# Self-learning software to identify slipper orchids from pictures of flowers to simplify identification for customs officers



**Figure 1 *Brachypetalum bellatulum* [1]**

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# Abstract

Slipper orchids are very popular ornamentals among hobbyists and therefore highly endangered due to over collecting in the wild. To prevent them from going extinct all slipper orchids were placed on the international CITES list, which means that permits are required for trade all over the world. Some slipper orchid species are more endangered than others. This is reflected by different legislation as some species are placed on CITES Appendix 1 (highest level of protection) whereas others are placed on Appendix 2 (lower level of protection). Flowers of slipper orchids can be classified by characteristics like shape of the petals, the absence or presence of wards on the petals and the colour of the lip. During this internship the concept of classifying slipper orchids to section level from pictures was tested. To test the possibilities of picture-based classification, pictures of well-identified orchids were collected. From these, different sets were created, one for training Artificial Neural Networks (ANNs) and one for testing them. ANNs are computer models based on the nervous system of animals. ANNs can be trained in pattern recognition. In this project the ANNs were trained in recognition patterns in colour intensities of 50 vertical bins and 25 horizontal bins. During a training, connections between different "neurons" will be created. These connections together form a network, which can be used in pattern recognition. After training, the created network was tested. This means that the network received a new picture. This picture was translated to the colour intensities of 50 vertical bins and 25 horizontal bins. These intensities were used to find a pattern the network already knows. When the network had found a pattern, the sections that contains this pattern was saved as the output of the classification.

The results show that some sections were harder to classify than others. Adding new pictures to the training set could improve the classification, but could also worsen the classification, depending on the quality of the new pictures and how well the new networks were trained. In general, better-trained networks, trained with more than a single picture, were able to correctly classify slipper orchid flowers, showing that visual recognition software can be used for identification of these orchids.

To make the classification software available to the outside world, a first concept of a website was developed. Users can upload a picture of a slipper orchid flower to the website. The website then runs the classification software using a pre-trained ANN. The result of this classification is then translated to a human readable result. This result is returned to the website. With this application, customs officers can check whether the permits of imported slipper orchids are correct. As compared to classification using a book, the website improves the identification by laymen which will help customs officers to prevent illegal trade of these orchids.

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# Introduction

## Illegal trade in endangered orchids

There are thousands of different orchid species known all over the world [2]. None of these are allowed to be imported into the Netherlands without CITES permits. Since 1973 orchids are primarily protected by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), which is signed by over 120 nations [3-4]. Despite this convention many orchids are traded illegally. To trade species that are protected by CITES, a licence or certificate is required.

It is difficult to monitor the illegal trade of orchids because some orchids look very similar to non-protected plants and so accurate identification can be very difficult. To improve identification, software that can identify orchids from pictures of tubers, leaves or flowers could be vital. This software would in particular aid customs officers and employees of nature conservation organizations involved in confiscating illegally-traded material. During this project, the focus was on slipper orchids and orchids from which *salep* is produced.

## Slipper orchids

In Europe and Asia the slipper orchids (Cypripedioideae) are widely distributed between sea level up to 2000 m altitude. They prefer to live in calcareous environments and are found in deciduous or mixed deciduous and coniferous woods. They grow best in light to deep shade. The slipper orchid is an herbaceous perennial plant species that has a long lifespan. It can grow up to 60 cm and each season the slipper orchid will produce new growths. Each stem of the orchid can contain 3 to 4 leaves that often have upwardly curved sides. The flower stalk can be one-flowered or two-flowered with leaf-like bracts. The sepals and petals are rarely green but commonly brightly coloured. These sepals and petals are also often twisted [5]. Slipper orchids are highly desired ornamentals, wich is why they were placed on CITES Appendices, which means they are protected from unregulated export. Different levels of protection exist: the genera *Paphiopedilum* and *Phragmipedilum* and the species *Aerangis ellisii, Dendrobium cruentum, Laelia jongheana, Laelia lobata, Peristeria elata* and *Renanthera imschootiana* are placed on Appendix I (very strict control in trade) whereas all other species of ORCHIDACEAE are placed on Appendix II (less strict control in trade) [6].

## *Salep* orchids

Ground orchid bulbs of the Orchidoideae, also known as *salep,* are very popular in Turkey and adjacent countries in central Asia. They are used to produce ice cream in summer and hot drinks during winter. *Salep* is also used as medicine. In the early 1990s the trade of *salep* increased strongly. Official statistics from the Turkish State Institute of Statistics shows that the export between 1995 and 1999 was 282.000 kg annually. To achieve this amount of *salep* 9.825.000 – 19.650.000 bulbs are required. It is unknown if this information is related to pure *salep*, substitutes or mixtures. However, as this harvesting is unsustainable, laws have been established to protect these orchids. In Turkey there are three laws that protect them: the first law is the Turkish Forest Law, which regulates the use of non-wood forest products. In short, this law states that it is forbidden to collect and remove any form of forest vegetation. The second law, the Turkish Law of Natural Parks, states that "The production of forest products, hunting and disturbing the natural balance is prohibited." Since collecting *salep* is classified as production of forest products, it is prohibited in all protected areas. The final law in Turkey is The Regulation on Collection, Production and

Export of Bulbs of Wildflowers. As the title of this law suggests, this law regulates the production and the export of bulbs, roots and tubers of flowers. It also defines a list with species that may not be taken away from the wild for export [7]. The exact ingredients in *salep* cannot be identified without molecular identification tools, which makes it difficult to enforce these laws.

## How a web application can improve control in illegal orchid trade

To make it easier to follow the trade routes of orchid smuggling, a web application that can identify illegally traded orchids is desired. This application could be used on laptops or desktops as well as mobile devices by taking pictures of flowers, leaves or underground tubers and uploading the pictures to a website. A simple flowchart of the application is shown in figure 2. In this project the focus was on creating the website and integrating the identification application for pictures taken of flowers of slipper orchids. This application is currently under development at Naturalis.
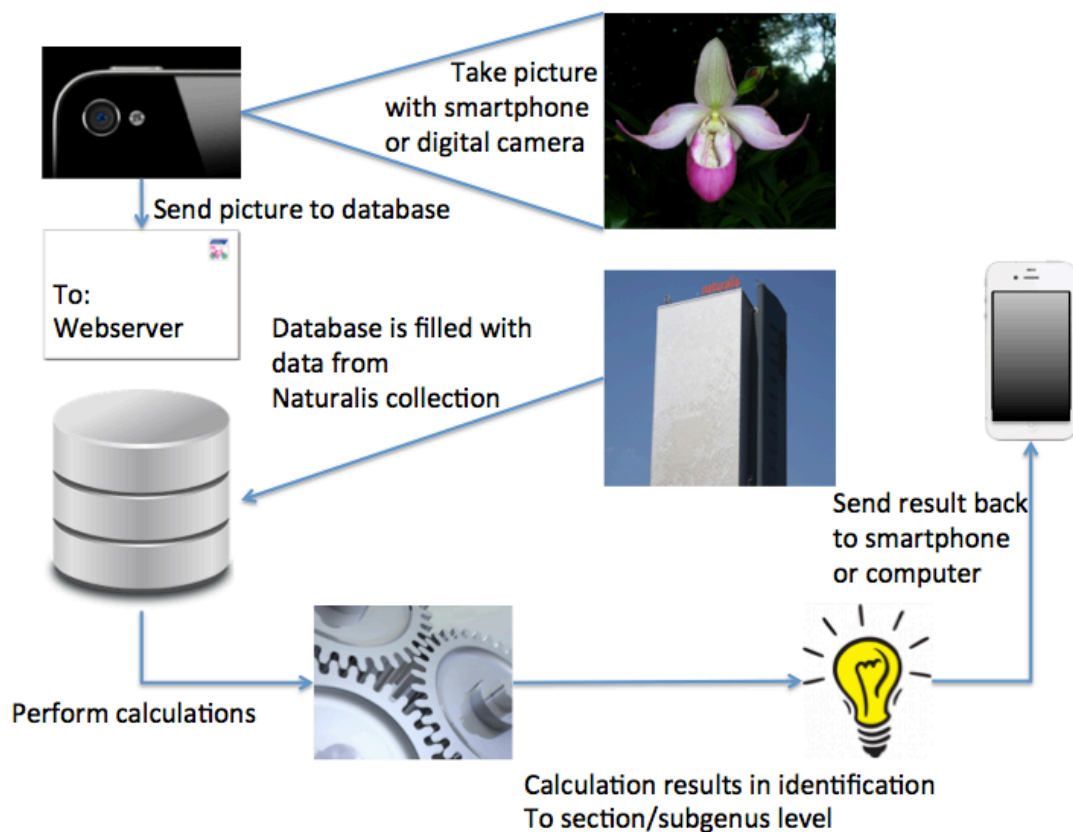


**Figure 2 A simple flowchart of the application made during this project. Resources of the pictures: [8-15]**

## Comparable software

There is software available that can identify a person using face recognition, for example the software KeyLemon [16]. This software could be used to unlock a computer.
Essentially the software takes a picture or series of pictures of your face. When it takes a series of pictures it is almost always required to move your head up and down and / or left and right. The software saves this picture or pictures. When you use the software to unlock your computer the software takes a picture or series of pictures of your face and compares this with the saved picture(s). If it finds a match you will be logged-in to your account. The

existence of this kind of software demonstrates that it is possible to identify objects that look very similar to each other, such as two different persons. If this is possible, it would also be possible to identify orchids to section level. All sections have some very specific characteristics that are unique to that section.

Another example of comparable software is LeafSnap [17]. LeafSnap is an iPhone and android application that allows the user to take a picture of a leaf. After taking a picture the software turns the picture in a way that it can recognize the shape. The shape of the leaf will be used to create a list of possible trees.

These applications differ from the pipeline that was developing during this internship in several aspects. First of all, KeyLemon is made to recognize a human face and LeafSnap is made to recognize different leaves. The pipeline that was developed during this internship focused on slipper orchid flowers and *salep* orchid tubers. Secondly the pipeline will be available on a website, while the comparable software needs to be installed on a local machine (e.g. a computer or a smartphone). This makes the pipeline usable from different platforms. The comparable applications are specific for smartphones or computers, and also to the Operating System (OS) of the used device.

## Artificial Neural Networks

Artificial Neural Networks (ANNs) are computational models based on the animal nervous system. They are capable of pattern recognition. To train a ANN, the pictures in the train data were translated to the colour intensities of Red, Blue and Green (RBG) for 50 vertical bins and 25 horizontal bins. These colour intensities were used to create connections between different "neurons". These connections together form a network. A part of the training was coincidence. Coincidence caused different connections between networks. This may result in different classifications between two networks. Figure 3 shows a schematic representation of an ANN. In this study, the inputs were the colour intensities. In the hidden layer the network search for a known pattern. The outputs were seven numbers that represents the seven different sections.

To test the created network, a new picture was load into the network. This picture was also translated to the colour intensities of RBG for 50 vertical bins and 25 horizontal bins. The network used its connections to search a pattern in the data of the new picture that the network already knows. Because the network was trained on recognizing patterns of seven sections of the slipper orchid, the output will be a list with seven numbers. These numbers corresponds with the seven sections. The seven sections were sorted from Z to A. the index of the positive number is the index of the section.
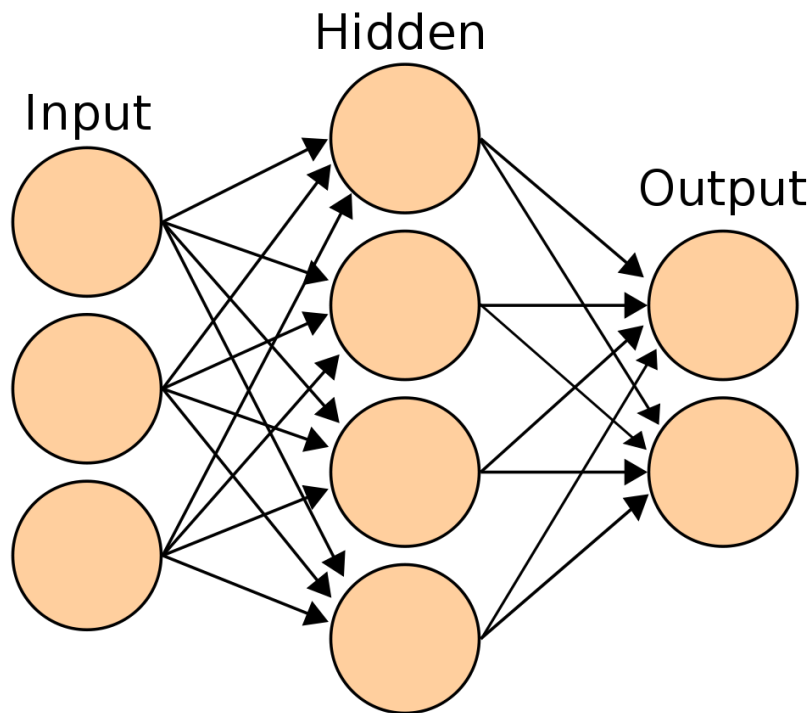
**Figure 3 Schematic representation of an Artificial Neural Network [18]**

## Goal of this internship

The goal of this internship was to demonstrate that it is possible to classify slipper orchid flowers from pictures. Once the classification software works sufficiently accurate, it will be available online. Customs officers can then use this software to check whether accompanying permits are correct when confiscating material. If this control is simplified, it will help prevent illegal trade in slipper orchids, which will prevent them from going extinct in the wild.

# Materials and Methods

## Website

During this internship a website was developed. Users of this website can upload a picture to the server. On the server the software will classify the orchid on the picture to section level. The processes behind this website, like clicking on a button, were written in Python 2.7 using the Django package. The layouts of the webpages were written in HTML, using CSS style sheets. There are two versions of every HTML file, one for computers and one for mobile devices. The different CSS style sheets, HTML files and python scripts can be found in appendices 1.2, 1.3 and 1.6. To make the website usable, a well-trained Artificial Neural Network (ANN) is required. To train this network, pictures of slipper orchid flowers were needed. These pictures were saved on a private shared Flickr account on https://www.flickr.com/photos/113733456@N06/, to make the pictures accessible to everyone who needs them.

## Flickr

To store the pictures in a safe place where they are accessible to whoever needs them, a shared Flickr account was created. Flickr is a website for saving and sharing pictures. Because the flower pictures are from a private collection of David Roberts, it is not allowed to freely share the pictures of the flowers, so the settings of the Flickr account were set to private. This means that only persons with the account name and password can access the pictures.

On Flickr it is possible to add metadata tags to the pictures. These tags were used later in the preparation process to save the pictures in the correct directory. To download the pictures and the metadata via the command line, a python script written by Hugo Haas, Offlickr.py, was modified and used (see appendix 1.5.4) [19].

## Training

### Preparation

Before training of the ANNs is possible, a preparation step is needed. First of all, pictures of the *salep* orchid tubers and the tubers of the look-a-likes were required. So pictures of *salep* orchid tubers and tubers of look-a-likes were taken at the Sylvius lab. It is required that the orientation is the same for all pictures. For instance, if the first picture of a tuber with appendices has the appendices on the right, all other tubers with appendices must have the appendices on the right as well. The user has to use the same orientation as the trainer. The background has to be one colour, like white or black, and this colour must be the same for every picture. The last requirement is that there is only one tuber on the picture.

The second step in this process is to download the pictures and metadata and search for the tags in the metadata. An example of the metadata can be found in supplementary 1.1. The blue square indicates the location of the tags. The next step is to convert the pictures from .jpg- to .png-format. This is needed for the training scripts, which work only with .png files. Finally the pictures will be placed into the correct directory using the tags. The tuber pictures were divided by shape and look-a-like or not, which resulted in six directories. Round, Spur and Oblong for the different *salep* orchid tubers, LRound, LSpur and LOblong for the different look-a-like tubers. The slipper orchid flowers were divided by section and within each section the pictures were divided by species. A section is a taxonomic level below a genus but above a species. Sections were created to obtain a better

overview of species rich genera. Species in he same section share a common ancestor. In this project the classification of Chochai, who carried out molecular phylogenetic research to come up with an evolutionary based list of sections, is used [20]. Some sections contain many species, such as *Barbata* and *Paphiopedilum*. Other sections just contain a few species, such as *Pardalopetalum* and *Cochlopetalum*.

After separating the pictures of the tubers from the flowers, the pictures of the tubers will be segmented. This means that the background is made entirely white and the tuber is cut out of the picture. Figure S-6 shows a picture before and after segmentating. It was not necessary to segmentate the flower pictures, because these pictures were already segmented.

## Slipper orchids

A total of 5 genera within the slipper orchids exist. The genera are *Cypripedium, Mexipedium Paphiopedilum, Phragmipedium* and *Selenipedium*. Due to time constraints, only the genus *Paphiopedilum* was used in this project. The sections of this genus are *Barbata, Brachypetalum, Cochlopetalum, Coryopedilmu, Paphiopedilum, Pardalopetalum* and *Parvisepalum*, which are based on molecular phylogenetic research [20]. The ANNs were trained on all these sections and tested on the four sections *Barbata, Brachypetalum, Coryopedilum* and *Parvisepalum* The ANNs were trained on more sections than they were tested with. This resulted in more realistic outcome, because the ANNs have to classify a new picture to all possible sections. If the ANNs were only trained on the sections used in the test runs, this could affect the outcome in a way that the results look much better because 3 of the 7 sections were missing.

The script that trained the network was already developed at Naturalis by Rutger Vos. This script accepts a parameter to specify the Desired Error. This is the maximum error rate that will be accepted. If the parameter is left empty the Desired Error will be 0.0001. When the error drops below this threshold the training is finished. To find the optimal Desired Error, seven networks were trained with a Desired Error in tenfold increments: the first network had a Desired Error of 0.0001, the second network had a Desired Error of 0.00001 and so on. The expectation was that a network with a lower Desired Error would classify a new picture better. To semi-automate the preparation for the training some scripts were written in python and bash. The workflow of these scripts can be found in figure 4. These scripts were for training the Artificial Neural Networks (ANNs), which is only done by the administrator of the website and not by the end-users of the website. The administrator has access to the shared Flickr account, so the manual check (and download) of the pictures that is required for one of the scripts, would not be a problem. Besides networks for classifying the slipper orchid flowers, ANNs for classifying *salep* orchid tubers were also created.

## *Salep* orchids

*Salep* orchid tubers are very popular in Turkey. These tubers are used to make ice creams during summer and hot drinks during winter. Due to a lack of information about the collected tubers, the ANNs could only be trained to recognize differences between *salep* orchid tubers and look-a-likes obtained from non orchid families. The tubers of look-a-likes that were used were from *Arum maculatum* (Araceae), *Asparagus officinalis* (Asparagaceae), *Polygonatum verticillatum, Tulipa greigii,* and *T. sp.* (Liliaceae) [21]. Supplementary 2 contains pictures of these tubers.

**training.sh**
- Offlickr.py: Download photographs and metadata from Flickr
- get_tags.py: Extract tags from the metadata
- Manual check: check if all pictures were downloaded correct. If not, download the broken pictures by hand. (terminal displays instructions)
- Convert jpg to png and move to correct directory

**create_traindata.sh**
- traindata.pl: Create data useful for training the Artificial Neural Networks for Tubers
- traindata2.pl: Create data useful for training the Artificial Neural Networks for Flowers

**modify_flower_data.sh**
- combine_files.py: Create tab separated value (tsv) files per section
- add_columns.py: Add columns to the tsv files

**trainai.pl**
- Create trained Artificial Neural Networks for slipper orchid flower photographs or *salep* orchid tuber photographs

**Figure 4 Flowchart of training preparation scripts. Blue: preparation steps. Green: processing step to produce useful data for training the flower Artificial Neural Networks. Purple: Training of the Artificial Neural Networks**

## Testing the networks

### Slipper orchids

After training the networks for the slipper orchid flowers, they were tested on pictures of four sections. The tested sections were *Barbata, Brachypetalum, Coryopedilum* and *Parvisepalum*. The networks were also tested with pictures of some primary hybrids of *Parvisepalum* and *Brachypetalum* with the aim of testing if it is also possible to correctly identify hybrids with the software. The assumption was that for primary hybrids a trained network would ideally list the sections of both parents as possible identification. However, some results of the first test round were very poor. To find the source of these bad results, pictures of some poorly classified species were checked for detection ability of the defining characteristics of the corresponding section. Table 1 holds a list with the characteristics per section based on Cribb P. [22]. During this research it was discovered that some species had only one picture in the train data. Therefore, extra pictures were added to the train data and the networks were trained again to find out if better results could be obtained after more extensive training. These networks were tested again with the same test sets.

**Table 1 characteristics per section**

| Characteristic | Barbata | Brachypetalum | Coryopedilum | Parvisepalum |
|---|---|---|---|---|
| **Petals** | Spathulate | Broad-elliptic, pale yellow or white | Long, hanging down, spirally twisted, tapering, glandular at tip | Broad-elliptic, Subcircular, Cream/yellow coloured |
| **Spotted or warted?** | Yes | Yes | Yes | No |
| **Lip** | Incurved side lobes | Small, ovoid with incurved margin | Incurved side lobes | Large, thin-textured |
| **Staminode** | Lunate | Ovate to transversely elliptic | Oblong | Large |

### *Salep* orchids

Due to time constraints, pictures of these orchids could not be investigated further during this internship.

## Testing the website

To test the website, a working ANN was required. After testing the ANNs, a working ANN was implemented on the website. This website was tested on receiving a picture, running the classify script using the given network and sending back a result. First this was tested for only one device. Once this was working correctly, the website was also tested to receive pictures from more than one device at the same time and send a result back. Receiving the pictures was working correctly, but sending back a result was not. The result of the first uploaded picture was send back to all devices. So this part of the website was made operable during this internship. The IP-address was used to save the uploaded picture in a directory. The name of this directory will be the IP-address. Only the picture in the directory with the correct IP-address will be classified, and its result is sent back to the website.

# Results

## Website

To make the software available for end-users a website was developed. A first design of this website was finished during this internship. It consists of a homepage, a page for uploading a picture, a page to show the picture is uploaded correctly, and a results page. On the homepage it is possible to choose to upload a picture or remove unused files from the server. The last option requires to log in with a valid account. The administrator of the website has a valid username and password. After choosing the option of removing unused files, the user is redirected to the login page. A workflow of this website is shown in figure 5. Figure 6 zooms in on the uploading part of the website. After selecting the upload option the user is forwarded to the upload page. On this page the user can select a picture to upload. On iPhones it is also possible to take a picture after tapping the "select file" button. The website will check whether the selected file is a picture. If it is not, the user stays on the upload page and a warning is issued. After uploading the file, the picture will be renamed. When these modifications are done the user is directed to the upload success page. Here the user can see the uploaded picture. The user can choose to see the results or upload another picture, which will replace the first picture. If the user selects the result option, the classify.pl script will run to classify the picture (see appendix 1.4.1). A flowchart of the classification step of the website can be found in figure 7. The output of this program is a list with numbers. An example of this output can be found in supplementary 1.2. This list is sent to a python script, result.py, that translates this list to a readable result (see appendix 1.6.2). Figure 8 shows a flowchart of this script. The output of this script is sent back to the result page, where the user can view it. Supplementary 3 contains screenshots of this website.
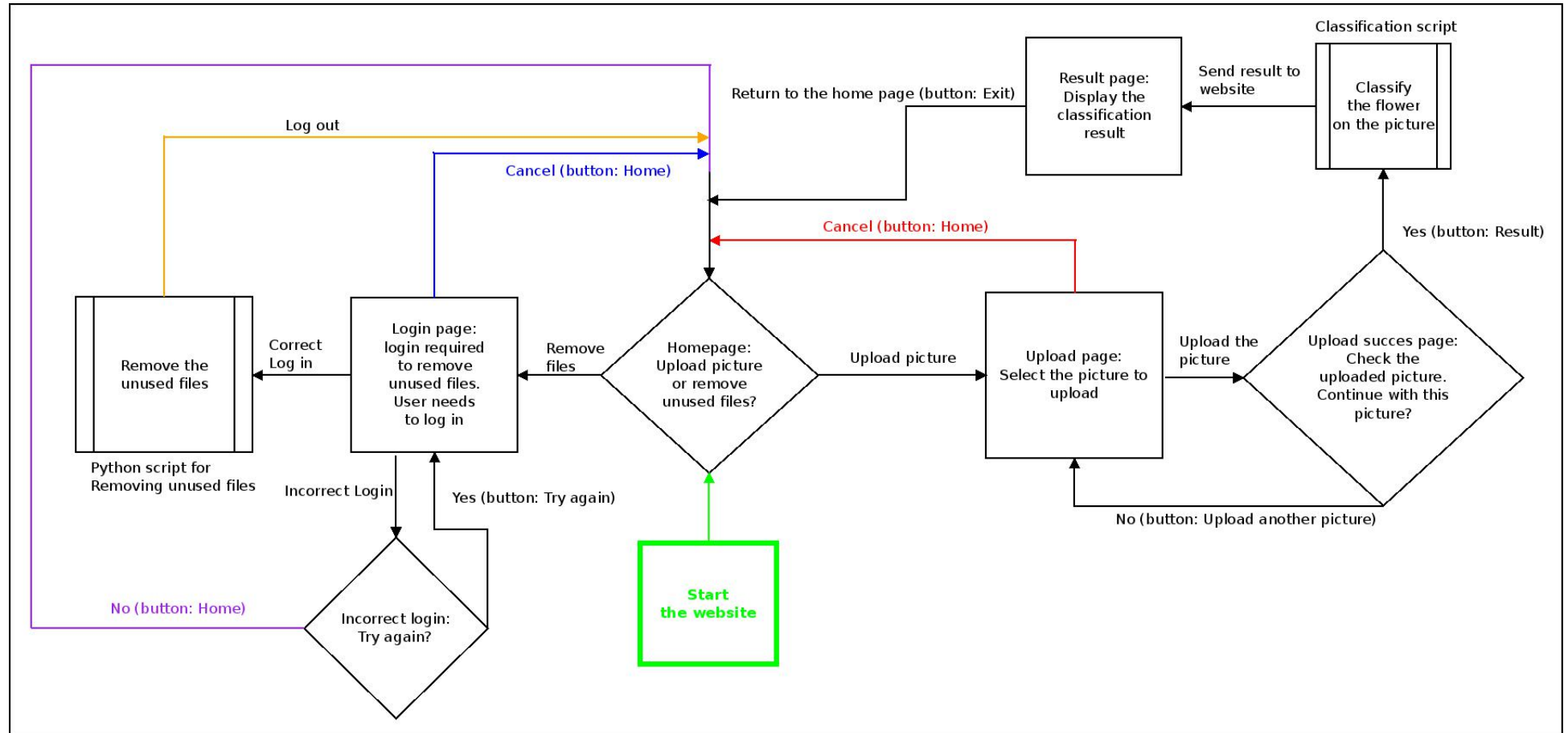
**Figure 5 Flowchart of the website. Green: Start of the workflow, start the website.**
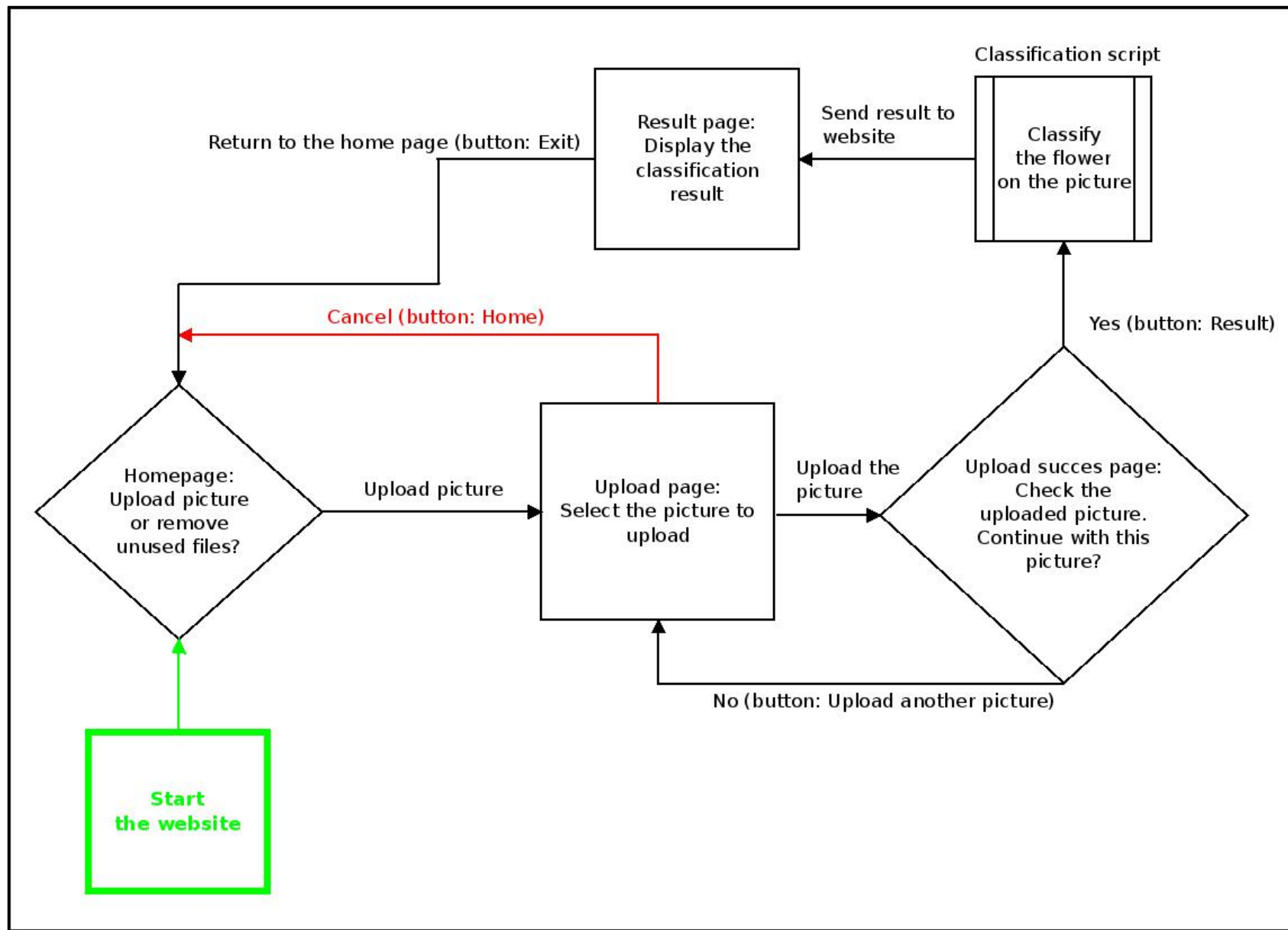
**Figure 6 flowchart of the website, zoomed in on uploading. Green: Start of the workflow, start the website.**
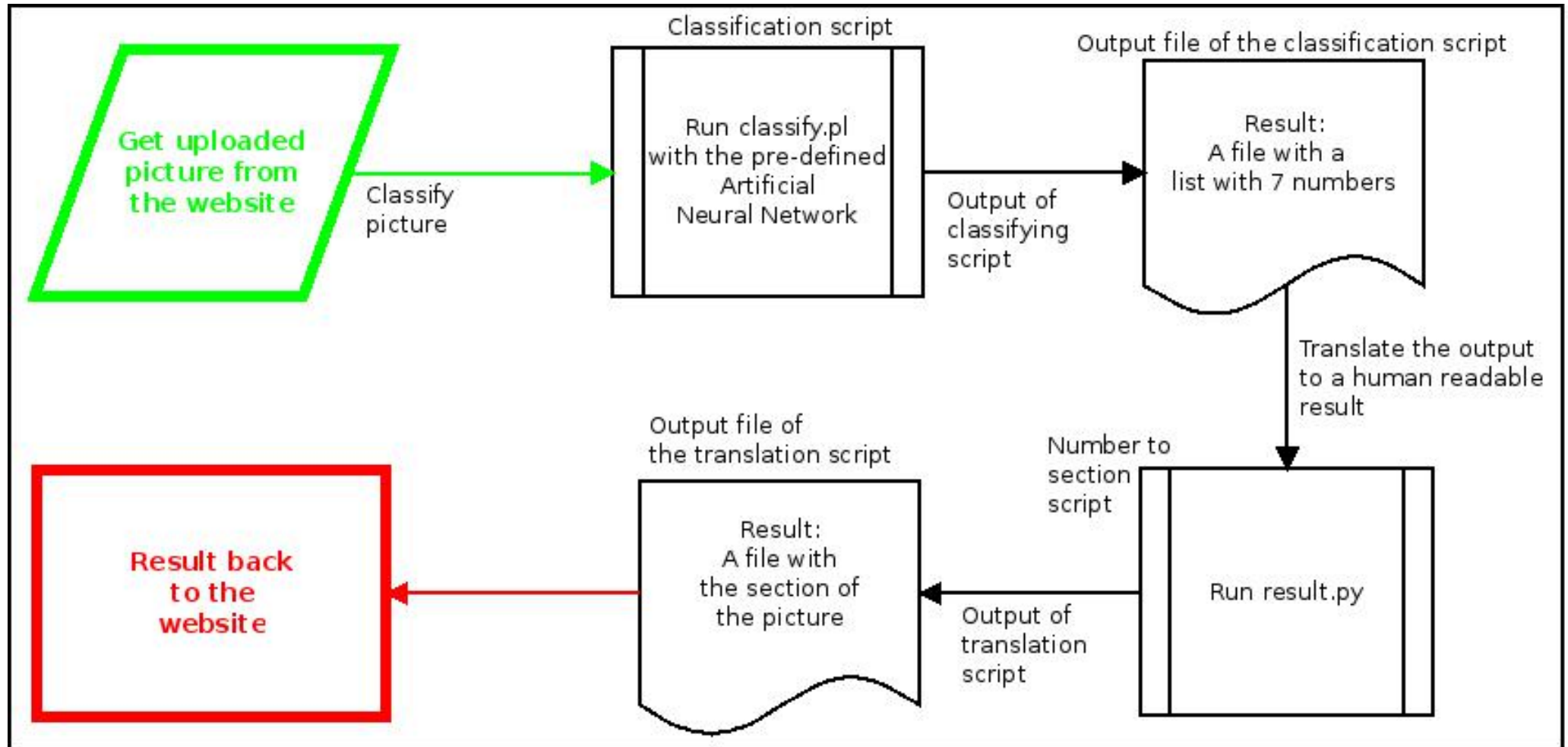
**Figure 7 Flowchart of the classification step of the website. Green: Start of the workflow, get the picture, Red: End of the workflow, send the result.**
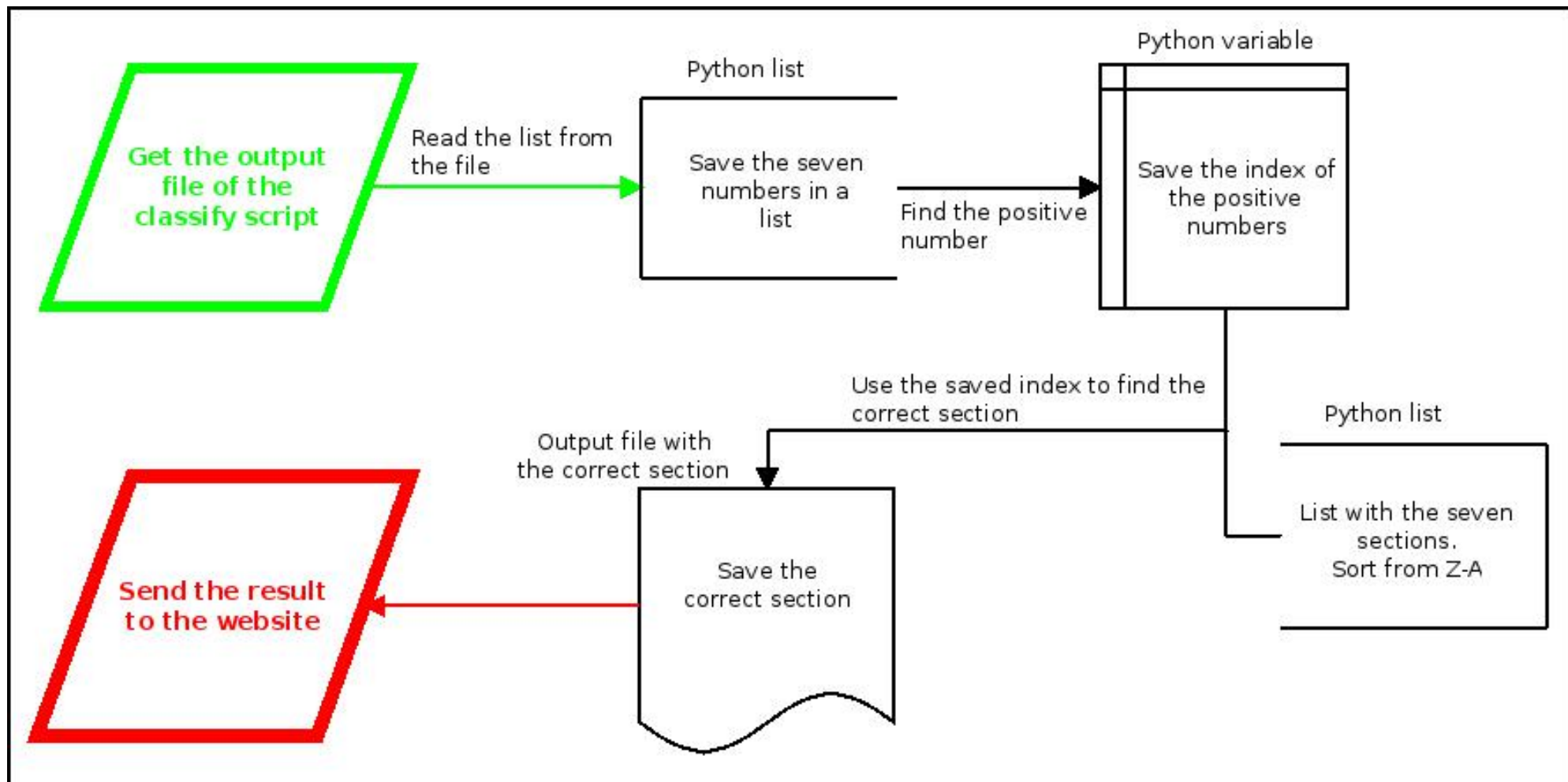
**Figure 8 Flowchart of result.py. Green: Start of the workflow, get the input file. Red: End of the workflow, send the result.**

## Preparation scripts

To semi-automate the preparation process, a bash script, training.sh, was developed (see appendix 1.1.3, and the first script in figure 4). Figure 9 contains a flowchart of this script. The first step in this script was running Offlickr.py to download the pictures as .jpg and the metadata files as .xml. After downloading these files, the script will run another python script, get_tags.py (see appendix 1.5.3), to get the original names and the tags from the metadata. A workflow of this script can be found in figure 10. This info will be saved in .txt files, using the id of the picture as name. For example, if the picture name is 123456789.jpg the tag file of this picture is 123456789_tags.txt. At the end of this step the .xml files are removed. Examples of the different tag files can be found in supplements 1.3-1.5. The structure of these files is always the same: the first line is the original name of the picture, then an empty line, after that the shape for the tuber pictures or the section and species for the flower pictures. The last tag indicates whether the object is a slipper orchid flower or a *salep* orchid tuber. The knowledge of this structure can be used in the next step.

In the next step the pictures are divided between two directories, Flower and Tuber. Before the pictures and tags are moved to the correct directory, the pictures were converted from .jpg to .png. This conversion was required because the training scripts only work with .png files. After converting the pictures, the .jpg files were not used anymore, so all .jpg files were removed.

After dividing the pictures between the directories Flower and Tuber, the separation goes further. First the Flower pictures were divided between the different slipper orchid sections and species. After this division there are some directories with the section names inside the Flower directory, and every section directory contains further species directories. After dividing the Flower pictures, the Tuber pictures were divided between shape and Look-a-Like or orchid. This step produced six directories: LOblong, LSpur, LRound, Oblong, Spur and Round. All directories starting with an "L" are for the Look-a-Like tubers.

The last step in the preparation process is segmenting the pictures of the tubers, using a Perl script developed by Rutger Vos: splitter.pl [23] (see appendix 1.4.2). This script uses the Perl package Image::Magick to modify the picture so that only the tuber is on the picture, with a minimum background. With an option of Image::Magick the background is modified to be completely white (see the square in appendix 1.4.2). Figure S-11 in supplementary 2 shows a picture before and after segmentation. The pictures of the flowers were already segmented, so this step was not required for these pictures.
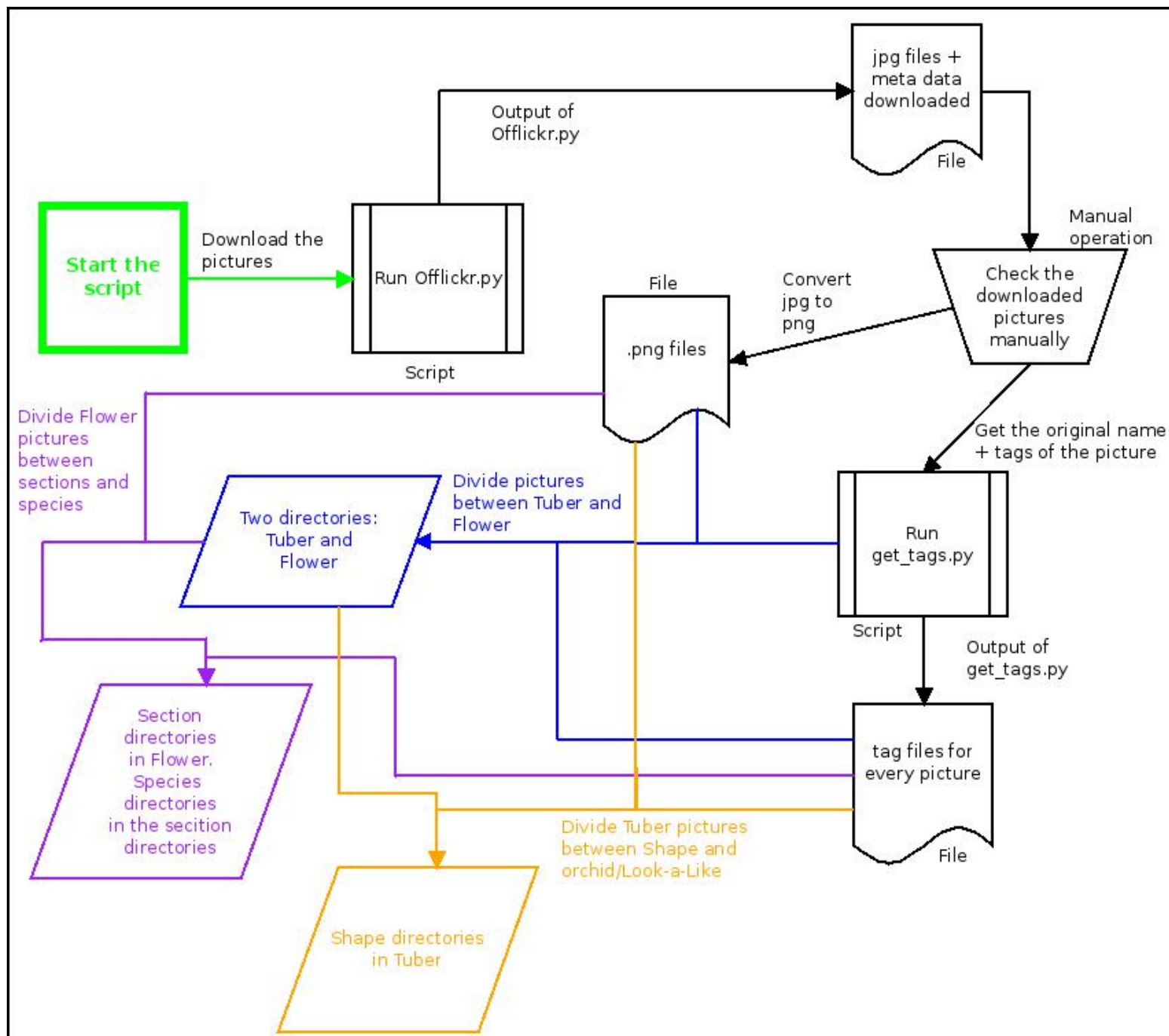
**Figure 9 Flowchart of training.sh. The colour of the arrows indicates in which step they are involved.**
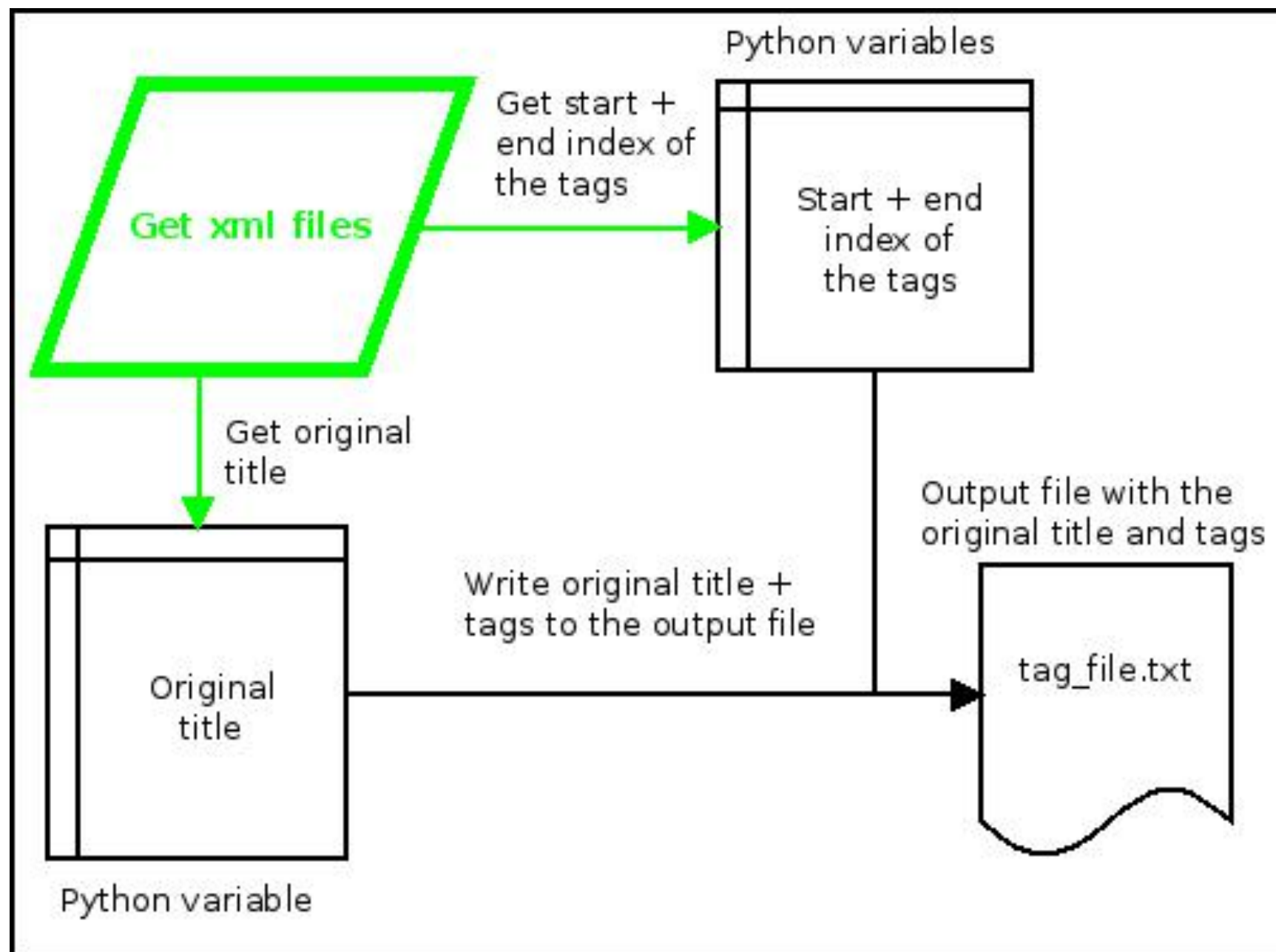
**Figure 10 Flowchart of get_tags.py. Green: Start of the workflow.**

## Create training data

When the preparation script is finished the training data can be generated. To do this, a bash script, create_traindata.sh, was developed (see appendix 1.1.1, and the second script in figure 4). This script runs two different Perl scripts developed by Rutger Vos. One of these scripts, traindata.pl, is for the tubers and the other, traindata2.pl, for the flowers (see appendices 1.4.4 and 1.4.5). The only difference between these two scripts is the accepted input files. The script for the tubers only accept files with a name in the format <number>,<number>.png, while the other script accepts files with a name that contains at least one number. These scripts create .tsv (tab separated value) files for every directory. So after running create_traindata.sh there is a .tsv file for every species of the flower pictures and a .tsv file for every shape of the tuber. These .tsv files contain the intensities of Red, Blue and Green (RBG) of 50 vertical bins and 25 horizontal bins. This means that the classification is based on both colour and shape. The shape was used to create a digital contour of the flower. The colour was used to create a digital phenotype inside of the digital contour. Figure 11 shows an example of the translation from picture to digital phenotype.

From this point the .tsv files of the tuber can be used for training the neural networks. The .tsv files of the flowers need to be modified before using them for training the neural networks. To automate this modification process a bash script, modify_flower_data.sh, was developed that runs two python scripts (see appendix 1.1.2, the third script in figure 4 and appendices 1.5.1 and 1.5.1). The first python script, combine_files.py, creates .tsv files per section by combining the .tsv files in that specific section. When all sections have a .tsv file the second python script, add_columns.py, is run. This script creates extra columns, one column per section. After creating the columns they are filled in. The guideline for this step is: the first section gets 1's in the first column and -1's in all other columns. The second section gets 1's in the second column and -1's in all other columns and so on. The sections were sorted from A to Z. This convention was subsequently used in the classification step. This step produces a list with seven numbers, one for each possible section, sorted from Z to A. So when the last of these seven numbers is positive this means the pictures is classified as the first section and so on. After adding these columns the data can be used to train the neural networks.
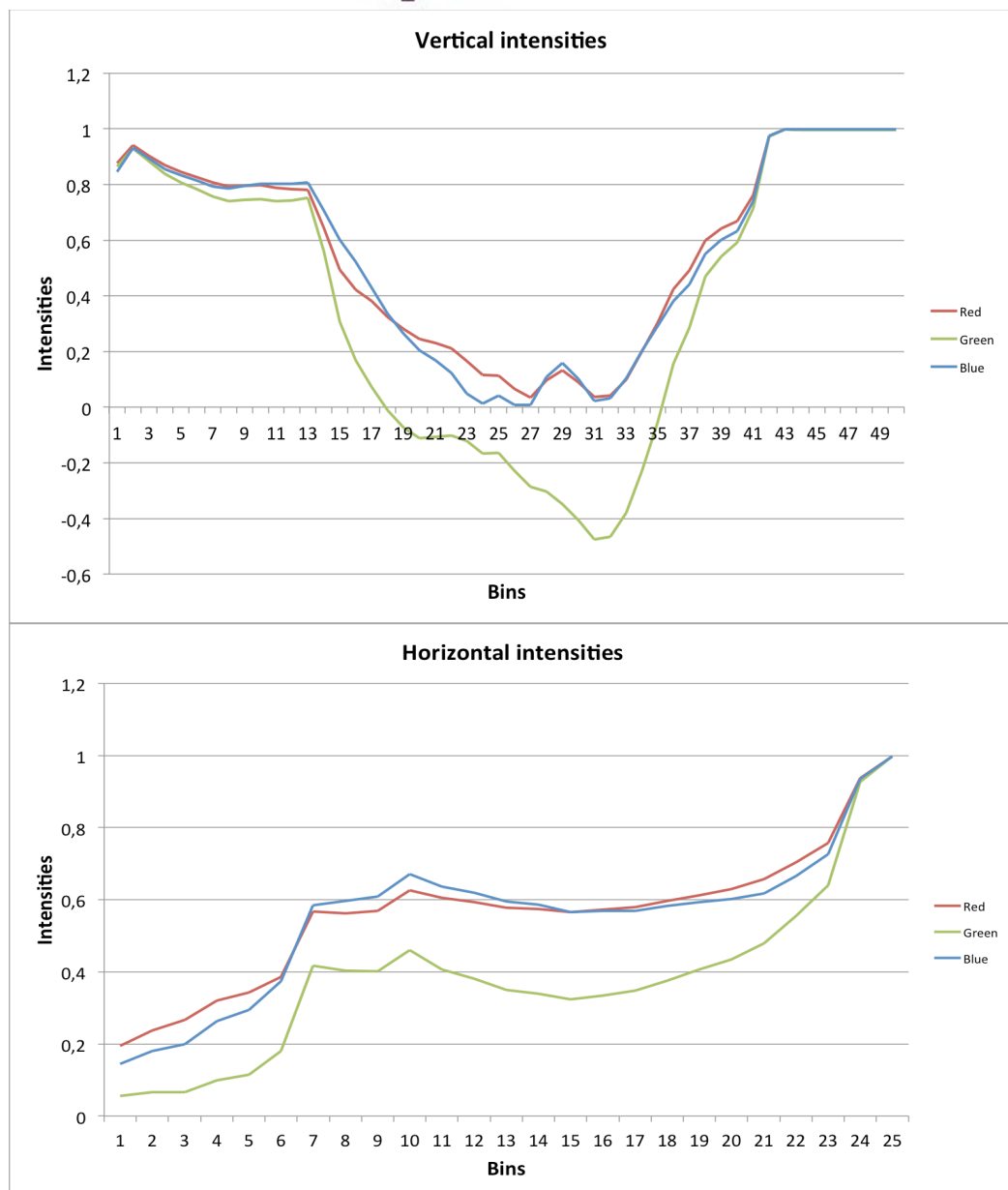
**Figure 11 Example of translation from picture to digital phenotype. A purple phenotype results in high intensities of red and blue.**

## Neural networks

After completing these preparation process, a neural network can be trained. To train the network a Perl script written by Rutger Vos, trainai.pl [23], was used (see appendix 1.4.3). This script accepts a directory with .tsv files, the number of categories (the number of extra columns), the output file, a Desired Error and the maximal number of epochs. The last one is the maximum number of rounds the network will be trained. When either the Desired Error or the number of epochs is reached, the training process will stop. Because the network is trained with the .tsv files, it is trained to see patterns in the colour intensities of RBG. Now the network acts like it can see different colours and shapes.

During this project 14 ANNs were created for identifying slipper orchid flowers. Seven for the first test run and seven for the second test run. As mentioned earlier the Desired Error was incremented tenfold per network. The networks can be found on: https://github.com/naturalis/img-classify/tree/master/webapp/ann All ANNs with a name ending with 4x.ann were used for the first test run and all ANN's with 5x.ann were used for the second test run. Due to time constraints, networks for tubers of *salep* orchids and look-a-likes were created, but not tested.

## First test run

In the first test run four of the seven sections of *Paphiopedilum*, i.e. *Barbata, Brachypetalum, Coryopedilum* and *Parvisepalum* were tested. The ANNs were also tested with a few pictures of hybrids between species of *Parvisepalum* and *Brachypetalum*. The results of these tests can be found in supplementary 4. The different networks are shown horizontally and the different pictures vertically. A green cell with the text 'Correct' means the network classified the picture to the correct section. A yellow cell with the text 'Unknown' means the network was unable to classify the picture to any section. A yellow cell with the text 'Unknown <number>/<number>' means the network was unable to select a section from two options. When this text is green, one of the options was the correct section. A red cell with the text 'Incorrect <number>' means the network classified the picture to a wrong section. The number indicates to which section the network erroneously classified the picture. Below, the obtained results will be discussed in more detail.

## Section *Barbata*

This section is characterized morphologically by spathulated, spotted and/or warted petals and incurved side lobes of the lip. Most of the species of the section *Barbata* were classified incorrectly. As seen in table 2 in Supplementary 4, most of the incorrectly classified pictures were classified as section *Paphiopedilum*. One explanation for this mistake could be that the species in both sections share several similar characteristics. The petals for instance have mostly the same shape. Another explanation is that both sections have many species so variation is high.

After characteristic pictures of three different species of the section *Barbata* were added to the test set, belonging to *P. argus, P. tonsum* and *P. wardii*, it turned out that even pictures with all characteristics of the section clearly visible were hard to classify correctly (see table 3 in supplementary 4). Like before, one of the possible explanations could be that species of the section *Barbata* share characteristics with the section *Paphiopedilum*. Another explanation could be that not enough train data of these species were added yet.

### Section *Brachypetalum*

This section is characterized morphologically by broad-elliptic petals with purple spots, a small and ovoid lip with an incurved margin and pale yellow or white flowers. The visual recognition software developed during this internship identified this section very well (see table 4 in supplementary 3). None of the pictures were classified incorrectly and only a few were classified as unknown. But even then, most of the time the correct section was one of the options. A possible explanation could be that this section contains few species only so variation is low.

### Section *Coryopedilum*

This section is characterized morphologically by long, tapering, spirally twisted and hanging petals with warts on the margins and glands at the tip and a lip with incurved side lobes. In this section one picture stands out, *P. rothschildianium*1. This picture was classified correctly with all networks (See table 5 in supplementary 4). So this is a good picture for classifying. Further, it is shown that the other two pictures of this species were much harder to identify. Possible explanations are that the first picture has more characteristics visible than the other two (i.e. spirally twisted petals and incurved side lobes) or that the resolution of the first picture is better than the other two.

### Section *Parvisepalum*

This section is characterized morphologically by broad-elliptic, subcircular cream/yellow coloured petals and a large staminode. This section also has a striking picture, *P. emersonii*2_1. This picture was always incorrectly classified. Research on this picture shows that the petals are darker than the petals on the other pictures of this section. This is caused by some shadow on the flower. In addition, table 6 in supplementary 4 shows that *P. armeniacum* was the best recognized species. All test pictures of this species were classified correct by all networks. A possible explanation could be that this section contains few species only so variation is low.

### Hybrids of species from sections *Parvisepalum* and *Brachypetalum*

Besides testing the ANNs with pictures of the sections, the networks were also tested with pictures of hybrids of species of different sections. This was done to test if it was possible to identify one or both of the parental species. It could be hard to identify both parental species because the hybrid shares a part of its morphology with the mother and another part with the father. Since the ANNs were not trained with pictures of hybrids, the assumption was that only one parental section would be found by the neural networks. Table 7 in supplementary 4 shows that most of the time the pictures were indeed classified as one of the parental sections. In just one case, *armeniacum* x *concolor* using the network with Desired Error 0.00001, both parental sections were found.

## Characteristic research

Following the results of the first run, research on the characteristics of some species was done to understand why some species or sections were hard to classify. The results of this research can be found in supplementary 5. These results show that most of the test pictures do not have all section characteristics visible. The results indicate also that some characteristics were shared between different sections, like broad-elliptic petals in the sections *Brachypetalum* and *Parvisepalum*. This could be a reason why some species were classified very poorly. Essential characters necessary for correct identification turned out to

be the shape of the petals, the presence or absence of wards on the petals, the colour of the flower and the shape of the lip (incurved or not). Especially the colour was often distorted (i.e. white flowers looked yellow or yellow flowers looked green) which might explain some of the poor results obtained. To improve the classification it is required to standardize the pictures of the train data. Knowledge of the different sections of slipper orchids is needed to standardize the pictures of the train data.

During this research it was also discovered that some species of the sections *Barbata* and *Coryopedilum* had only one picture in the train data. This could also be a reason why these species were classified poorly. Extra pictures of these species were added to the train data. This expanded train set was used to train the ANNs again. These new networks were tested again with the same test sets to find out if better classification results were obtained. The results of this experiment are described in more detail below.

### Second test run
To demonstrate that more pictures in the train data improves the ability of the ANNs to classify pictures, a second test run was done. The results of this run can be found in supplementary 6. The structure of these tables is the same as in supplementary 4. Some pictures (i.e. 50 out of 124; roughly 40%) were indeed classified better, showing that more training pays of. Other pictures (i.e. 30 out of 124; roughly 25%) were classified worse than in the first test run. One explanation could be coincidence during training. When you train two networks with the same settings and the same train set, both networks will be different nonetheless. The cause of this phenomenon is that during the training the networks create connections. These connections will be different every time you train the network. To classify a new picture the connections in the network found at that moment are used to give a result. This means that different connections can result in a different classification. The remaining 44 pictures (roughly 35%) were classified as good as in the first test run.

### Section *Barbata*
After the second test, species belonging to section *Barbata* were still difficult to classify (See tables 12 and 13 in supplementary 6). The results do show that many of the pictures of this section were classified better (i.e. 25 out of 45; roughly 56%). It is striking that some pictures of species with additional pictures in the train set were classified worse, though, because the assumption is that more pictures in the train set will improve the classification. These concerned the species *P. argus*, *P. hennisianum, P. tonsum* and *P. wardii*. A possible explanation is the different connections in the ANN's of the first test run and the second test run.

### Section *Brachypetalum*
*Brachypetalum* is one of the sections that did not get additional pictures in the train set. Nevertheless, there are some pictures that were better classified than before (See table 14 in supplementary 6). These concerned some pictures of *P. concolor* and *P. godefroyae*. But also in this section there were some pictures that were classified worse. These concerned other pictures of *P. concolor* and *P. godefroyae* and also some pictures of *P. niveum*. A possible explanation is again the different connections between the ANNs of the first test run and the second test run. Another possible explanation could be that the patterns of the sections with additional pictures were more specific in the second test run. This means that in the first run the patterns of a picture of this section could be belong by two sections, but after adding pictures to the other section, this pattern does not fit anymore in this section.

### Section *Coryopedilum*

This is a notable section. This section received additional pictures in the train data, but not of the species in the test data. Nevertheless, the pictures were much better classified than in the first run (See table 15 in supplementary 6). This is also the only section that has no longer incorrectly classified pictures. Still some pictures were classified as unknown. A possible explanation could be that the train data contains more variation after adding some pictures. The pictures in the test data looked more like the new variations, which made it possible to classify the picture to the correct section.

### Section *Parvisepalum*

After the first test run this section was one of the best-classified sections. Although there were no additional pictures of this section added, some pictures were classified better during the second test run (See table 16 in supplementary 6). Again, one of the possible explanations could be the different connections between the first ANNs and the second ANNs. Also more specific patterns for the other sections could again be a possible explanation.

### Hybrids of species from section *Parvisepalum* and *Brachypetalum*

Most of the hybrids were classified correctly in the first test run. During the second test run it was seen that some pictures were classified better to one of the parental sections (See table 17 in supplementary 6). The picture that was classified to both parental sections in the first run, was classified to only one parental section in this run. Because it was only seen one time in the first test run that both parental sections were recognized, it could be coincidence. This could be an explanation to the results of the second test run. A possible explanation for the better results of some pictures could be again the different connections between the different ANNs.

# Discussion

### Tubers
Because it is hard to extract DNA from a dried tuber, most of the tubers of confiscated *salep* orchids could not yet be identified to species level during my internship. During this project they could therefore only be used to train the neural network to see differences between orchid tubers and lookalike tubers up to the family (i.e. orchid versus non orchid) level. The time necessary to test this was lacking, though, so this is not worked out completely. A new student will use the pictures that were made to further train the neural network to identify them to orchids versus lookalikes.

### Slipper orchids
Sections of slipper orchids that could be identified correctly included *Brachypetalum* (75-95% in the second test run), *Coryopedilum* (67-100% in the second test run), *Parvisepalum* (73-85% in the second test run) and primary hybrids of species of *Parvisepalum* and *Brachypetalum* (75-100% in the second test run). The only section that was less easy to identify was *Barbata* (24-41% in the second test run). The section *Barbata* has more characteristics in common with the section *Paphiopedilum* than the other sections, which might explain why pictures of the section *Barbata* were often classified as *Paphiopedilum*.

### Training networks
During training of the networks it was found that it was very hard to find good pictures of flowers of some species. When this fact is combined with the fact that some species had few pictures in the train set, this could be a reason why these species were poorly classified. This assumption is supported by the fact that when more pictures were added to the train set, identification improved. This was especially found for *P. hennisianum, P. tonsum, P. violascens, P. glanduliferum, P. wilhelminiae* and *P. rothschildianium*.


# Conclusions

### Classifying slipper orchids from pictures is possible
Although some species were very hard to classify, the results show that it is possible for most species to be classified to section level correctly using a picture of a flower. Some species need more or better pictures in the train set, but the concept of classifying slipper orchids from a picture of a flower has been demonstrated during this project.

### Differences between well classifiable vs hard classifiable sections of slipper orchids
The only section of those tested that remained hard to classify was the section *Barbata*. Most of the floral characteristics of this section are shared with the section *Paphiopedilum*. All other tested sections have unique characteristics. This might explain why some of the pictures of the section *Barbata* were classified as *Paphiopedilum*.
After adding pictures of this section to the training set the classification improved a little bit. Still many pictures were classified as *Paphiopedilum*. This supports the assumption that the shared characteristics make it hard to classify pictures of this section correctly.

## Suggestions for follow-ups

To make this software available for the outside world, the website needs to become online. Before the website will be made online, the ANNs need also to be tested for species of the sections *Cochlopetalum, Paphiopedilum* and *Pardalopetalum* and for species of the slipper orchid genera *Cypripedilum, Mexipedilum, Phragmipedium* and *Selenipedium* that could not yet be dealt with during this internship due to time constraints. Depending on the results of these tests, the ANNs need to be trained again with more/better train data of one or more of these sections. The ANNs have to be re-trained with more/better train data of the section *Barbata* anyway.

When the website is online, customs officers can use this website to classify slipper orchid flowers. To make the website more useful for customs officers, the software needs to be expanded by options for classifying orchid tubers and orchid leaves as well.

Since slipper orchids are a popular group among plant growers, the software could be further developed into an app for orchid hobbyists as well. Similar app's for carnivorous plants (such as Nepi) and edible mushrooms (such as Casa Foresta) already exist. In the last two apps information about distribution areas of species in the wild and recipes are linked to photographs. For slipper orchids cultivation requirements could be included. Building such an extended app for slipper orchids seems a great idea for which a large market demand exist so seeking sponsors for this should not be too difficult.

## Acknowledgements

## References

[1] David Roberts, Durrell Institute of Conservation and Ecology, University of Kent

[2] The Plant List, 2010, http://www.theplantlist.org/browse/A/Orchidaceae/

[3] Orchid Smuggling and Conservation (ORCHID), http://www1.american.edu/ted/orchid.htm

[4] http://www.cites.org

[5] Royal Botanic Gardens Kew, 2001, http://www.kew.org/plants-fungi/Cypripedium-calceolus.htm

[6]CITES Appendices, June 2013, http://www.cites.org/eng/app/appendices.php

[7] Kasparek M and Grimm U, 1999, European trade in Turkish Salep with Special Reference to Germany. Economic Botany 53(4): 396-406

[8] Camera: gsmnationblog, 2013, http://www.gsmnation.com/blog/2013/02/19/snap-away-5-best-smartphone-cameras-available/

[9] Envelop: Tuxx, 2004 - 2013, http://www.tuxx.nl/post/adressering/

[10] Naturalis tower: unityfm, 2013, http://www.unityfm.nl/nieuws.php?id=26906

[11] Database: introduction to query optimizer, 2013, http://prabathsql.blogspot.nl/2013/01/introdiuction-to-query-optimizer.html

[12] Wheelwork: op eigen kracht praktijk voor ergotherapie, 2013, http://www.ergotherapieopeigenkracht.nl/vergoeding-ergotherapie/

[13] Lamp: ledweeklampen, http://www.ledkweeklampen.nl

[14] iPhone: T-Mobile, http://shop.t-mobile.nl/eca/RAPRD/Apple-iPhone-4-8GB-wit/map48gbpwi.html?ab_agid=1021

[15] Slipper orchid: Wikimedia commons, 2009, http://commons.wikimedia.org/wiki/File:Slipper_orchid_wyn1.jpg

[16] KeyLemon, 2013, https://www.keylemon.com/product/

[17] LeafSnap, 2011, www.leafsnap.com

[18] gigaom, 2014, https://gigaom.com/2013/08/16/were-on-the-cusp-of-deep-learning-for-the-masses-you-can-thank-google-later/

[19] Offlickr, Hugo Haas, http://code.google.com/p/offlickr

[20] Chochai A, 2012, Molecular phylogenetics of *Paphiopedilum* (Cypripedioideae; Orchidaceae) based on nuclear ribosomal ITS and plastid sequences, In: Botanical Journal of the Linnean Society 170: 176-196

[21] Lawler LJ, 1984, Ethnobotany of the Orchidaceae, In: Arditti J (ed.), Orchid biology: reviews and perspectives: 27-149. Cornell University Press, Ithaca, New York, USA

[22] Cribb P, 1998, The genus *Paphiopedilum* second edition

[23] Rutger Vos, Bioinformaticist at Naturalis Biodiversity Center

[24] Photographs by Patrick Wijntjes

# Supplements

## 1. Input and output files

### 1.1. Example of an xml file

```
<photo id="12342126885" secret="ca74c114fa" server="7451" farm="8" dateuploaded="1391690138"
isfavorite="0" license="0" safety_level="2" rotation="0" originalsecret="29fddd19e8"
originalformat="jpg" views="0" media="photo">
        <owner nsid="113733456@N06" username="patrick_naturalis" realname="Patrick Wijntjes"
location="" iconserver="0" iconfarm="0" path_alias=""/>
        <title>charlesworthii5</title>
        <description/>
        <visibility ispublic="0" isfriend="0" isfamily="0"/>
        <dates posted="1391690138" taken="2012-08-29 17:13:09" takengranularity="0"
lastupdate="1391690248"/>
        <permissions permcomment="0" permaddmeta="0"/>
        <editability cancomment="1" canaddmeta="1"/>
        <publiceditability cancomment="0" canaddmeta="0"/>
        <usage candownload="1" canblog="1" canprint="1" canshare="0"/>
        <comments>0</comments>
        <notes/>
        <people haspeople="0"/>
        <tags>
                <tag id="113688134-12342126885-10993197" author="113733456@N06"
raw="genus:Paphiopedilum" machine_tag="0">genuspaphiopedilum</tag>
                <tag id="113688134-12342126885-188931923" author="113733456@N06"
raw="species:charlesworthii" machine_tag="0">speciescharlesworthii</tag>
                <tag id="113688134-12342126885-535" author="113733456@N06" raw="Flower"
machine_tag="0">flower</tag>
        </tags>
        <urls>
                <url
type="photopage">http://www.flickr.com/photos/113733456@N06/12342126885/</url>
        </urls>
</photo>
```

## 1.2. Example of an output file of classify.pl

Entry: color-100,451.png
$VAR1 = [
      '-0.456072704368231',
      '-0.973874677375054',
      '-1',
      '-0.999999808175595',
      '0.990980698747592'
      ];
Entry: color-129,334.png
$VAR1 = [
      '-0.811027796569903',
      '-0.999812464339958',
      '0.99572448600037',
      '-0.996400768699541',
      '-1'
      ];
Entry: color-141,711.png
$VAR1 = [
      '0.971726551475096',
      '-0.999312299486709',
      '-0.981400879260904',
      '-0.99960776872456',
      '-1'
      ];
Entry: color-222,648.png
$VAR1 = [
      '0.996738096627912',
      '-0.919456120335819',
      '-0.999987677705016',
      '-0.999994486624424',
      '-0.99999973650751'
      ];
Entry: color-447,1931.png
$VAR1 = [
      '0.935067461526289',
      '-0.999821434281431',
      '-0.999766410047794',
      '-0.996420240471305',
      '-1'
      ];
Entry: color-46,379.png
$VAR1 = [
      '0.997483774166035',
      '-0.994043337286478',
      '-0.998988899850576',

```
        '-0.999999999293947',
        '-0.99999999995774'
      ];
Entry: color-50,380.png
$VAR1 = [
        '0.940404321606217',
        '-0.758403411429261',
        '-0.999999840072036',
        '-0.999999955862603',
        '-0.999999983567608'
      ];
Entry: color-56,651.png
$VAR1 = [
        '-0.897130009835269',
        '0.994303714419604',
        '-0.999999951703297',
        '-0.999999993987055',
        '-1'
      ];
Entry: color-64,737.png
$VAR1 = [
        '0.93481407861017',
        '0.345711139511172',
        '-0.999999999999977',
        '-0.999999985064081',
        '-1'
      ];
Entry: color-7,390.png
$VAR1 = [
        '-0.999853813787961',
        '-0.303503446288619',
        '-0.999984006201254',
        '-0.999999238570459',
        '-1'
      ];
```

### 1.3. Tag file of a flower

bellatulum12 phot

genus:Brachypetalum
species:bellatulum
Flower

### 1.4. Tag file of a *salep* tuber

TEH-1.1_5

Orchid_spur
Orchid
Spur
genus:Dactylorhiza
species:incarnata
Tuber

### 1.5. Tag file of a Look-a-Like tuber

tulipa red riding hood3

Look-a-Like_round
Look-a-Like
Round
genus:Tulipa
species:greigii
Tuber

## 2. Photographs of *salep* orchid look-a-likes [24]



Figure S-1 *Arum maculatum* [24]



Figure S-2 *Asparagus officinalis* [24]



Figure S-3 *Polygonatum verticillatum* [24]



Figure S-4 *Tulipa greigii* [24]



Figure S-5 *Tulipa sp.* [24]
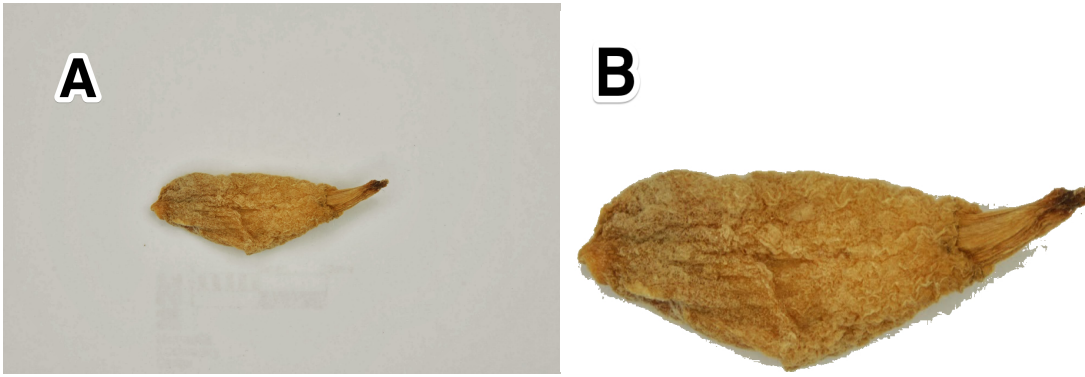
**Figure S-6 A: A picture of a tuber, before segmenting. B: A picture of the same tuber after segmenting [24].**

### 3. Screenshots of the classification website



**Welcome**

**Welcome on the orchid identifier website of Naturalis**

After uploading a picture the website will identify the orchid.
Please click the upload picture button below to upload a picture.
*You can upload a picture of a tuber, a leaf or a flower.*

Upload picture

To remove all unused uploaded pictures and their temporary files
click below **(login required)**

Remove unused files

device: computer

**Figure S-7 Homepage of the classification website**

**Figure S-8 Upload page of the classification website**
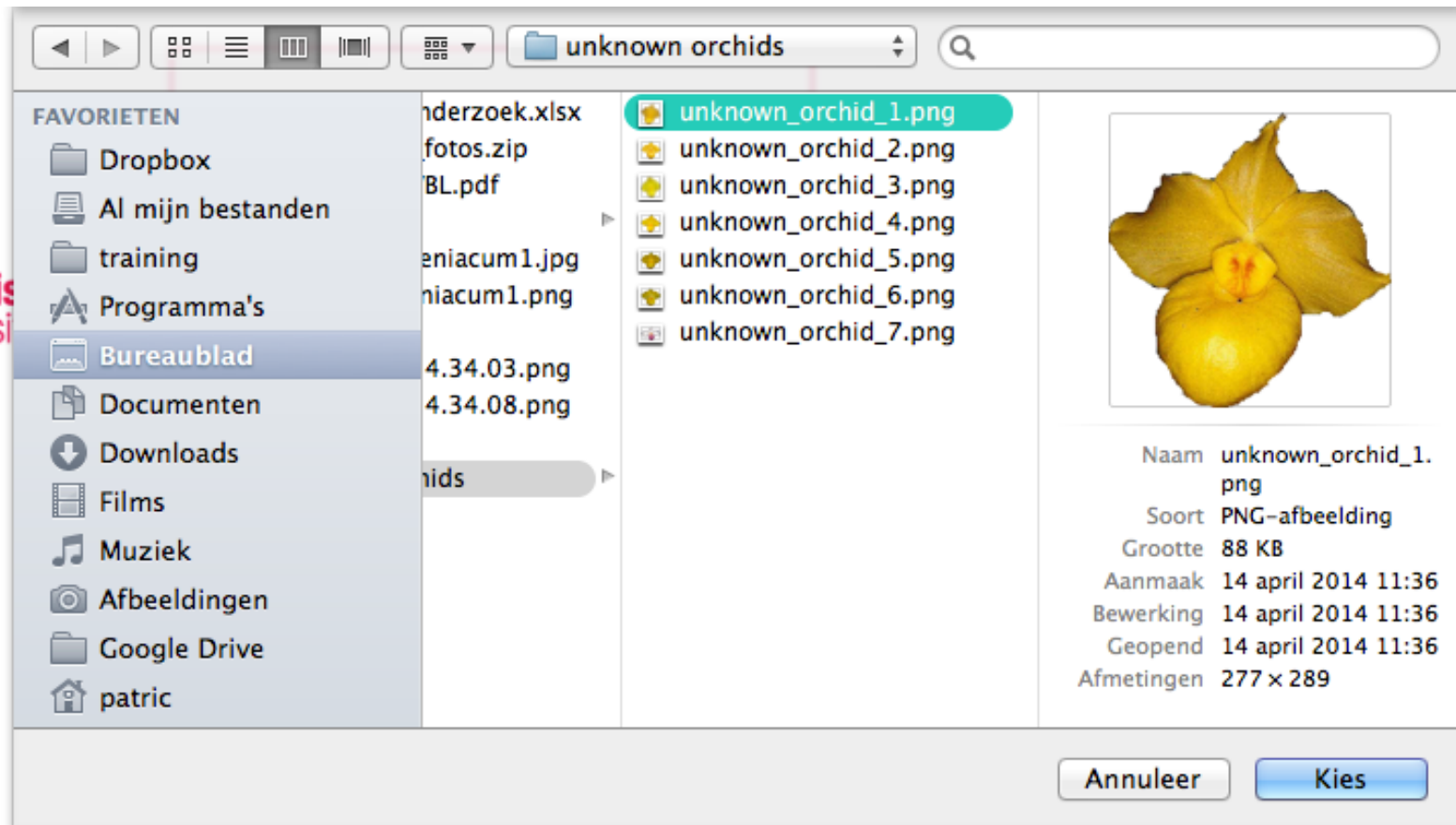
**Figure S-9 Screen to select the picture to be classified**

**Figure S-10 page to check if the picture is uploaded correctly**

**Figure S-11 Result page of the classification website**

## 4. Results of first test run

Table 2 Results of first test of *Paphiopedilum* section *Barbata*. Red: incorrectly classified. Green: Correctly classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.

### *Paphiopedilum* sect. *Barbata* run1_2

| ANN | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|
| Desired Error | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| Time to classify (s) | 16 | 15 | 15 | 15 | 14 | 15 | 14 |
| **Pictures** | | | | | | | |
| acmodontum1 | Incorrect 1 | Incorrect 1 | Unknown 7/1 | Incorrect 1 | Incorrect 1 | Incorrect 1 | Incorrect 1 |
| appletonianum1 | Incorrect 3 | Unknown | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 6 | Incorrect 6 |
| argus1 | Unknown 7/3 | Unknown | Correct | Unknown 7/3 | Unknown 7/3 | Correct | Unknown 3/7 |
| argus2_2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| barbatum1 | Incorrect 1 (low) | Unknown 7/3 | Unknown 3/1(low) | Incorrect 3 | Unknown 7/3 | Incorrect 3 | Unknown |
| barbatum2_2 | Incorrect 3 | Incorrect 3(low) | Unknown | Unknown | Incorrect 3 | Unknown | Incorrect 3 |
| bougainvilleanum1* | Unknown 7/1(low) | Incorrect 3 | Unknown | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 |
| bullenianum1 | Unknown 3/1(low) | Incorrect 3 | Incorrect 1 | Unknown 1/3 | Incorrect 3 | Incorrect 1 | Unknown |
| callosum1 | Incorrect 6 | Unknown 6/3(low) | Unknown | Incorrect 1(low) | Incorrect 1 | Incorrect 6 | Incorrect 6 |
| callosum2 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 1 | Unknown | Incorrect 3 |
| callosum3 | Unknown | Incorrect 3 | Incorrect 2 | Unknown | Incorrect 3 | Unknown | Correct |
| dayanum1 | Unknown | Unknown | Unknown | Unknown | Correct | Incorrect 6 | Unknown |
| dayanum2_3 | Unknown 7/2 | Correct | Unknown 7/3 | Unknown | Incorrect 6 | Correct | Unknown |
| dayanum2 | Incorrect 3 | Incorrect 3 | Unknown | Unknown 3/1(low) | Unknown | Incorrect 1 | Unknown |
| fowliei1* | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Unknown | Correct | Correct |
| fowliei2* | Unknown | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 |
| hennisianum1 | Unknown 3/1 | Incorrect 1 | Incorrect 3 | Incorrect 1 | Incorrect 1 | Incorrect 3 | Unknown 1/7 |
| hennisianum2_1 | Unknown 3/7(low) | Incorrect 3 | Correct | Unknown 7/3(low) | Unknown 7/3 | Correct | Unknown |
| hennisianum2 | Incorrect 3 | Correct(low) | Incorrect 3 | Unknown | Incorrect 3 | Incorrect 5 | Unknown |
| hookerae1 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3(low) | Incorrect 3 | Incorrect 3 |
| hookerae2_4 | Correct | Correct | Incorrect 3 | Correct | Correct | Correct | Correct |
| javanicum1* | Correct | Correct | Correct | Unknown 1/2/7(low) | Correct | Correct | Correct |
| javanicum2* | Unknown 7/1 | Unknown | Unknown 7/1 | Incorrect 1 | Unknown | Correct | Unknown |

| | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|
| lawrenceanum1 | Correct | Unknown | Unknown | Incorrect 5 | Unknown | Unknown | Unknown |
| mastersianum1 | Incorrect 3 | Incorrect 3 | Unknown 3/1(low) | Incorrect 3 | Incorrect 3 | Unknown 3/7 | Correct |
| mastersianum2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Incorrect 5 |
| papuanum1* | Correct | Incorrect 1 | Incorrect 1 | Incorrect 1 | Correct | Unknown | Correct |
| purpuratum1 | Incorrect 1 | Incorrect 1 | Incorrect 6 | Incorrect 1 | Unknown 1/3 | Incorrect 1(low) | Unknown 1/3 |
| purpuratum2_1 | Unknown 7/3 | Correct | Unknown 3/7 | Correct | Correct | Unknown 7/3 | Correct |
| purpuratum2 | Incorrect 1 | Incorrect 1 | Unknown 1/7 | Incorrect 1 | Incorrect 1 | Incorrect 1 | Unknown 1/7 |
| schoseri1* | Incorrect 1 | Unknown | Unknown | Unknown | Unknown | Incorrect 6(low) | Unknown |
| sukhakulii1 | Incorrect 1 | Unknown | Incorrect 1 | Correct | Unknown | Incorrect 3 | Unknown |
| superbiens1§ | Unknown 3/7 | Correct | Incorrect 3 | Correct | Incorrect 3(low) | Unknown 7/3 | Incorrect 3 |
| tonsum1 | Correct | Unknown 7/1 | Correct | Correct | Incorrect 1 | Correct | Correct |
| tonsum2_2 | Correct | Correct | Correct | Correct | Unknown | Incorrect 3 | Incorrect 3 |
| tonsum2 | Correct | Correct | Unknown 3/7 | Correct | Unknown | Correct | Incorrect 3 |
| tonsum3 | Correct | Correct | Unknown | Unknown | Unknown | Correct | Unknown |
| urbanianum1 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3(low) | Unknown 1/7 | Correct | Unknown 3/7 |
| urbanianum2_3 | Unknown | Correct | Correct | Unknown | Correct | Correct | Unknown |
| violascens1 | Incorrect 1 | Unknown 7/1 | Incorrect 3 | Correct | Incorrect 3 | Incorrect 3 | Unknown 3/1 |
| violascens2 | Unknown | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Unknown 3/7 | Incorrect 3 |
| wardii1 | Incorrect 1 (low) | Unknown 3/1 | Unknown 7/1 | Incorrect 1 | Incorrect 1 | Incorrect 1 | Unknown |
| wardii2_1 | Correct | Correct | Unknown 7/1 | Correct | Unknown 5/1 | Unknown 7/5 | Incorrect 5 |
| wentworthianum1* | Incorrect 1 | Unknown | Incorrect 4 | Incorrect 1 | Incorrect 1 | Incorrect 1(low) | Unknown |
| wentworthianum2* | Unknown | Incorrect 3 | Incorrect 4 | Unknown | Unknown | Unknown | Unknown |
| **Pictures** | 41 | 42 | 43 | 44 | 45 | 46 | 47 |

*= not in train set / on dear.smartweb.tw
§=only var. Curtisii in train set

1:*Parvisepalum*  2:*Pardalopetalum*  3:*Paphiopedilum*  4:*Coryopedilum*  5: *Cochlopetalum*
6:*Brachypetalum*  7:*Barbata*
The order in Unknown x/y is <best_sore>/<lower_score>. No numbers? All scores are negative

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**Table 3 Results of first test of extra pictures of *Paphiopedilum* section *Barbata*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

### *Paphiopedilum* sect. *Barbata* run1_2

| ANN | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 2 | 2 | 2 | 2 | 2 | 1 | 2 |
| **Picture** | | | | | | | |
| paph_argus | Correct | Unknown | Correct | Unknown 2/7 | Correct | Correct | Correct |
| Paptonsum_blaine | Correct | Unknown | Unknown | Correct | Unknown | Unknown | Unknown |
| Paphtonsum_elle | Unknown | Incorrect 1 | Incorrect 3 | Unknown | Incorrect 3 | Incorrect 1 | Unknown |
| Paphwardii | Incorrect 3 | Incorrect 3 | Correct | Incorrect 3 | Incorrect 3 | Incorrect 3 | Unknown |

Legend Incorrect/Unknown

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |

The order in Unknown x/y is <best_score>/<lower_score>. No numbers? All scores are negative!

**Table 4 Results of first test of *Paphiopedilum* section *Brachypetalum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

### *Paphiopedilum* sect. *Brachypetalum* run1

| ANN | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|
| Desired Error | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| Time to classify (s) | 8 | 7 | 7 | 7 | 7 | 7 | 8 |
| **Pictures** | | | | | | | |
| bellatum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| concolor1 | Correct | Unknown 6/1 | Correct | Correct | Unknown | Correct | Correct |
| concolor2_2 | Correct | Correct | Unknown 6/1 | Correct | Unknown 6/1 | Correct | Correct |
| concolor2_4 | Correct | Correct | Correct | Correct | Correct | Unknown 6/3 | Correct |
| concolor2_6 | Correct | Unknown 6/1 | Unknown 6/1(low) | Correct | Unknown 6/1 | Correct | Correct |
| concolor2 | Correct | Correct | Correct | Correct | Unknown 6/3 | Unknown | Correct |
| godefroyae1 | Unknown 6/1(low) | Unknown | Unknown 6/7 | Unknown 6/1 | Unknown 7/6 | Correct | Correct |
| godefroyae2_11 | Unknown 6/3 | Correct | Unknown 6/3 | Correct | Correct | Correct | Correct |
| godefroyae2_13 | Correct | Unknown | Unknown 1/3 | Correct | Correct | Correct | Correct(low) |
| godefroyae2_15 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Unknown 6/3 |
| godefroyae2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_9 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| niveum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| niveum2_4 | Unknown 6/2(low) | Correct | Correct | Correct | Correct | Correct | Correct |
| niveum2_5 | Correct | Correct | Correct | Correct | Correct | Unknown | Correct |
| niveum2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |

1:*Parvisepalum*   2:*Pardalopetalum*   3:*Paphiopedilum*   4:*Coryopedilum*   5: *Cochlopetalum*

6:*Brachypetalum*   7:*Barbata*

The order in Unknown x/y is <best_score>/<lower_score>. No numbers? All scores are negative!

**Table 5 Results of first test of *Paphiopedilum* section *Coryopedilum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

| | *Paphiopedilum* sect. *Coryopedilum* run1 | | | | | | |
|---|---|---|---|---|---|---|---|
| **ANN** | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Pictures** | | | | | | | |
| glanduliferum3 | Incorrect 3 | Unknown | Unknown | Incorrect 3 | Incorrect 3 | Unknown | Unknown |
| rothschildianium1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| wilhelminiae1 | Unknown | Unknown 4/3 | Unknown | Unknown | Correct | Correct | Correct |
| philippinense1 | Correct | Correct | Unknown | Incorrect 1 | Unknown | Unknown | Unknown |
| rothschildianium2 | Unknown 4/5 | Unknown | Incorrect 1 | Correct | Correct | Correct | Correct |
| rothschildianium3 | Correct | Correct | Incorrect 1(low) | Incorrect 1(low) | Unknown | Unknown 3/4 | Correct |

Legend Incorrect/Unknown

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |

**Table 6 Results of first test of *Paphiopedilum* section *Parvisepalum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

| | | | *Paphiopedilum* sect. *Parvisepalum* run1 | | | | |
|---|---|---|---|---|---|---|---|
| **ANN** | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 15 | 15 | 15 | 15 | 14 | 15 | 15 |
| **Pictures** | | | | | | | |
| armeniacum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_8 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii1 | Correct | Unknown | Unknown | Unknown | Correct | Correct | Correct(low) |
| delenatii2_2 | Correct | Correct(low) | Correct | Correct | Correct | Correct | Unknown 1/7 |
| delenatii2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii2 | Correct | Correct | Correct | Correct | Unknown 7/1 | Correct | Correct |
| emersonii1 | Unknown 3/1 | Unknown | Correct | Incorrect 3(low) | Correct | Correct | Unknown |
| emersonii2_1 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Unknown | Incorrect 3 |
| emersonii2_3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| emersonii2_5 | Correct | Correct | Unknown 1/3 | Correct(low) | Correct | Correct | Correct |
| malipoense1 | Correct | Correct | Unknown 3/1 | Unknown | Incorrect 3(low) | Correct | Incorrect 3 |
| malipoense2_10 | Correct | Correct | Correct | Correct | Unknown 1/7 | Correct | Correct |
| malipoense2_12 | Correct | Correct | Unknown 3/1 | Correct | Correct | Correct | Correct |
| malipoense2_14 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_16 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_18 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_2 | Correct | Correct | Correct | Correct | Correct | Unknown 1/3 | Correct |

| | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|
| malipoense2_4 | Unknown 1/7 | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_8 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2 | Unknown | Unknown | Unknown | Correct | Correct | Unknown | Correct |
| malipoense3 | Correct | Unknown | Incorrect 7 | Unknown | Correct | Unknown | Correct |
| micranthum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_11 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_13 | Correct | Correct | Unknown | Correct | Correct | Unknown | Correct |
| micranthum2_15 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_17 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_19 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct(low) |
| micranthum2_21 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_5 | Correct | Correct | Incorrect 3 | Correct | Incorrect 3 | Unknown | Unknown |
| micranthum2_7 | Correct (very low) | Correct | Unknown 7/1(low) | Correct | Incorrect 7 | Incorrect 5 | Unknown |
| micranthum2_9 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2 | Correct | Unknown 1/6 | Correct | Correct | Correct | Correct | Correct |
| micranthum3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| **Picture** | **41** | **42** | **43** | **44** | **45** | **46** | **47** |

1:*Parvisepalum*  2:*Pardalopetalum*  3:*Paphiopedilum*  4:*Coryopedilum*  5: *Cochlopetalum*
6:*Brachypetalum*  7:*Barbata*

The order in Un-known x/y is <best_sore>/<lower_score>. No numbers? All scores are negative

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**Table 7 Results of first test of hybrids of *Paphiopedilum* sect. *Parvisepalum* and *Brachypetalum*. Red: incorrect classified. Green: Correct classification to one of the parental sections. Green and bold: Correct classification to both parental sections. Yellow background and brown text: Unable to classify.**

| *Paphiopedilum* sect. *Parvisepalum* X *Brachypetalum* run1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANN | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| Desired Error | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| Time to classify (s) | 7 | 5 | 5 | 5 | 5 | 4 | 5 |
| Pictures | | | | | | | |
| armeniacumXconcolor2 | Unknown | 1 | 1 | 1 | 1 | 1 | 1 |
| delenatiiXniveum2 | 1 | Unknown | Unknown | 6 | Unknown | 1 | Unknown |
| armeniacumXconcolor1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| armeniacumXconcolor6 | 6 | *1&6* | 1 | 1 | 1 | 1 | 1 |
| emersoniiXbellatulum | 3&1 | 1 | 1&7 | Unknown | Unknown | 3 | 1 |
| delenatiiXniveum1 | 6 | 6 | 6 | Unknown | 6(low) | 6 | 6 |
| armeniacumXconcolor5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| armeniacumXconcolor4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Legend

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |

## 5. Results of characteristic research

Table 8 Characteristics o*f Paphiopedilum* section *Barbata*

### *Paphiopedilum* sect. *Barbata*

| Characteristics | argus1* | argus2_2§ | mastersianum1* | mastersianum2_5§ | tonsum1*$ | tonsum2_2§ |
|---|---|---|---|---|---|---|
| | | | | | | |
| spathulate petals | ! | ✓ | ✓ | ✓ | ! | ✓ |
| spotted and/or warted petals | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ |
| incurved side lobes | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Note | artificial white patches caused by scanning | | artificial white patches caused by scanning | | artificial white patches caused by scanning + Small pic. | artificial white patches caused by scanning |

| Characteristics | tonsum2* | tonsum3* | wardii1* | wardii2_1§ |
|---|---|---|---|---|
| | | | | |
| spathulate petals | ✓ | ✓ | ✗ | ✓ |
| spotted and/or warted petals | ✓ | ✓ | ✓ | ✓ |
| incurved side lobes | ✓ | ✓ | ✓ | ✓ |
| Note | artificial white patches caused by scanning | artificial white patches caused by scanning | artificial white patches caused by scanning | |

| | |
|---|---|
| ✓ | Visible |
| ! | Difficult to see |
| ✗ | Invisible |
| * | Picture scanned from Cribb, 1998 |
| § | Picture from dear.smartweb.tw |
| Name | Incorrectly identified to sectional level in max 1 of the 7 different networks |
| Name | Incorrectly identified to sectional level in max 3 of the 7 different networks |
| Name | Incorrectly identified to sectional level in more than 3 of the 7 networks |

**Table 9 Characteristics of *Paphiopedilum* section *Brachypetalum*.**

## *Paphiopedilum* sect. *Brachypetalum*

| Characteristics | concolor1* | concolor2_2§ | concolor2_4§ | concolor2_6§ | concolor2* |
|---|---|---|---|---|---|
| | | | | | |
| variously ornamented with purple spots | ✔ | ✔ | ✔ | ✔ | ✔ |
| broad-elliptic petals | ✔ | ✔ | ✔ | ✔ | ! |
| small lip | ✔ | ✔ | ✔ | ✔ | ✔ |
| ovoid lip | ✔ | ✔ | ✔ | ✘ | ✔ |
| lip with incurved margin | ✔ | ✘ | ✔ | ✔ | ✔ |
| pale yellow or white flower | ✘ | ✔ | ✔ | ✔ | ✔ |

| | |
|---|---|
| ✔ | Visible |
| ! | Difficult to see |
| ✘ | Invisible |
| * | Picture scanned from Cribb, 1998 |
| § | Picture from dear.smartweb.tw |
| Name | Incorrectly identified to sectional level in max 1 of the 7 different networks |
| Name | Incorrectly identified to sectional level in max 3 of the 7 different networks |
| Name | Incorrectly identified to sectional level in more than 3 of the 7 networks |

Table 10 Characteristics of *Paphiopedilum* section *Coryopedilum*.

## *Paphiopedilum* sect. *Coryopedilum*

| Characteristics | rothschildianium1* | rothschildianium2* | rothschildianium3* |
|---|---|---|---|
| | | | |
| Long petals | ✓ | ✓ | ✓ |
| Petals hanging down | ✓ | ✓ | ✓ |
| Tapering petals | ✓ | ✓ | ✓ |
| Spirally twisted petals | ✓ | ✓ | ! |
| Warts on margins of petals | ✘ | ✘ | ✘ |
| Glandular at tip | ✘ | ✘ | ✘ |
| incurved side lobes | ✓ | ✘ | ✘ |

| | |
|---|---|
| ✓ | Visible |
| ! | Difficult to see |
| ✘ | Invisible |
| * | Picture scanned from Cribb, 1998 |
| § | Picture from dear.smartweb.tw |
| Name | Incorrectly identified to sectional level in max 1 of the 7 different networks |
| Name | Incorrectly identified to sectional level in max 3 of the 7 different networks |
| Name | Incorrectly identified to sectional level in more than 3 of the 7 networks |

**Table 11 Characteristics of *Paphiopedilum* section *Parvisepalum*.**

## *Paphiopedilum* sect. *Parvisepalum*

| Characteristics | delenatii1* | delenatii2_2§ | delenatii2_4§ | delenatii2_6§ | delenatii2* |
|---|---|---|---|---|---|
| | | | | | |
| broad-elliptic petals | ✓ | ✓ | ✓ | ✓ | ✓ |
| subcircular petals | ✓ | ✓ | ✓ | ✓ | ! |
| large staminode | ✓ | ✓ | ✓ | ✓ | ✓ |
| cream/yellow coloured petals | ✗ | ✓ | ✓ | ✓ | ✗ |
| Note | artificial white patches caused by scanning | | | | artificial brown patches caused by scanning |

| Characteristics | emersonii1* | emersonii2_1§ | emersonii2_3§ | emersonii2_5§ | malipoense1* |
|---|---|---|---|---|---|
| | | | | | |
| broad-elliptic petals | ✓ | ✓ | ✓ | ✓ | ✓ |
| subcircular petals | ✓ | ✓ | ✓ | ✓ | ✗ |
| large staminode | ✓ | ✓ | ✓ | ✓ | ✓ |
| cream/yellow coloured petals | ✗ | ✗ | ✓ | ✗ | ✓ |
| Note | artificial white patches caused by scanning | Flower dark | | Flower grey/ blue like | |

| Characteristics | malipoense2_10§ | malipoense2_12§ | malipoense2_14§ | malipoense2_8§ | malipoense2* |
|---|---|---|---|---|---|
| | | | | | |
| broad-elliptic petals | ✓ | ✓ | ✓ | ✓ | ! |
| subcircular petals | ✓ | ✓ | ✓ | ✓ | ✗ |
| large staminode | ✓ | ✓ | ✓ | ✓ | ✓ |
| cream/yellow coloured petals | ✓ | ✓ | ✓ | ✓ | ✗ |
| Note | | | | | Not fully frontal |

| Characteristics | malipoense3* | malipoense2_16§ | malipoense2_18§ | malipoense2_2§ | malipoense2_4§ |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| broad-elliptic petals | ! | ✓ | ✓ | ✓ | ✓ |
| subcircular petals | ✗ | ✓ | ✓ | ✓ | ✓ |
| large staminode | ✓ | ✓ | ✓ | ✓ | ✓ |
| cream/yellow coloured petals | ✗ | ✓ | ✓ | ✓ | ✓ |
| Note | Not fully frontal |  |  |  |  |

| Characteristics | malipoense2_6§ |
|---|---|
|  |  |
| broad-elliptic petals | ✓ |
| subcircular petals | ✓ |
| large staminode | ✓ |
| cream/yellow coloured petals | ✓ |

| | |
|---|---|
| ✓ | Visible |
| ! | Difficult to see |
| ✗ | Invisible |
| * | Picture scanned from Cribb, 1998 |
| § | Picture from dear.smartweb.tw |
| Name | Incorrectly identified to sectional level in max 1 of the 7 different networks |
| Name | Incorrectly identified to sectional level in max 3 of the 7 different networks |
| Name | Incorrectly identified to sectional level in more than 3 of the 7 networks |

## 6. Results of second test run

Table 12 Results of second test run of *Paphiopedilum* section *Barbata*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.

| | *Paphiopedilum* sect. *Barbata* run2_1 | | | | | | |
|---|---|---|---|---|---|---|---|
| **ANN** | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 17 | 15 | 14 | 15 | 16 | 14 | 14 |
| **Pictures** | | | | | | | |
| acmodontum1 | Unknown 1/2 | Incorrect 1 | Incorrect 1 | Incorrect 1 | Unknown 7/1 | Incorrect 1 | Incorrect 1 |
| appletonianum1 | Incorrect 1 | Unknown | Incorrect 3(low) | Incorrect 6 | Unknown | Unknown | Incorrect 1 |
| argus1 | Unknown 7/3 | Correct | Correct | Unknown | Incorrect 3 | Correct | Unknown 7/3 |
| argus2_2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| barbatum1 | Unknown | Unknown | Incorrect 3 | Incorrect 3 | Incorrect 1 | Unknown 3/7 | Incorrect 3 |
| barbatum2_2 | Unknown | Incorrect 5 | Unknown 7/3(low) | Unknown | Incorrect 4 | Incorrect 5 | Unknown |
| bougainvilleanum1* | Unknown 7/3 | Incorrect 3 | Correct | Correct | Unknown 3/7 | Unknown 7/3 | Unknown 7/3 |
| bullenianum1 | Incorrect 1 | Incorrect 1(low) | Unknown | Unknown | Incorrect 1 | Incorrect 3 | Unknown |
| callosum1 | Unknown 6/3 | Incorrect 3 | Incorrect 6 | Unknown 3/6 | Incorrect 6 | Incorrect 6 | Unknown |
| callosum2 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 |
| callosum3 | Correct | Unknown | Unknown | Correct | Correct | Correct | Correct |
| dayanum1 | Unknown | Unknown | Unknown | Unknown | Incorrect 6 | Incorrect 6(low) | Unknown |
| dayanum2_3 | Incorrect 4(low) | Unknown 1/7 | Unknown | Unknown | Unknown | Unknown 4/7 | Unknown |
| dayanum2 | Incorrect 3(low) | Incorrect 3 | Unknown 5/4 | Unknown | Unknown | Unknown | Incorrect 5 |
| fowliei1* | Unknown low:3/7 | Unknown 3/7(low) | Correct | Incorrect 3 | Incorrect 3(low) | Incorrect 3 | Unknown |
| fowliei2* | Incorrect 3 | Incorrect 3 | Incorrect 3(low) | Unknown | Incorrect 3 | Incorrect 3(low) | Incorrect 3 |
| hennisianum1 | Unknown | Incorrect 1(low) | Unknown | Unknown | Incorrect 1 | Incorrect 1 | Incorrect 1 |
| hennisianum2_1 | Correct | Incorrect 3 | Correct | Correct | Unknown 7/3 | Correct | Correct |
| hennisianum2 | Incorrect 3(low) | Unknown | Unknown | Unknown | Unknown | Unknown | Incorrect 3 |
| hookerae1 | Incorrect 3 | Incorrect 3 | Unknown 3/7 | Incorrect 3 | Incorrect 3 | Unknown | Incorrect 3 |
| hookerae2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| javanicum1* | Correct | Correct | Correct | Correct | Correct | Unknown 7/3 | Correct |

| | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
|---|---|---|---|---|---|---|---|
| javanicum2* | Unknown | Incorrect 1 | Correct | Correct(low) | Unknown 7/1 | Unknown 7/1 | Incorrect 1(low) |
| lawrenceanum1 | Incorrect 4 | Unknown | Correct | Unknown | Unknown | Unknown | Unknown |
| mastersianum1 | Unknown | Correct | Unknown 7/3(low) | Correct | Correct | Correct | Correct(low) |
| mastersianum2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| papuanum1* | Unknown 4/7/1(L) | Unknown | Unknown 7/6/1 | Unknown | Correct | Unknown 3/7(low) | Incorrect 5 |
| purpuratum1 | Incorrect 1 | Incorrect 1 | Incorrect 1 | Unknown 1/3(low) | Unknown | Incorrect 1 | Incorrect 1 |
| purpuratum2_1 | Unknown 7/3 | Unknown 7/5 | Correct | Correct | Correct | Correct | Correct |
| purpuratum2 | Incorrect 1 | Unknown 7/1 | Unknown 1/7 | Unknown 1/7 | Unknown 7/1 | Incorrect 1 | Incorrect 1 |
| schoseri1* | Unknown | Unknown | Unknown | Unknown | Incorrect 6 | Unknown | Incorrect 1 |
| sukhakulii1 | Incorrect 1 | Unknown 1/7(low) | Incorrect 3 | Incorrect 1 | Incorrect 4 | Incorrect 1 | Unknown |
| superbiens1§ | Unknown | Unknown 7/3 | Correct | Correct(low) | Unknown 3/7(L) | Unknown | Correct |
| tonsum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| tonsum2_2 | Correct | Correct | Incorrect 5 | Correct | Correct | Correct | Correct |
| tonsum2 | Unknown | Correct | Correct | Unknown | Correct | Correct | Correct |
| tonsum3 | Correct | Incorrect 3 | Correct | Correct | Unknown | Incorrect 3 | Unknown |
| urbanianum1 | Correct | Unknown 7/1(low) | Incorrect 3 | Unknown | Unknown | Unknown | Incorrect 3(low) |
| urbanianum2_3 | Correct(low) | Correct | Correct | Correct(low) | Correct | Correct(low) | Correct |
| violascens1 | Unknown 3/7(low) | Incorrect 3 | Incorrect 3 | Unknown | Correct(low) | Unknown | Incorrect 3 |
| violascens2 | Unknown 7/3 | Incorrect 3(low) | Incorrect 3(low) | Correct | Unknown 3/7 | Unknown | Incorrect 3 |
| wardii1 | Incorrect 1 | Unknown 1/3(low) | Incorrect 1 | Incorrect 1 | Unknown 3/1 | Incorrect 1 | Unknown |
| wardii2_1 | Correct | Correct | Correct | Correct | Correct | Correct | Unknown 1/7(low) |
| wentworthianum1* | Correct | Unknown | Unknown | Correct(low) | Unknown | Unknown | Unknown |
| wentworthianum2* | Unknown | Unknown | Correct | Unknown | Unknown | Unknown | Unknown |
| **Pictures** | 51 | 52 | 53 | 54 | 55 | 56 | 57 |

| | |
|---|---|
| | *= not in train set / on dear.smartweb.tw |
| | §= only var. Curtisii in train set. |

1:*Parvisepalum*  2:*Pardalopetalum*  3:*Paphiopedilum*  4:*Coryopedilum*  5: *Cochlopetalum*
6:*Brachypetalum*  7:*Barbata*  L:low
The order in Unknown x/y is \<best_sore>/\<lower_score>. No numbers? All scores are negative

**Table 13 Results of second test of the extra pictures of *Paphiopedilum* section *Barbata*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

| | *Paphiopedilum* sect. *Barbata* run2_2 | | | | | | |
|---|---|---|---|---|---|---|---|
| **ANN** | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | | | | | | | |
| paph_argus | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| Paptonsum_blaine | Incorrect 1(low) | Unknown | Unknown | Correct(low) | Correct | Correct | Correct |
| Paphtonsum_elle | Incorrect 1 | Incorrect 3(low) | Unknown | Unknown | Unknown | Incorrect 1 | Incorrect 1(low) |
| Paphwardii | Incorrect 3 | Incorrect 3 | Unknown 3/6 | Incorrect 3 | Unknown 3/7 | Unknown | Incorrect 3 |

Legend Incorrect/Unknown

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |

The order in Unknown x/y is <best_score>/<lower_score>/ No numbers? All scores are negative

**Table 14 Results of second test run of *Paphiopedilum* section *Brachypetalum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

## *Paphiopedilum* sect. *Brachypetalum* run2

| ANN | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
|---|---|---|---|---|---|---|---|
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 7 | 7 | 8 | 7 | 7 | 6 | 7 |
| **Pictures** | | | | | | | |
| bellatum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| concolor1 | Correct | Correct | Correct | Unknown | Correct | Correct | Correct |
| concolor2_2 | Correct | Unknown 6/1 | Unknown 6/1 | Correct | Unknown 6/1 | Unknown 6/1 | Correct |
| concolor2_4 | Correct | Correct | Unknown 6/1 | Unknown 6/1 | Correct | Unknown 6/1 | Correct |
| concolor2_6 | Correct | Correct | Unknown 6/1 | Correct | Unknown 6/1 | Unknown 6/1 | Correct |
| concolor2 | Correct | Correct | Correct | Correct | Unknown | Correct | Correct |
| godefroyae1 | Unknown | Unknown | Unknown 6/7 | Correct | Unknown 6/1 | Incorrect 1 | Incorrect 1 |
| godefroyae2_11 | Correct | Unknown | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_13 | Correct | Unknown | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_15 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2_9 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| godefroyae2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| niveum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| niveum2_4 | Unknown | Correct | Correct | Correct | Correct | Unknown 6/1 | Correct |
| niveum2_5 | Correct | Correct | Unknown 6/3(low) | Unknown | Correct | Correct | Correct |
| niveum2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |

| | | | |
|---|---|---|---|
| 1:Parvisepalum | 2:Pardalopetalum | 3:Paphiopedilum | 4:Coryopedilum |
| 5: Cochlopetalum | 6: Brachypetalum | 7:Barbata | |

The order in Unknown x/y is <best_sore>/<lower_score>. No numbers? All scores are negative!

**Table 15 Results of second test of *Paphiopedilum* section *Coryopedilum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

### *Paphiopedilum* sect. *Coryopedilum* run2

| ANN | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
|---|---|---|---|---|---|---|---|
| Desired Error | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| Time to classify (s) | 3 | 3 | 3 | 2 | 2 | 3 | 2 |
| **Picture** | | | | | | | |
| glanduliferum3 | Correct | Correct | Unknown | Correct | Unknown 4/3 | Unknown | Correct |
| rothschildianium1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| wilhelminiae1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| philippinense1 | Correct | Unknown 4/1 | Correct | Correct | Unknown 4/6 | Correct | Correct |
| rothschildianium2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| rothschildianium3 | Correct | Correct | Correct | Unknown | Correct | Correct | Correct |

Legend Incorrect/Unknown

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |

The order in Unknown x/y is <best_score>/<lower_score>/ No numbers? All scores are negative

**Table 16 Results of second test of *Paphiopedilum* section *Parvisepalum*. Red: incorrect classified. Green: Correct classified. Yellow background and brown text: Unable to classify (to one section). Yellow background and green text: Unable to classify to one section, but the correct one is in the options.**

| | *Paphiopedilum* sect. *Parvisepalum* run2 | | | | | | |
|---|---|---|---|---|---|---|---|
| **ANN** | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 15 | 14 | 14 | 14 | 15 | 14 | 14 |
| **Picture** | | | | | | | |
| armeniacum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_5 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| armeniacum2_8 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii1 | Unknown | Correct | Unknown | Correct | Correct | Correct | Unknown |
| delenatii2_2 | Correct | Correct | Correct | Correct | Unknown | Correct | Unknown |
| delenatii2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| delenatii2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| emersonii1 | Unknown low:1/3 | Correct | Correct | Correct | Incorrect 3 | Incorrect 3 | Unknown |
| emersonii2_1 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 | Incorrect 3 |
| emersonii2_3 | Unknown 1/3(low) | Correct | Correct | Unknown | Unknown 3/1 | Unknown 1/3 | Correct |
| emersonii2_5 | Unknown | Correct | Unknown | Unknown | Unknown | Unknown | Correct |
| malipoense1 | Correct | Unknown 1/3 | Unknown | Correct | Unknown 3/1(low) | Correct | Correct |
| malipoense2_10 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_12 | Correct | Correct | Correct | Correct | Incorrect 3 | Correct | Correct |
| malipoense2_14 | Correct | Correct | Correct | Unknown | Correct | Correct | Correct |
| malipoense2_16 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_18 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_2 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_4 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2_6 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |

| | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
|---|---|---|---|---|---|---|---|
| malipoense2_8 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| malipoense2 | Correct | Correct | Correct | Unknown | Correct | Correct | Correct |
| malipoense3 | Unknown | Unknown | Incorrect 7 | Unknown | Unknown | Incorrect 7 | Incorrect 7 |
| micranthum1 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_11 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_13 | Unknown | Unknown | Unknown | Correct | Unknown | Unknown | Unknown |
| micranthum2_15 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_17 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_19 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_1 | Correct(low) | Incorrect 5 | Incorrect 6 | Correct | Correct | Correct | Unknown |
| micranthum2_21 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_3 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2_5 | Unknown | Incorrect 7 | Unknown | Correct | Unknown | Unknown | Unknown 3/1 |
| micranthum2_7 | Correct | Correct | Correct | Correct | Correct | Correct | Correct(low) |
| micranthum2_9 | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| micranthum2 | Correct | Correct | Incorrect 4 | Correct | Unknown | Correct | Correct |
| micranthum3 | Correct | Correct | Unknown 1/4 | Correct | Correct | Correct | Correct |
| **Picture** | **51** | **52** | **53** | **54** | **55** | **56** | **57** |

| | | | | | |
|---|---|---|---|---|---|
| 1:*Parvisepalum* | 2:*Pardalopetalum* | 3:*Paphiopedilum* | 4:*Coryopedilum* | 5: *Cochlopetalum* |
| 6:*Brachypetalum* | 7:*Barbata* | | | |

The order in Un-known x/y is &lt;best_sore&gt;/&lt;lower_score&gt;. No numbers? All scores are negative!

Table 17 Results of second test of hybrids of *Paphiopedilum* sections *Parvisepalum* and *Brachypetalum*. Red: incorrect classified. Green: Correct classification to one of the parental sections. Green and bold: Correct classification to both parental sections. Yellow background and brown text: Unable to classify.

| *Paphiopedilum* sect. *Parvisepalum* X *Brachypetalum* run2 | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANN | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| **Desired Error** | 1,00E-04 | 1,00E-05 | 1,00E-06 | 1,00E-07 | 1,00E-08 | 1,00E-09 | 1,00E-10 |
| **Time to classify (s)** | 5 | 4 | 4 | 4 | 4 | 4 | 3 |
| **Picture** | | | | | | | |
| armeniacumXconcolor2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| delenatiiXniveum2 | Unknown | Unknown | 1 | 2(low) | Unknown | 1 | 6 |
| armeniacumXconcolor1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| armeniacumXconcolor6 | 1 | 1 | 1 | 1 | 1 | 1 | 1(low) |
| emersoniiXbellatulum | 1 | 1&3 | 1&3 | 1 | Unknown | Unknown | Unknown |
| delenatiiXniveum1 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| armeniacumXconcolor5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| armeniacumXconcolor4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Legend

| | | | |
|---|---|---|---|
| 1 | *Parvisepalum* | 2 | *Pardalopetalum* |
| 3 | *Paphiopedilum* | 4 | *Coryopedilum* |
| 5 | *Cochlopetalum* | 6 | *Brachypetalum* |
| 7 | *Barbata* | | |