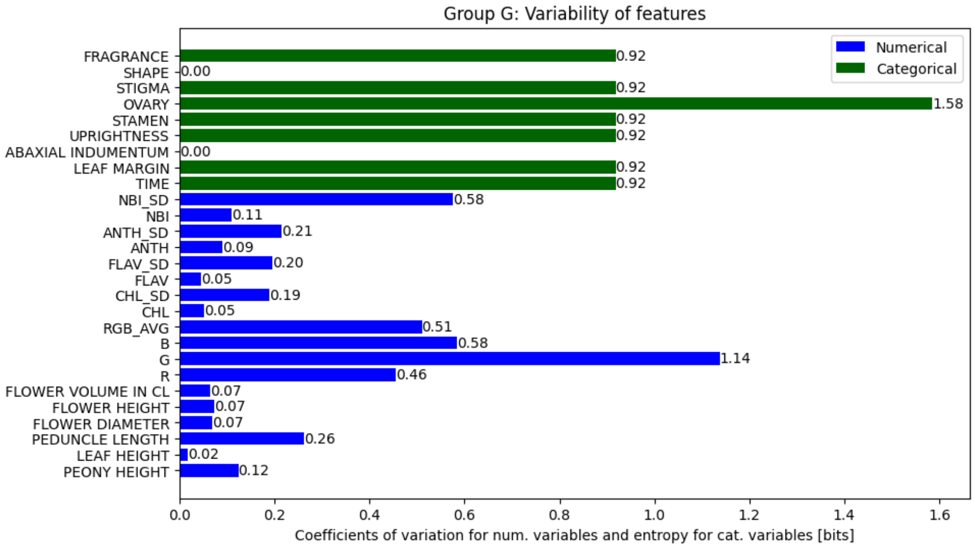


Figure 78: Variability of features in peony group G.

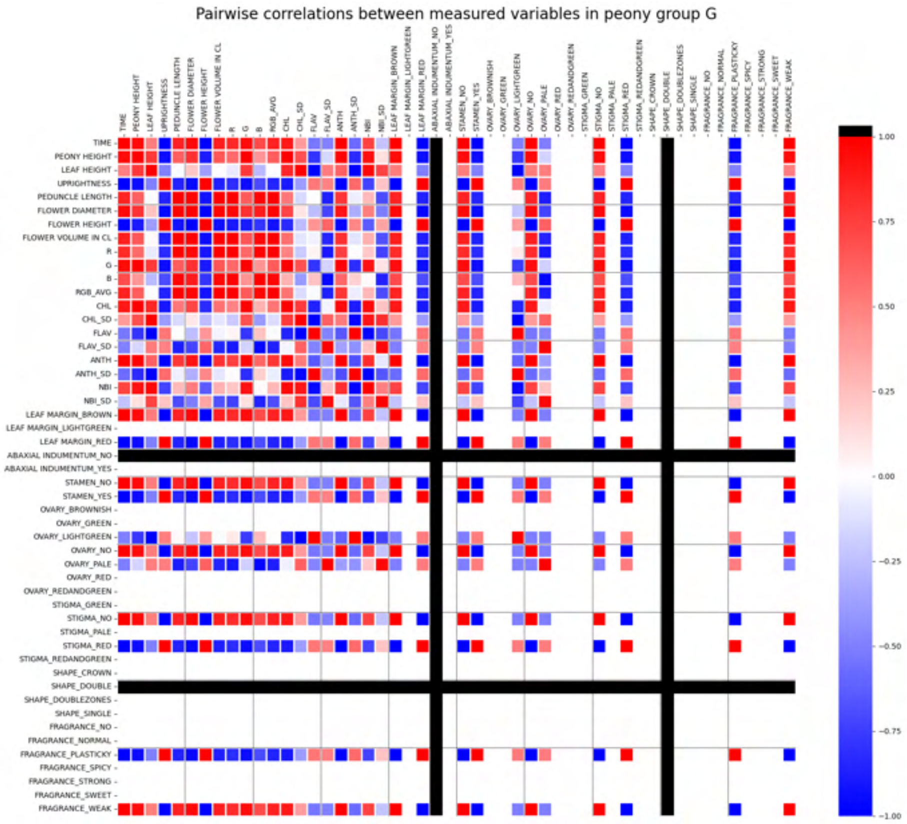


Figure 79: Heat map of correlations between measured and calculated variables in peony sample group G.

Recognizing the varieties

Sample 246 was already suggested the variety name of as 'Monsieur Martin Cahuzac' (Dessert, 1899) in the analysis of duplicate group 4 in section 4.2.4. Sample 241 differs only slightly by the shade of ovaries and the time of blooming. It is reasonable to assume it to be of same variety.

Sample 268, however, seems like a lone wolf here. It differs from the other two samples in nearly every way. On a quick look it might seem like the samples recognized as 'Sarah Bernhardt', but there are distinct differences. Sample 268 doesn't have stamens and neither does it have any other reproductive plant parts within the flower. Color is stronger, flower shape is DOUBLE and scent is WEAK, but pleasant. Time of blooming was fairly late (3 out of 4). There was no indumentum on abaxial leaf surfaces and the peony would greatly benefit from mechanical support. Unfortunately, sample 268 bloomed with only a few flowers.

There are numerous Chinese peony varieties that look a lot like this one. It could be roughly classified either as a pink or a red flower. The full double flower is seen in natural light in the image below (Fig. 80). 'Felix Crousse' (Crousse, 1881) fits close to the notes made from this sample. It is confirmed to have been sold in Finland for a long time [2, p. 142]. 'Felix Crousse' is decribed as one of the best red peonies, which has fairly weak stems and blooms in the late midseason [50]. Sulev Savisaar's book Pojeng states 'Felix Crousse' as a stamen-free variety [33, p. 82], which also matches the notes of this sample.

Figure 80: Sample 268, assumed variety 'Felix Crousse', blooming on the test field.

4.3.8 Group H - Assumed variety 'Maréchal MacMahon'

233 (LUKE-2247) | 262 (LUKE-4675) | 256 (LUKE-4712)

235 (LUKE-1903) | 229 (LUKE-3454) | 265 (LUKE-4618)

Figure 81: Images of group H. Sample 233 visually differs from all others.

Group H is a genetically diverse group of six samples, where samples 262 and 256 were genetic duplicates. They all are red flowering peonies (Fig. 81). Sample 234 (Fig. 82) is genetically close, but visually too different to be included in the group even though it is placed in the same branch of the genetic dendrogram (Fig. 23).

Figure 82: Sample 234 is genetically fairly close to the samples of group H, but it had a significantly different type of flower.

Sample 233 is genetically most different from the other samples in this group. Looking at the categorical values of these samples (Fig. 24) shows that sample 233 is an outlier that causes most of the differences in the chart of feature variabilities (Fig. 83). If the values wouldn't be calculated with sample 233 in the group, values for STAMEN, STIGMA, SHAPE, FRAGRANCE, TIME, LEAF MARGIN and ABAXIAL INDUMENTUM would be identical for all the other samples. This shows the connection between the quality of input and output of analysis. Due to this difference in samples within the group, many feature values are present in the heat map of feature correlations as well (Fig. 84). No exact analysis of samples of the same group can be achieved, when a similar, but critically different sample, is introduced in the sample set.

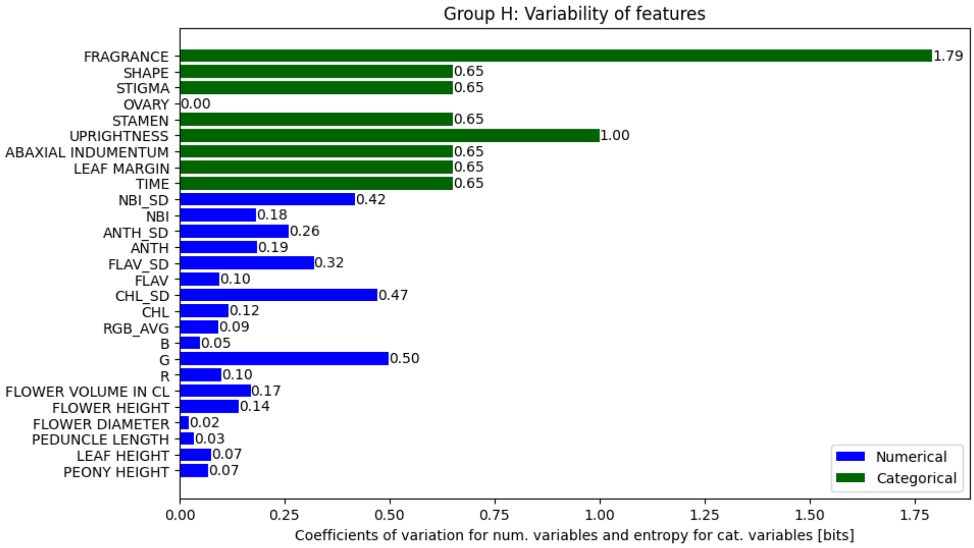


Figure 83: Variability of features in peony group H.

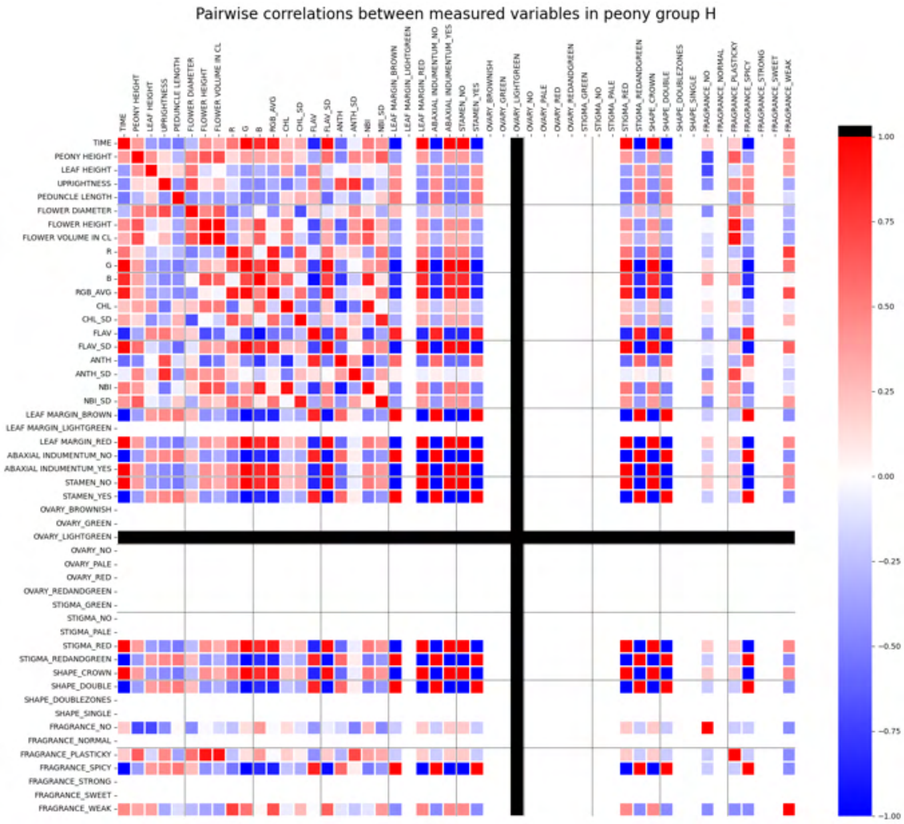


Figure 84: Heat map of correlations between measured and calculated variables in peony sample group H.

Recognizing the variety

The five most similar samples in this group share most measured categorical features (Fig. 24). None of the samples have any stamens. Ovaries are shaded light green with red stigmas on top. Every flower is of crown shape. Every sample bloomed fairly early in the flowering season (2 out of 4), all have red leaf margins and some indumentum present on abaxial leaf surfaces. Slight differences are seen for fragrances, which were recorded mostly as WEAK with single values of PLASTICKY (sample 235) and NO (sample 229). Some of the samples also had their flowers lying slightly more close to the ground than others. Numerical values show that the heights of the plants and sizes of the flowers were fairly uniform across the samples (Fig. 25). As a slight exception, sample 235 had a slightly larger flower measured.

A noteworthy Chinese peony variety, sold in Finland for over a century, that matches these descriptions fairly well is 'Maréchal MacMahon' (Calot, 1867). Flowers are round with an interesting fragrance. Originally, this variety was known as 'Augustin d'Hour'. The same variety is also sold as 'General MacMahon'. [2, p. 196]

'Augustin d'Hour' is described as a vigorous Chinese peony with bomb-shaped flowers. Deep magenta colored guard petals surround deeply divided inner petals. 'Augustin d'Hour' has no stamens and the carpels are green with stylus, which are flat and stained with magenta. Flowers pale towards silver heavily in the sunshine and have little fragrance. [1, p. 77]

These descriptions fit the notes and imagery of these samples very well. It is reasonable to assume that these samples are of true variety 'Maréchal MacMahon' (Fig. 85).

Figure 85: Sample 256 - freshly blooming flower of assumed variety 'Maréchal MacMahon'.

5 Conclusions

5.1 Summary of features for identifying Chinese peonies

Below is a short wrap-up of features measured in this work. They are described in means of how similar or different their values were for discussed sample groupings. Features that had mostly similar values for samples of the same variety, but different values for samples of different varieties, can be thought of as being most useful for variety recognition.

Blooming time

For most sample groups, the time of blooming differed by one tier at most. In the discussed duplicate groups, sample 231 was the only one to have a different measurement. The scale of measurement was not evenly spread, but still blooming time is confirmed to be a solid feature for variety recognition for peonies with identical growing conditions. The effect of environmental effects were not explored here.

Heights of peonies

Heights of peonies are often listed as a fairly important value in peony listings. In the analysis of peonies in this work, there was no case, where the height of the peonies would have been constant for the samples within a group. Practically all samples' heights were between 70 cm and 90 cm, and no group was clearly taller or shorter than the others. In groups E and F, the values for heights were the most constant, but there still was sample to sample differences.

Plant posture / Uprightness

There were distinctly some groups of peonies that stood well up without mechanical support. Duplicate group 3 was a good example of this, with no exceptions. Duplicate group 2 was a group, where all samples were on the opposite side of the scale with some flowers lying on the ground. For other samples, the measurements were very subjective and often depended on single stems being out of shape to alter the classification. Plant maturity, or the amount of flowers, seemed to have a great effect on the posture of stems as well. Plant form is a good feature for variety recognition, but it is mostly useful for varieties that can clearly hold their flowers upright or ones that tend to fall to the ground. Any inbetweeners are difficult to assess.

Peduncle length

Peduncle lengths didn't group with the sample groupings in any meaningful way. Lengths were sometimes difficult to measure due to irregularities in the top-most leaflets close to the flowers. Even though the values for each sample were an average of three measurements, the differences in values within duplicate group was often tens of percents.

Flower size

The calculated flower volumes did show some connection with the sample groupings. Some varieties did have distinctively smaller flowers, group F is a good example of this. The size of the flowers did sometimes vary greatly, especially with the larger flowering varieties. Duplicate group 2 showed some flowers being nearly double the size of others within the same group. Less mature plants also presented smaller flowers.

Flower shape

The sample set of this work was fairly homogeneous in terms of the shapes of the flowers. Nearly all samples were of double or crown type. Sometimes the crown shape was not very well present in the specific flowers chosen for analysis, as the flowers would have needed to develop to their full extent on the field.

The classification of double flowers containing zones of different sized petals did not seem very useful in the end. Most of the samples that separated from the group only by being of this shape value, usually were otherwise mostly identical to the other samples within the group.

Petal color / artificial luminance values (RGB)

As is fairly obvious, the samples within the same variety groupings were mostly very similar in terms of flower color as well. Presenting the color as a synthetic value of luminance showed very little variation for samples within the same variety, even if they were originally assigned to a slightly different color group using the RHS charts. The method of first evaluating the colors with reference color sheets and then converting the values neglected the effects of environmental lighting completely. However, breaking down the artificial RGB value of the color to separate components did not prove to be very useful.

Polyphenolic compounds in leaves (Dualex measurements)

Generally, duplicate groups of samples had less variance to polyphenolic compounds than what was present at the scale of the whole data set. The amounts of deviation per feature was always fairly high. As many leaves were measured per peony, there was usually a lot more difference within the sample as for the averages between samples. These measurements clearly showed differences in measurements within the peonies, which might prove very useful for something else than variety recognition.

Leaf margin color

Leaf margin color was a very subjective feature to measure. At the time of making measurements, recording this value felt to be one of the most difficult ones. Looking at the broad scale of the whole sample set, it seems like the samples with red and strong pink flowers usually also had red leaf margins. For flowers with other colors, the assigned color values don't seem to correlate with variety groupings.

Indumentum on abaxial leaf surfaces

Indumentum on abaxial leaf surfaces was one of the categorical features that received identical values usually for all samples within the group, or at least for those with the closest genetic relationship. As stated earlier(section 3.2), indumentum has been used as a means of recognition between different species of peonies. This work confirms that the presence of indumentum seems to be connected to the varieties within Chinese peonies as well.

Values were recorded by feeling the leaves with bare hands. A deeper look at the types of the types of abaxial leaf indumentum in Chinese peony varieties might be an interesting thing to focus on for future tasks in variety recognition.

Reproductive plant parts

The reproductive plant parts were some of the best indicators in terms of variety recognition. However, as they are not usually present for the viewer to see, these features are rarely listed in variety descriptions. Many of the features considering the reproductive plant parts were prone to natural variation, and often different forms were seen in different flowers within the same sample plant.

In duplicate groups of samples, the recorded colors of ovaries and stigmas were often the same or very similar to each other. It was not uncommon in some varieties for the carpels in seldom flowers to be completely missing or at least partly transformed into petals (carpelodes). The classifications of types and colors of ovaries and carpels altogether would be better done inspecting multiple flowers from a single peony sample to reduce the effects of natural variation of the flowers.

Some carpels had short indumentum on the surfaces and some were glabrous. This feature was not explored in this work, although it might have been an interesting one to look at.

Stamens were the reproductive plant part least prone to variation within the groups of genetically close samples. It was a binary variable in the sense that for all samples the presence or absence of stamens was always clear to define. There were no exceptions in stamens for peonies that were regarded to be of same variety. For some flowers, the stamens were more easily visible than for others, but breaking the flowers apart always showed the binary nature of this feature. In every part of the dendrogram, where there were differences in stamens, the samples in question were clearly not of the same variety.

Fragrance

Fragrance was one of the most difficult features to assess. The most clear types of fragrance, strong and plasticky fragrances separated the samples into discrete groupings rather well. For someone not familiar with the types of scents in peonies, finding descriptions for the fragrances is definitely difficult. The weaker scents and types of scents showed more variance, which probably was partly due to actual scent differences in the peonies, and partly due to the challenges in smelling the scents one after another. The differences in fragrances within the groups of samples were never of great magnitude, but relying on a single sample to assess the fragrance of the whole variety does not seem like a fool-proof method.

5.2 Summary of the recognized Chinese peony varieties

All these Chinese peony varieties play a significant part in the history of Finnish garden culture. As stated earlier, no actual named reference varieties were available at the test field for variety recognition. All assumptions of varieties were based off of literature and online sources. All prominent varieties were discussed separately earlier in their own subsections (section 4). The varieties are also listed below. Each of them is an essential part in Finnish peony history and worth of considering to store in a gene bank.

- Duplicate group 1, Group B - 'Edulis Superba'
- Duplicate group 2, Group D - 'Sarah Bernhardt'
- Duplicate group 3, Group F - 'Karl Rosenfield'
- Duplicate group 4, Group G - 'Monsieur Martin Cahuzac'
- Group A, samples 232 and 225 - 'Mons. Jules Elie'
- Group C - 'Inspecteur Lavergne'
- Group D - 'Duchesse de Nemours', 'Sarah Bernhardt'
- Group E - 'Festiva Maxima'
- Group G - 'Monsieur Martin Cahuzac', sample 268 'Felix Crousse'
- Group H - 'Maréchal MacMahon'

Plant sample material was additionally photographed a month after the time of blooming focusing on the flower bases. The amount of material analyzed was narrowed down to the bloom time to not overflow on the amount of work, and for the assessment of features to be focused on measurements, that can be taken, when peonies are at their prime. All the measurements, Python code used for analysis, and all additional photography of the samples are listed in the online repository for future referencing and exploration (Appendix A).

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Appendix A - Availability of materials and code

Data collected from measurements at the field is presented both in raw and cleaned forms in this online repository: https://github.com/anzakanza/peonies

Data collected in LUKE's Dear old peonies study or personal details related to this data are not shared alongside this thesis work. Genetic data used in this work is property of Luonnonvarakeskus and it is not shared in this work's repository. The genetic data is presented along the other materials of this work only in the processed (PCA) form. The PCA method and code for creating a genetic dendrogram is presented in the repository with placeholder genetic code. Peony samples are referred to only as sample numbers and LUKE codes. Personal details related to the origin of the samples are not shared.

Python code used in analysis and plotting of data is available in the same repository.

Photographic extra materials of samples mentioned in this work are also available in the same repository.

Appendix B - Photographic documentation

Collection of photographic materials was a great part of this thesis work to assist later analysis of the peony samples outside their short time of prime bloom. Below are listed three similar types of photos for every sample. Many of these photos were already presented above in analysing the samples, but all are listed here for a collective listing. Above the three pictures are stated the sample number with the corresponding LUKE code and the date of collecting the flower sample in its prime bloom.

Multiple additional photos were taken of every sample. These additional photos were taken at different times and of varying perspectives so they are not quite as useful in evaluating the samples. All photos and other materials are available in higher resolutions in the online repository of this thesis work.

#25 (LUKE-5050) | 30.6.2022

#26 (LUKE-5051) | 30.6.2022

#27 (LUKE-5052) | 30.6.2022

#30 (LUKE-4901) | 30.6.2022

#32 (LUKE-3425) | 30.6.2022

#33 (LUKE-5237 B) | 30.6.2022

#34 (LUKE-5237 A) | 30.6.2022

#36 (LUKE-5186) | 30.6.2022

#37 (LUKE-5239) | 30.6.2022

#202 (LUKE-4928) | 30.6.2022

#204 (LUKE-4515) | 30.6.2022

#214 (LUKE-70) | 6.7.2022

#217 (LUKE-4503) | 30.6.2022

#218 (LUKE-4500) | 30.6.2022

#219 (LUKE-4497) | 30.6.2022

#220 (LUKE-4481) | 6.7.2022

#221 (LUKE-4459) | 30.6.2022

#222 (LUKE-4415) | 30.6.2022

#223 (LUKE-4405) | 30.6.2022

#224 (LUKE-4393) | 30.6.2022

#225 (LUKE-4384) | 30.6.2022

#226 (LUKE-42) | 30.6.2022

#227 (LUKE-4047) | 30.6.2022

#228 (LUKE-3463) | 30.6.2022

#229 (LUKE-3454) | 30.6.2022

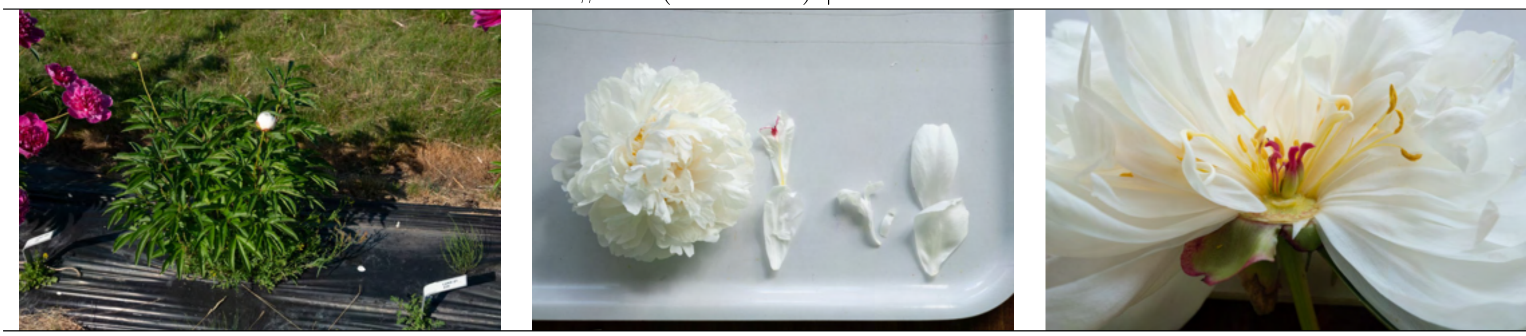
#230 (LUKE-3447) | 30.6.2022

#231 (LUKE-288) | 6.7.2022

#232 (LUKE-2816) | 30.6.2022

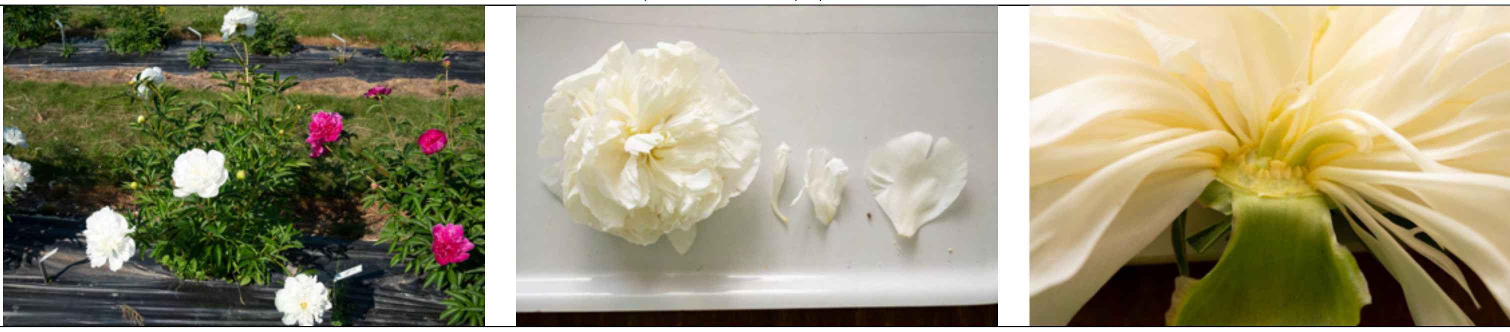
#233 (LUKE-2247) | 30.6.2022

#234 (LUKE-21) | 30.6.2022



#235 (LUKE-1903) | 30.6.2022

#236 (LUKE-135) | 30.6.2022



#237 (LUKE-13) | 30.6.2022

#238 (LUKE-126) | 30.6.2022

#239 (LUKE-1228) | 30.6.2022

#241 (LUKE-4702 B) | 30.6.2022

#243 (LUKE-528) | 30.6.2022

#244 (LUKE-4921) | 30.6.2022

#245 (LUKE-4903) | 30.6.2022

#246 (LUKE-4901) | 30.6.2022

#248 (LUKE-4861) | 30.6.2022

#249 (LUKE-4831) | 30.6.2022

#250 (LUKE-4830) | 30.6.2022

#251 (LUKE-4828) | 6.7.2022

#252 (LUKE-4764) | 30.6.2022

#253 (LUKE-4763) | 30.6.2022

#254 (LUKE-4762) | 30.6.2022

#255 (LUKE-4752) | 30.6.2022

#256 (LUKE-4712) | 30.6.2022

#259 (LUKE-4685) | 30.6.2022

#260 (LUKE-4684) | 30.6.2022

#261 (LUKE-4682) | 6.7.2022

#262 (LUKE-4675) | 30.6.2022

#263 (LUKE-4620) | 30.6.2022

#264 (LUKE-4619) | 6.7.2022

#265 (LUKE-4618) | 30.6.2022

#266 (LUKE-4583) | 30.6.2022

#267 (LUKE-4566) | 30.6.2022

#268 (LUKE-4519) | 6.7.2022

#269 (LUKE-4506) | 30.6.2022

#270 (LUKE-4504) | 30.6.2022

#271 (LUKE-4501) | 30.6.2022