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GAIA SOFTWARE

Document prepared by an expert from France

GAIA SOFTWARE

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Introduction:

1. GAIA is a software package developed and provided free of charge in English and French by France (GEVES), GAIA is the name of the Greek "mother earth" Goddess.

2. The aim of the software is to assist the crop expert in identifying for each candidate variety, the varieties which are close to the candidate and the varieties which are very different from the candidate.

3. How close or how different is based on simple computations on the observed characteristics, characteristic-by-characteristic of each pair comparison. Differences are summarised in a synthetic value which allow quantification of the size of the difference on a scale that the crop expert can manage and use over years.

4. GAIA has already been presented in 2003 at the 21st session of the Technical Working Party on Automation and Computer Programs (TWC) held in Tjele, Denmark (document TWC/21/4).

History of GAIA development:

5. In the late 1970s and in the 1980s a number of software programs were developed in different UPOV countries in order to assist crop experts in managing and performing computations on numerous data sets. Each UPOV member implements its own system, but cooperation and sharing is offered via UPOV. As an example, dissemination of the United Kingdom's DUST package was encouraged by UPOV and, in particular, TWC members.

6. GAIA has first been used in France since the 1980s, and has been made available to other UPOV members since 2004.

7. The first official use of GAIA, at the time named L.C.L.M **(**Logiciel de comparaison des lignées de maïs), was made in 1990. The software was written in C language and implemented on a central mini computer. The computations were fast enough, and the outputs followed the needs of the crop experts, but the program was not interactive. In 1997, the software was made usable on any Windows PC computer. In order to have a built-in database, and to be able to have a unique program in different languages (English and French are available, other languages could be used) WINDEV was selected. It also allowed a user-friendly machine-human interface to be included, with a number of facilities to select and navigate through the data and computations, depending of the need of the moment.
Since 2004 GAIA is distributed via CD ROM.

8. The following workshops were organised and run in order to show why and how to use GAIA: France 2005, Republic of Korea 2006, France and Romania 2007.

Dates for the first official use of GAIA in France:

- maize (1990)
- oilseed rape (1999)
- flax and linseed (2000)
- cereals (2002)
- peas (2003)

Purpose for the use of GAIA

9. GAIA is mainly used in management of reference collections.

10. In the first year of DUS trials depending on the species, the whole reference collection or a part of it is grown. When the whole reference collection is not grown, the selection of the reference varieties is made on the basis of the information received by the breeder, taking into account the possible differences between the breeder's description and the GEVES descriptions. In addition to the reference varieties selected on the basis of the descriptions of the new candidates, a number of reference varieties are grown to cover the whole range of expression.

11. Breeding programs in some crops follow a general trend (e.g. looking for specific disease resistance, earliness, etc). This is also taken into account in the selection of the reference varieties to include in the trials.

12. From the observations collected in this first-year trial, the second-year trial is prepared with two aims:

- to avoid including in the second-year trial reference varieties that are very different from all the candidates,
- to optimise the output of the trial: for example, having close varieties next to each candidate in the field, so facilitating the checking by crop experts on their successive visits.

Indication of the reduction of the number of reference varieties in the second year trial:

13. The table below illustrates with three crops how GAIA may reduce the number of pairs of comparisons in the second year of study.

	Maïze 2004	**Flax and linseed** 2004	**Winter oilseed rape** 2004
Number of pairs of comparisons in first year	860,472	500	21,753
Number of pairs of comparisons in second year **(remaining number of pairs%)**	↓ **GAIA** 1,151 **(0,13%)**	↓ **GAIA** 54 **(10%)**	↓ **GAIA** 1,444 **(7%)**
Size of reference collection	**2500 (lines)**	**150**	**400 (B,C,R lines)**

14. Document TWC/21/4 provided illustrations of how GAIA can be used on 1-9 scale, measurements, and isozymes.

Illustration of the use of GAIA on observed differences in maize in France:

15. We will illustrate the use of GAIA on some UPOV characteristics on 1 to 9 scales for Maize in France.

16. The principle for establishment of a super distinct threshold in GAIA for maize in France:

6 is the **threshold defined for "super distinction"** in maize.

- an extremely reliable difference is weighted as 6
- a very reliable difference is weighted as 3
- a reliable difference is weighted as 2

17. In other words

- at least 3 reliable differences,
- or 2 very reliable differences ,
- or 1 extremely reliable difference,

is needed to declare a reference variety as super distinct from a candidate.

18. The term "super distinct" has been introduced in GAIA, in order to clarify that GAIA is not used to set a threshold limit between distinct and non distinct on a given characteristic; as would do an expert on the basis of his knowledge in some ornamental crops, or on the basis of a statistical criterion on a forage crop through the use of COY method. When 2 varieties are "super distinct", the crop expert is convinced that there is no doubt that the differences are such that distinctness is very clear and would be found again in further field trials.

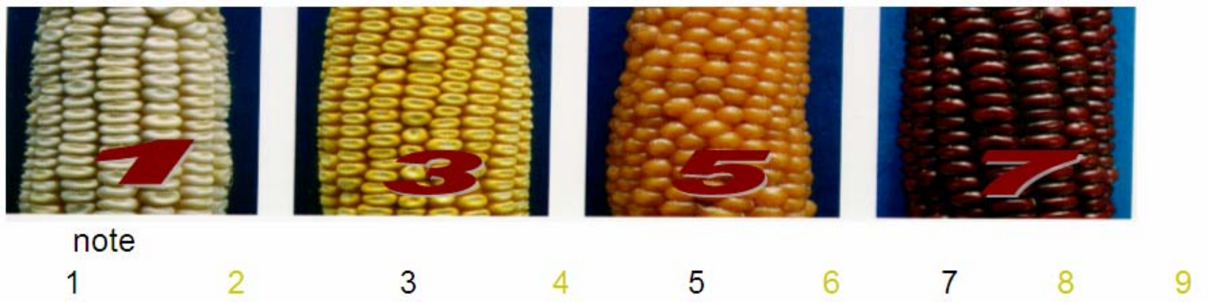
<u>Example on reliability of differences on three UPOV characteristics;</u>

Ear: Color of silks

Maize crop experts decided:

- differences of less than 3 notes will not be used at all (i.e. no use of a 5-7 difference)
- if there is a difference of 3, or more, notes between two lines, the same weight is used (i.e. a 1-4 difference will have the same weight as a 1-9 difference)
- a difference of 3 notes or more is very reliable (weight=3)

Ear: color of tip of grain



Maize crop experts decided:

- differences of less than 2 notes will not be used at all (i.e. no use of a 3-4 difference)
- if there is a difference of 2, or more, notes, between two lines, the same weight is used
- (i.e. a 1-3 difference will have the same weight as a 1-7 difference)
- a difference of 3 notes or more is very reliable (weight=3)

Tassel: angle between main axis and lateral branches

Maize crop experts decided:

- differences of less than 2 notes will not be used at all
- a difference of 2 notes is very reliable (weight 3)
- a difference of 3 notes is extremely reliable (weight 6)

These examples show that observed differences that are not considered as reliable enough do not contribute at all in the computation of a difference in a pair comparison.

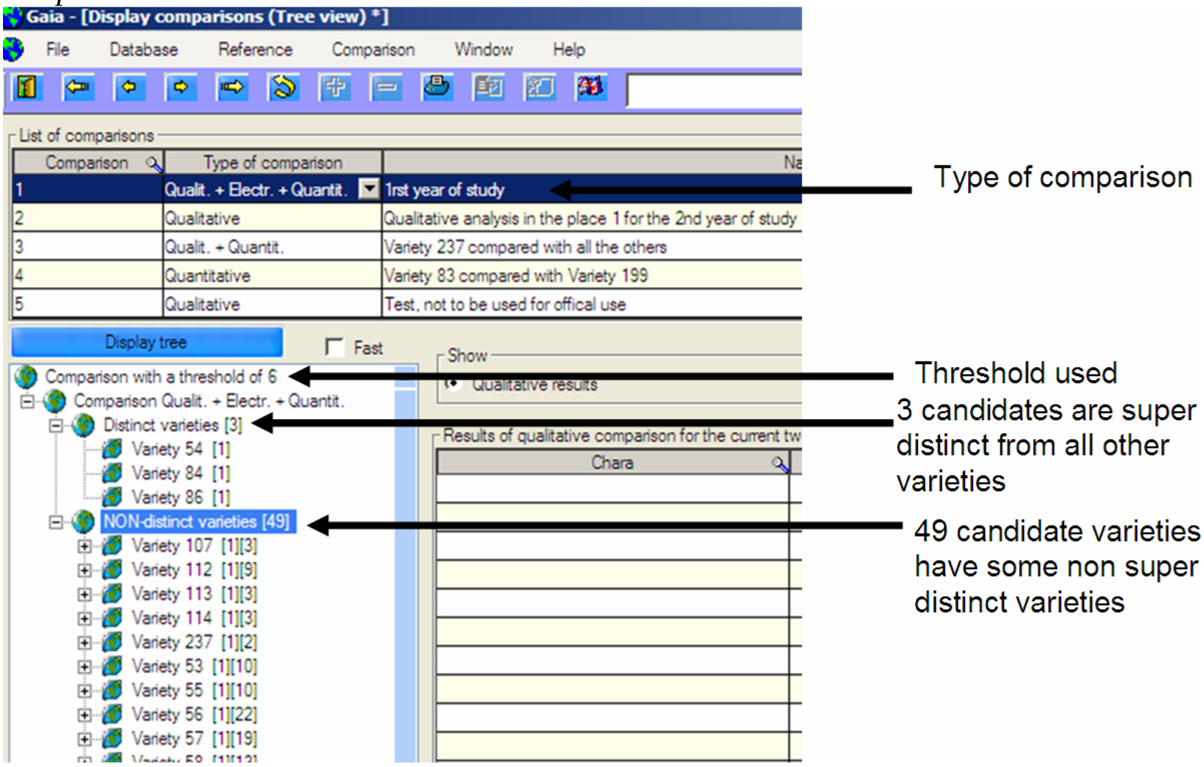
Illustration of GAIA outputs:

19. GAIA can store and retrieve a number of comparisons. For a given comparison, the threshold used is also recalled.

20. Usually the crop expert will ask for all pair comparisons of candidate varieties compared to all varieties (candidates and reference).

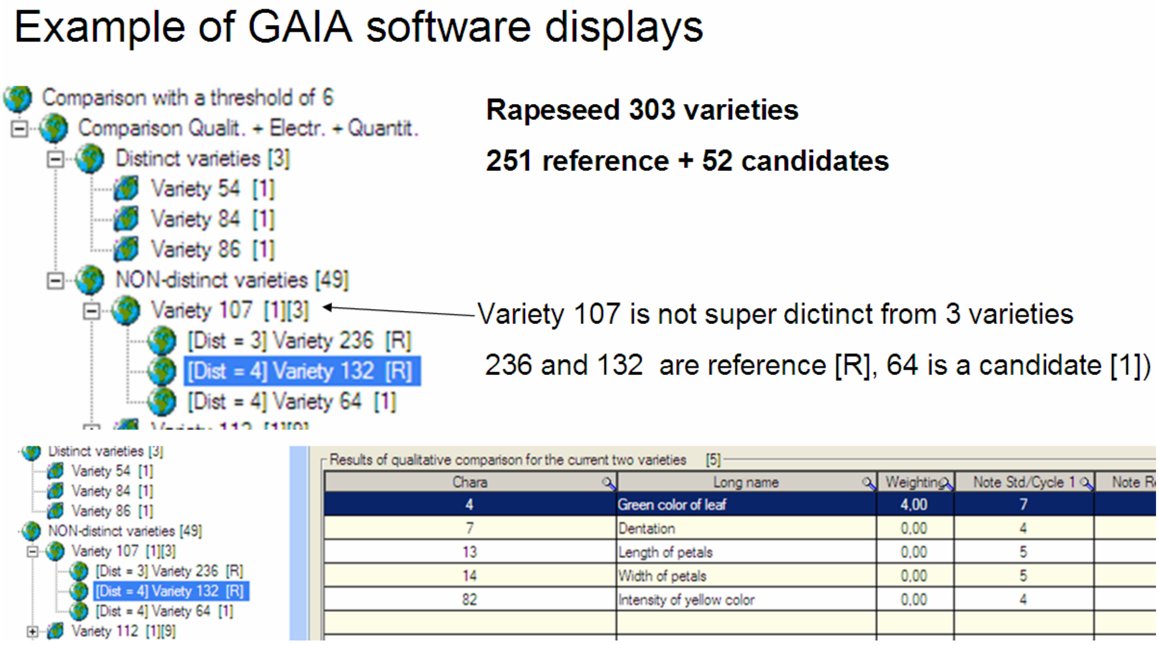
21. In the example below in screenshot 1, from 52 candidates in the first year of study, 3 varieties are super distinct from all candidates and reference varieties, and 49 candidates have a number of non super distinct varieties.

Screenshot 1: for a comparison with a threshold, GAIA offers a tree view facility on varieties compared.



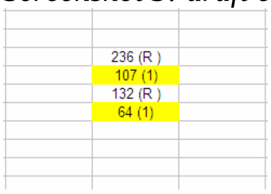
22. The display of Variety 107, shown below in screenshot 2 indicates that 2 reference varieties and 1 candidate could be placed nearby in the next trial, as the differences with candidate 107 are below the threshold.

Screenshot 2: at each branch of the tree view facility, a click will expand to a further branch (more detail), here screen 2 is obtained after a click on variety 107 from screenshot 1.



A possible layout for the second year trial is shown below in screenshot 3 below.
Candidate 107 is close to variety 236 and 132 and 64.
Candidate 64 is close to a number of varieties, including 132.
Crop experts design the next year trial by growing close varieties on nearby plots to facilitate the checks during the visits.

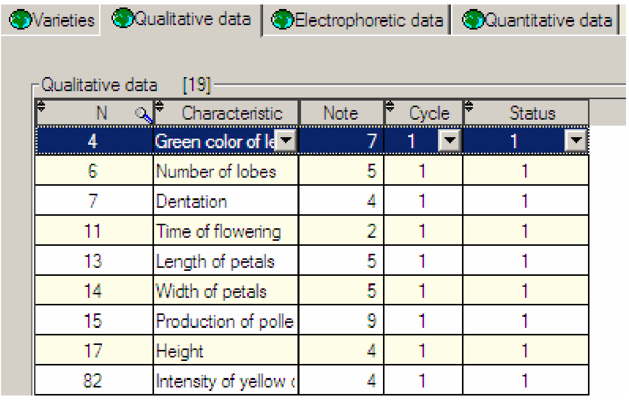
Screenshot 3: draft of trial design after GAIA computation



23. GAIA allows the production of various reports that can be seen, printed, filed, or sent by e_mail in different formats (Word, Excel, HTML, XML, PDF). Screenshots 4 and 5 illustrate some display views, and screenshots 6 and 7 illustrate some reports.

24. In the screen display below (screenshot 4) the nine qualitative characteristics observed on variety 107 are displayed because the folder **Qualitative data** is active. A click on the **Electrophoretic data** folder or on the **Quantitative data** folder allows the display of respectively electrophoretic data or quantitative data. The variety to view is selected from the left folder named **Varieties.**

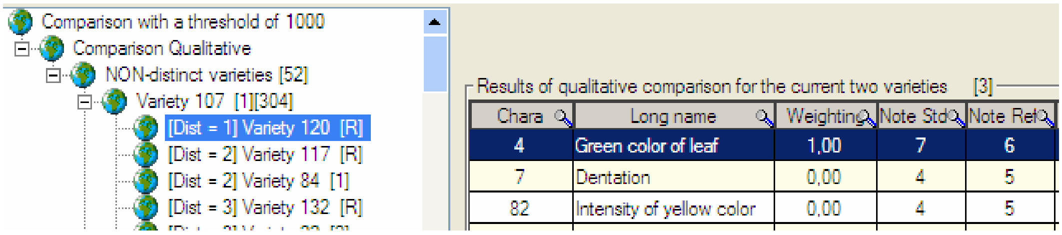
Screenshot 4: display of qualitative data available on variety 107:



N	Characteristic	Note	Cycle	Status
4	Green color of le	7	1	1
6	Number of lobes	5	1	1
7	Dentation	4	1	1
11	Time of flowering	2	1	1
13	Length of petals	5	1	1
14	Width of petals	5	1	1
15	Production of polle	9	1	1
17	Height	4	1	1
82	Intensity of yellow (	4	1	1

25. When displaying the pair comparison between variety 107 and variety 120, only the 3 qualitative characteristics in which the notes differ are shown (see screenshot 5 below). The 6 non displayed characteristics have the same note for the two varieties in comparison.

Screenshot 5: display of qualitative characteristics for which notes are different for the pair comparison variety 107 versus variety 120:



Chara	Long name	Weighting	Note Std	Note Ref
4	Green color of leaf	1,00	7	6
7	Dentation	0,00	4	5
82	Intensity of yellow color	0,00	4	5

.

26. In screenshot 5, the use of a high threshold (1000) allows the display of all possible pair comparisons, and thus allows the screen display and the creation of electronic reports which contain all comparisons when this is required, for instance for quality assurance purposes.

27. Quantitative or electrophoretic data can be displayed in their respective folders, if this type of data is used in the comparison. If quantitative or electrophoretic data are available in the database, but are not used for the comparison, they will neither be used nor displayed.

28. Screenshot 6 and screenshot 7 are two examples of electronic reports that can be produced by GAIA.

Screenshot 6: report of differences for pair comparison variety 107 versus variety 120 in HTML format:

Gaia

19/07/2007

Test, not to be used for offical use

GAIA NON-distinct varieties

Studied variety	2 431	Variety 107	(1)	Ql. = Phenotypic distance
Reference variety	139 105	Variety 120	(R)	1 = 1

Qualitative results

Charac.	Long name	Note Std / Cyc. 1	Note Ref / Cyc. 1	Note Std / Cyc. 2	Note Ref / Cyc. 2	Qual. Weighting
4	Green color of leaf	7	6	0	0	1
7	Dentation	4	5	0	0	0
82	Intensity of yellow color	4	5	0	0	0

Screenshot 7: report of differences for pair comparison variety 107 versus variety 120 in XML format:


```
<?xml version="1.0" encoding="ISO-8859-1" standalone="yes" ?>
- <DOCUMENT>
    <TEXT>Test, not to be used for offical use</TEXT>
    <TEXT>Gaia</TEXT>
    <TEXT>19/07/2007</TEXT>
    <TEXT>GAIA NON-distinct varieties</TEXT>
    <TEXT>Ql. = Phenotypic distance</TEXT>
    <TEXT>Studied variety</TEXT>
    <TEXT>2 431</TEXT>
    <TEXT>Variety 107</TEXT>
    <TEXT>1</TEXT>
    <TEXT>(</TEXT>
    <TEXT>)</TEXT>
    <TEXT>1 = 1</TEXT>
    <TEXT>Reference variety</TEXT>
    <TEXT>139 105</TEXT>
    <TEXT>Variety 120</TEXT>
    <TEXT>R</TEXT>
    <TEXT>(</TEXT>
    <TEXT>)</TEXT>
    <TEXT>Qualitative results</TEXT>
    <TEXT>Qual. Weighting</TEXT>
    <TEXT>Charac.</TEXT>
    <TEXT>Long name</TEXT>
```


<u>Conclusion:</u>

29. GAIA can use any type of UPOV characteristic, whether they are measurements, notes on a 1-9 scale, or supplementary evidence such as isozymes or proteins if they are included in the Test Guidelines. This is a unique and very interesting feature, as in many crops we observe different types of characteristics. As the software operates using a built-in database, the crop expert can store all the data that they will need, and select subsets of characters or varieties, as appropriate for his work.

30. The crop expert can define parameters for each characteristic, making transparent and objective his level of confidence on observed differences in the scale of measurement. These parameters can be discussed with other experts (e.g. breeders and experts from other UPOV members). This can encourage a better cooperation and harmonization. If parameters are set differently in one country to another, it is an accessible and understandable way to describe

the differences between the two countries, and assist in the use of results coming from the other country.

31. The Annex to this document contains a series of questions and answers on GAIA.

[Annex follows]

ANNEX

Below are examples of questions and answers from various discussions. Some questions are subject to controversy. The author raises them as an opportunity to let views and concerns be more widely known in order to reach a better understanding.

Some experts wonder if GAIA automatically sums very little differences in order to obtain a difference which in practice does not mean anything.

At each presentation and in workshops, we insist on the fact that differences in which the crop expert would not rely are simply set to zero by the system, so that the differences kept are only the reliable ones, and most of the time the threshold is set in order that, not only 1, but a number of reliable differences are observed before a variety is declared as super distinct.

Some experts asked whether GAIA could be used with historical date on reference varieties known from previous trials (specific year values, or averaged values).

GAIA is mainly used in France on data from the reference varieties and candidates grown in the same trial. This is the safest way to obtain comparable data, acknowledging that environment has an effect on observations.

The possibility of using past data from other trials should be looked at with caution, as values are influenced by the environmental conditions of the trials.

If this possibility is explored, various options can be studied, such as for instance:

- definition of an enlarged minimum difference between observations to allow for differences in trials.
- keeping only robust characteristics which are very little influenced by the environment.
- to always grow a sufficient number of reference varieties in each trial, and to adjust the historical data of absent reference varieties with an appropriate statistical model.

Some experts ask questions about the difficulty of establishing the decision rules on how to use observed differences.

GAIA needs the input of crop experts who know the crop, and the influence of the environment on the expression of the characteristics. Nevertheless, this is normally not an obstacle.

For characteristics that are measured, it is usually easy to compute LSDs (least significant differences) from individual trials or sets of trials.

COY can also be used to obtain such LSDs. COY is more sophisticated than a simple statistical analysis, because:

- It takes into account variety-by-year interaction to enlarge the LSD
- It can use the MJRA (modified joint regression analysis) to remove part of interaction
- It can be used at different alpha levels.

If LSDs are supposed to be the basis of a distinct/non distinct decision, the logic in GAIA is to use greater or enlarged LSD values, in order to take into account any potential interactions, and also to remain on the safe side.

Usually crop experts also have absolute or relative values that they believe will ensure that such a difference observed one year will indicate a clear and consistent difference in further trials.

Both types of values (enlarged LSDs, absolute or relative values) can be input in GAIA. For notes on a 1 to 9 scale, it is common practice not to rely on a 1 note difference on a scale during the study, but to look at differences of at least 2 notes. Of course this is a general statement, as for some characteristics that are greatly influenced by the environment crop experts would rely on differences of only 3 notes or more, while for other characters which have discrete and clearly separated states of expressions a difference of 1 can be enough.

Some experts wonder if GAIA is a statistical package

GAIA is not a statistical package, GAIA does not compute statistics.

Some parameters, such as the minimum difference to be taken into account can be derived from statistical analysis (Analysis of Variance, COY, …), but it is not compulsory, as experts can also define absolute differences (for instance 5 mm for a length characteristic, 5 days for a flowering date characteristic,…), or relative differences (for instance 20% of the average length of all varieties in trial for a length characteristic,…).

In many autogamous crops statistics are scarcely used. In ornamental crops statistics are almost never used and most crop experts are reluctant to use statistics. In allogamous crops the use of statistics is common (COY for instance on forage crops).

GAIA allows the use of statistical criteria computed by other software if the crop expert wishes, and does not require statistics if crop expert does not wish to use them. GAIA also offers the use of statistics for just a subset of the available characteristics.

Some experts wonder if GAIA is a black box

Sometimes crop experts make an expert decision on distinctness having considered all data available. In such circumstances the process to evaluate the threshold between distinct/non distinct is not formalised, and from the same data set two experts could draw different conclusions. In that respect GAIA is the opposite of a black box, as the way to use a given difference between two values is formally described in the parameters that are set by the crop expert, and these can be inspected and shared with other persons. Also, the outputs clearly show where differences were seen and how reliable these differences have been considered on each pair comparison. Furthermore, for a given characteristic the way to use a given difference is consistent for all pair comparisons, which might not always be the case in a non computerised process.

Statisticians might think that the parameters set by crop experts are not appropriate, and could be too lenient compared to what a statistical evaluation would bring. At the same time crop experts might think that statistical computations are not needed, or are a black box, as even if they understand the principle for computations, the choice of alpha level remains difficult to justify. In summary, statisticians may claim crop expertise is a black box for statisticians, and crop experts may claim that statistical computation is a black box for crop experts.

From experience, crop experts are most of the time more cautious than what the simple use of statistics provides. A common criticism about statistical values such as LSDs from crop experts is that statistical values are sometimes too small to be safe. As previously mentioned, if LSD is used to asses distinct/non distinct at end of 2 or 3 cycles, values that are greater than LSD have to be used in GAIA.

Furthermore statistical criteria will vary from computation to computation, whereas the crop experts usually prefer an absolute or a relative value that can be set and used over years. As previously mentioned statistical criteria, absolute or relative values can be used in GAIA. Those values are clearly visible in the screens and outputs. They can be documented, printed and filed to ensure transparency and traceability.

Some experts wonder if the use of GAIA is risky as it might be misused.

Any system can be misused, with any system you have to know and understand it in order to use it properly. An advantage of GAIA is that all data, rules, and results are stored in a database. So you can come back and look to what has been done previously.

GAIA is not more risky, or under less control, than other means providing the persons that use GAIA are transparent in their use of it and show how they used the software.

Some experts wonder if the introduction of GAIA in some UPOV documents is useful or premature.

GAIA already has a long history of use in France with formal support from the breeders, and this has contributed towards defining how the differences are used. The principle and the computations in GAIA are easier to understand than most of statistical models. A number of countries have shown interest and have tried GAIA. Some countries do not use GAIA because the need to define very different varieties and very close varieties at the end of year one is either not an issue, or would not lead to reduced workloads or costs in their conditions. Other countries have used GAIA and have seen some benefits.

If we look back to the introduction of COY in UPOV (in other documents than TWC documents) we can remember that the UPOV Office, successive TWC chairs and TWC members had to explain and support it time and again before COY was finally accepted as a recommended method to assess distinctness on measurements for some crops.

Some experts wonder if GAIA can be an opportunity to improve cooperation and sharing of knowledge.

The discussions on how to use the differences and their reliability are a good opportunity for experts within a country, or from different countries, to formalise and share their knowledge. It is also a way to identify characteristics that are considered similarly and others for which the confidence of experts vary. This can also help in the use of data received from colleagues in one’s own work. GAIA facilitates the sharing and exchange of data, and decision rules in the case of bilateral or multilateral agreements.

Comparisons of COY usage in different countries have shown the same kinds of features, some characteristics have little interaction and are useful in many countries, while other characteristics are of use in some countries and not in others. The level of variety-by-year interaction also varies from country to country which made the choice of a unique alpha level difficult. Despite these difficulties, the work on COY was a good way to promote the exchange of views and to enhance cooperation and harmonization within UPOV.

In Maize for instance GAIA results, along with other work such as the visiting of trials, has been used by experts from three countries. It helped improve harmonization in field notations. Data from the three countries are now regularly updated in a database used in each country at the time of trial planning.

Acknowledgments:

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[End of Annex and of document]