E

TGP/8.3 Draft 3
ORIGINAL: English
DATE: May 28, 2004

INTERNATIONAL UNION FOR THE PROTECTION OF NEW VARIETIES OF PLANTS

GENEVA

Associated Document
to
The General Introduction to the Examination
of Distinctness, Uniformity and Stability and the
Development of Harmonized Descriptions of New Varieties of Plants (document TG/1/3)

# DOCUMENT TGP/8

# "USE OF STATISTICAL PROCEDURES IN DISTINCTNESS, UNIFORMITY AND STABILITY TESTING"

## Section TGP/8.3: Types of Characteristics and Their Scale Levels

*Document prepared by experts from Germany*

*to be considered by the*

*Technical Working Party on Automation and Computer Programs (TWC),*
*at its twenty-second session to be held in Tsukuba, Japan, from June 14 to 17, 2004*

**SECTION 8.3**
**TYPES OF CHARACTERISTICS AND THEIR SCALE LEVELS**

Uwe Meyer and Beate Rücker
Bundessortenamt, Hannover, Germany

## 8.3.1 Introduction

For the revision of UPOV Test Guidelines or for establishing new ones, and in order to understand the relations between the different steps of work of the crop experts during the DUS test, it is necessary to have an answer to the following questions:

1. What is a characteristic?
2. What is a process level?
3. What is a scale level of a characteristic?
4. What is the influence of the scale level on the :
    - planning of a trial,
    - recording of data,
    - determination of distinctness and uniformity and
    - description of varieties?

## 8.3.2 Different levels to look at a characteristic

Characteristics can be considered in different levels of process (Table 1). The characteristics as expressed in the trial (type of expression) are considered as process level 1. The data taken from the trial for the assessment of distinctness, uniformity and stability are defined as process level 2. These data are transformed into states of expression for the purpose of variety description. The variety description is process level 3.

*Table 1: Definition of different process levels to consider characteristics*

| Process level | Description of the process level |
|---|---|
| 1 | characteristics as expressed in trial |
| 2 | data for evaluation of characteristics |
| 3 | variety description |

From the statistical point of view the information level decreases from process level 1 to 3. Statistical analysis is only applied in level 2.

Sometimes for crop experts it seems that there is no need to distinguish between different process levels. The process level 1, 2 and 3 could be identical. However, in general, this is not the case.

Understanding the need for process levels:

The crop expert looks for characteristics to examine distinctness, uniformity and stability, and knows from Test Guidelines or his own experience that, for example, 'Length of plant' is a good characteristic to differentiate between varieties. There are varieties in which the length of the plant is longer than other varieties. New varieties are expected to be uniform in this characteristic. Another characteristic could be 'Variegation of leaf blade'. For some varieties, variegation is present and for others not. The crop expert has now two characteristics and he knows that 'Plant length' is a quantitative characteristic and 'Variegation of leaf blade' is a qualitative one (definitions: see chapter 8.3.3). The expert observes the expression of the characteristics in the trial and has experience in expressions in the crop. But at this stage it has not yet been decided how the characteristics will be assessed and described. This stage of work is described as **process level 1.**

The crop expert then has to plan the trial and to decide on the type of observation for the characteristics. For characteristic 'Variegation of leaf blade', the decision is clear. There are two possible expressions: 'present' or 'absent'. The decision for characteristic 'Plant length' is not specific and depends on expected differences between the varieties and on the variation within the varieties. In many cases, the crop expert will decide to measure a number of plants (in cm) and to use special statistical procedures to examine distinctness and uniformity. But it could also be possible to assess the characteristic 'Plant length' visually by using expressions like 'short', 'medium' and 'long', if differences between varieties are large enough (for distinctness) and the variation within varieties is very small or absent in this characteristic. The continuous variation is assigned to appropriate states of expression which are recorded by notes. The crucial element in this stage of work is the recording of data for further evaluations. It is described as **process level 2**.

At the end of the DUS test, the crop expert has to establish a description of the varieties (**process level 3**). For 'Variegation of leaf blade' the crop expert can take the same states of expression (notes) he recorded in process level 2 and the three process levels appear to be the same. In cases where the crop expert decided to assess 'Plant length' visually, he can take the same states of expression (notes) he recorded in process level 2 and there is no obvious difference between process level 2 and 3. If the characteristic 'Plant length' is measured in cm, it is necessary to assign intervals of measurements to states of expressions like 'short', 'medium' and 'long' to establish a variety description. In this case, it is important to be clearly aware of the relevant level and to understand the differences between characteristics as expressed in the trial, data for evaluation of characteristics and the variety description. This is absolutely necessary for choosing the most appropriate statistical procedures in cooperation with statisticians or by the crop expert.

### 8.3.3 Types of expression of characteristics

In the 1991 Act of the UPOV Convention the term characteristics is used for the aspects of a variety which result from the expression of a given genotype or combination of genotypes and by which a variety can be defined.

Characteristics can be classified according to their types of expression or in other words according to their observed variation within the species. The consideration of the type of expression of characteristics corresponds with process level 1. The following types of expression of characteristics are defined in the General Introduction to the Examination of Distinctness, Uniformity and Stability and the Development of Harmonized Descriptions of New Varieties of Plants, (document TG/1/3, the "General Introduction", Chapter 4.4):

"Qualitative characteristics" are those that are expressed in discontinuous states (e.g. sex of plant: dioecious female (1), dioecious male (2), monoecious unisexual (3), monoecious hermaphrodite (4)). These states are self-explanatory and independently meaningful. All states are necessary to describe the full range of the characteristic, and every form of expression can be described by a single state. The order of states is not important. As a rule, the characteristics are not influenced by environment.

"Quantitative characteristics" are those where the expression covers the full range of variation from one extreme to the other. The expression can be recorded on a one-dimensional, continuous or discrete, linear scale. The range of expressions is divided into a number of states for the purpose of description (e.g. length of stem: very short (1), short (3), medium (5), long (7), very long (9)). The division seeks to provide, as far as practical, an even distribution across the scale. The Test Guidelines do not specify the difference needed for distinctness. The states of expression should, however, be meaningful for DUS assessment.

In the case of "pseudo-qualitative characteristics" the range of expression is at least partly continuous, but varies in more than one dimension (e.g. shape: ovate (1), elliptic (2), circular (3), obovate (4)) and cannot be adequately described by just defining two ends of a linear range. In a similar way to qualitative (discontinuous) characteristics – hence the term "pseudo-qualitative" – each individual state of expression needs to be identified to adequately describe the range of the characteristic.

The given classification of characteristics is based on the observations made by the crop expert, on what he can see in the tests and on his general experience in the specific crop. This classification is appropriate to give general recommendations for the definition of states of expression in the Technical Guidelines and to develop general rules for the assessment of distinctness, uniformity and stability.

### 8.3.4 Types of scales of data

The possibility to use specific procedures for the assessment of distinctness, uniformity and stability depends on the scale level of the data which are recorded for a characteristic. The scale level of data depends on the type of expression of the characteristic and on the way of recording this expression. The type of scale may be quantitative or qualitative.

4.1 Quantitatively scaled data

Quantitative data are all data which are recorded by measuring or counting. Weighing is a special form of measuring. Quantitative data can have a continuous or a discrete distribution. Continuous data result from measurements. They can take every value out of the defined range. Discrete quantitative data result from counting.

Examples:

| Quantitative data | Example | Example number |
|---|---|---|
| - continuous | Plant length in cm. | 1 |
| - discrete | Number of stamens | 2 |

For description of the states of expression, see Table 6.

The continuous quantitative data for the characteristic "Plant length" are measured on a continuous scale with defined units of assessment. It depends only on the costs and the necessity to get any value in cm or in mm. A change of unit of measurement e.g. from cm into mm is only a question of precision and not a change of type of scale.

The discrete quantitative data of the characteristic "Number of stamens " are assessed by counting (1, 2, 3, 4, and so on). The distances between the neighbouring units of assessment are constant and for this example equal to 1. There are no real values between two neighbouring units but it is allowed to compute an average which is between those units.

In biometrical terminology, quantitative scales are also designated as metric scales. A synonym for metric scale is cardinal scale. Quantitative scales can be subdivided into ratio scales and interval scales.

4.1.1 Ratio scale

A ratio scale is a quantitative scale with a defined absolute zero point. There is always a constant distance (different from zero) between two adjacent expressions. Ratio scaled data may be continuous or discrete.

The absolute zero point:

In the characteristic 'Plant length' assessed in cm it is obvious that there is a 'natural' lower limit for the expression which is '0 cm' (zero). It is possible to calculate the ratio of length of plant 'A' to length of plant 'B' by division:

Length of plant 'A' = 80 cm
Length of plant 'B' = 40 cm

Ratio = Length of plant 'A' / Length of plant 'B' = 80 cm / 40 cm = 2.

So it is possible in this example to state that plant 'A' is double the length of plant 'B'. The existence of an absolute zero point ensures an unambiguous ratio.

The characteristic 'Time of beginning of flowering' (Example 6 in Table 6) is defined as the number of days from April 1. The definition is useful but arbitrary and April 1 is not a natural limit. It would also be possible to define the characteristic as the number of days from January 1. But this date is not a natural limit either. In a leap year, February 29 leads to non-comparability of the number of days from January 1 over two years. Consequently there are different ratios.

Variety 'A' begins to flower on May 30 and variety 'B' on April 30

Case I) Number of days from April 1 of variety 'A' = 60
Number of days from April 1 of variety 'B' = 30

$$Ratio_I = \frac{\text{Number of days from April 1 of variety 'A'}}{\text{Number of days from April 1 of variety 'B}} = \frac{60 \text{ days}}{30 \text{ days}} = 2$$

Case II) Number of days from January 1 of variety 'A' = 150
Number of days from January 1 of variety 'B' = 120

$$Ratio_{II} = \frac{\text{Number of days from January 1 of variety 'A'}}{\text{Number of days from January 1 of variety 'B}} = \frac{150 \text{ days}}{120 \text{ days}} = 1.25$$

$Ratio_I = 2 > 1.25 = Ratio_{II}$

In this example, it is impossible to state that the time of flowering of variety 'A' is twice that of variety 'B'. The ratio depends on the choice of the zero point of the scale. In chapter 4.1.2 "Interval scale", this kind of scale is defined as an interval scale, a quantitative scale without a defined absolute zero point.

The ratio scale is the highest classification of the scales (Table 2). That means that ratio scaled data include the highest information about the characteristic and it is possible to use many statistical procedures (Chapter 7).

The examples 1 and 2 (Table 6) are examples for characteristics with ratio scaled data.

The definition of an absolute zero point makes it possible to define meaningful ratios. This is also a requirement for the construction of index numbers (e.g. the ratio of length to width). An index is the combination of at least two characteristics. In UPOV terms this special case is defined as a combined characteristic.

### 4.1.2 Interval scale

An Interval scale is a quantitative scale without a defined absolute zero point. There is always a constant distance (different from zero) between two adjacent expressions. Interval scaled data may be distributed continuously or discretely. An example for a discrete interval scaled characteristic is time of beginning of flowering measured as date which is given in chapter 4.1.1 (see also example 6 in Table 12).

An example of a characteristic with continuous interval scaled data is the relative measurement "Temperature in °C". It is probably impossible to find an example for this kind of scale in the UPOV Test Guidelines.

The interval scale is lower classified than the ratio scale (Table 2). Fewer statistical procedures can be used with interval scaled data than with ratio scaled data (Chapter 7). The interval scale is theoretically the minimum scale level to calculate arithmetic mean values.

## 4.2. Qualitatively scaled data

Qualitatively scaled data are data which can be arranged in discrete qualitative different categories. Usually they result from visual assessment. Subgroups of qualitative scales are ordinal and nominal scales.

4.2.1 Ordinal scale

Ordinally scaled data are qualitative data of which discrete categories can be arranged in an ascending or descending order. They result from visually assessed quantitative characteristics.

Example:

| Qualitative data | Example | Example number |
|---|---|---|
| - ordinal | Intensity of anthocyanin | 3 |

For description of the states of expressions, see Table 6.

An ordinal scale consists of numbers which correspond to the states of expression of the characteristic (notes). The expressions vary from one extreme to the other and thus they have a clear logical order. It is not possible to change this order, but it is not important which numbers are used to denote the categories. In some cases ordinal data may reach the level of discrete interval scaled data or of discrete ratio scaled data (Chapter 6)

The distances between the discrete categories of an ordinal scale are not exactly known and not necessarily equal. Therefore, an ordinal scale does not fulfil the condition to calculate arithmetic mean values, which is the equality of intervals throughout the scale.

The ordinal scale is lower classified than the interval scale (Table 2). Less statistical procedures can be used for ordinal scale than for each of the higher classified scale data (Chapter 7).

4.2.2 Nominal scale

Nominal scaled qualitative data are qualitative data without any logical order of the discrete categories.

Examples:

| Qualitative data | Example | Example number |
|---|---|---|
| - nominal | Sex of plant | 4 |
| - nominal with two states | Leaf blade: variegation | 5 |

For description of the states of expressions, see Table 6.

A nominal scale consists of numbers which correspond to the states of expression of the characteristic, which are referred to in the Test Guidelines as notes. Although numbers are used for designation there is no inevitable order for the expressions and so it is possible to arrange them in any order.

Characteristics with only two categories (dichotomous characteristic) are a special form of nominal scales.

The nominal scale is the lowest classification of the scales (Table 2). Only few statistical procedures are applicable for evaluations (Chapter 7).

The different types of scales are summarised in the following table.

*Table 2: Types of scales and scale levels*

| Type of scale | | Description | Distribution | Data recording | Scale Level |
|---|---|---|---|---|---|
| quantitative (metric) | ratio | constant distances with absolute zero point | Continuous | Absolute Measurements | High |
| | | | Discrete | Counting | |
| | interval | constant distances without absolute zero point | Continuous | Relative measurements | ↑ |
| | | | Discrete | Date | |
| qualitative with underlying quantitative variable | ordinal | Ordered expressions with varying distances | Discrete | Visually assessed notes | ↑ |
| qualitative | nominal | No order, no distances | Discrete | Visually assessed notes | Low |

From the statistical point of view a characteristic is only considered at the level of data which has been recorded, whether for analysis or for describing the expression of the characteristic. Therefore, characteristics with quantitative data are denoted as quantitative characteristics and characteristics with ordinal and nominal scaled data as qualitative characteristics.

### 8.3.5 Scale levels for variety description

The description of varieties is based on the states of expression (notes) which are given in the Test Guidelines for the specific crop. In the case of visual assessment, usually the notes from the Test Guidelines are used for recording the characteristic as well as for the assessment of DUS. As outlined in chapter 4, the notes are distributed on a nominal or ordinal scale. For measured or counted characteristics, DUS assessment is based on the recorded values and the recorded values are transformed into states of expression only for the purpose of variety description.

**8.3.6 Relation between types of expression of characteristics and scale levels of data**

Records taken for the assessment of qualitative characteristics are distributed on a nominal scale, for example "Sex of plant", "Leaf blade: variegation" (Table 6, examples 4 and 5).

For quantitative characteristics the scale level of data depends on the method of assessment. They can be recorded on a quantitative or ordinal scale. For example, "Length of plant" is usually recorded by measurements resulting in ratio scaled continuous quantitative data. Under specific circumstances, visual assessment on a 1 to 9 scale may be appropriate. In this case, the recorded data are qualitatively scaled (ordinal scale) because the size of intervals between the midpoints of categories is not exactly the same.

Remark: In some cases visually assessed data on quantitative characteristics may be handled as measurements. The possibility to apply statistical methods for quantitative data depends on the precision of the assessment and the robustness of the statistical procedures. In case of very precise visually assessed quantitative characteristics the usually ordinal data may reach the level of discrete interval scaled data or of discrete ratio scaled data.

A pseudo-qualitative type of expression is caused by a characteristic which varies in more than one dimension. The different dimensions are combined in one scale. At least one dimension is quantitatively expressed. The other dimensions may be qualitatively expressed or quantitatively expressed. The scale as a whole has to be considered as a nominal scale (e.g. "Shape", "Flower color"; Table 6, examples 7 and 8).

In the case of using the off-type procedure for the assessment of uniformity the recorded data are nominally scaled. The records fall into two qualitative classes: plants belonging to the variety (true-types) and plants not belonging to the variety (off-types). The type of scale is the same for qualitative, quantitative and pseudo-qualitative characteristics.

The relation between the type of characteristics (process level 1) and the type of scale of data recorded for the assessment of distinctness and uniformity is described in table 3. A qualitative characteristic is recorded on a nominal scale for distinctness (state of expression) and for uniformity (true-types vs. off-types). Pseudo-qualitative characteristics are recorded on a combined scale for distinctness (state of expression) and on a nominal scale for uniformity (true-types vs. off-types). Quantitative characteristics are recorded on an ordinal, interval or ratio scale for the assessment of distinctness depending on the characteristic and the way of assessment. If the records are taken from single plants the same data may be used for the assessment of distinctness and uniformity. If distinctness is assessed on the basis of a single record of a group of plants, uniformity has to be judged with the off-type procedure (nominal scale).

Table 3: Relation between type of characteristic and type of scale of assessed data

| Procedure | Type of scale (level 2) | Distribution | Type of characteristic (level 1) | | |
|---|---|---|---|---|---|
| | | | Quantitative | Pseudo-qualitative | Qualitative |
| Distinctness | ratio | Continuous | ▪ | | |
| | | Discrete | ▪ | | |
| | interval | Continuous | ▪ | | |
| | | Discrete | ▪ | | |
| | ordinal | Discrete | ▪ | | |
| | combined | Discrete | | ▪ | |
| | nominal | Discrete | | | ▪ |
| | | | | | |
| Uniformity | ratio | Continuous | ▪ | | |
| | | Discrete | ▪ | | |
| | interval | Continuous | ▪ | | |
| | | Discrete | ▪ | | |
| | ordinal | Discrete | ▪ | | |
| | combined | Discrete | ▪ | | |
| | nominal | Discrete | ▪ | ▪ | ▪ |

### 8.3.7 Relation between method of observation of characteristics, scale levels of data and recommended statistical procedures

The scale level of data and the way of observation of characteristics are most important conditions for the application of different statistical procedures. There are four possible ways to observe characteristics (see TGP/7 "Development of Test Guidelines"):

- measurements of a group of plants or parts of plants (MG)
- measurements of a number of single plants or parts of plants (MS)
- visual assessment of a group of plants or parts of plants (VG)
- visual assessment of a number of single plants or parts of plants (VS).

The observation method depends primarily on the variation within and between varieties and effects the choice of the statistical method. All of the four observation methods may be relevant for the assessment of distinctness. For the assessment of uniformity observations must be done on single plants. Consequently only MS or VS are appropriate. The indication of the method of observation of characteristics in the Technical Guidelines should refer to the assessment of distinctness.

Well-known statistical procedures can be recommended for the assessment of distinctness and uniformity considering the scale level and some further conditions like degree of freedom or unimodality (Tables 4 and 5).

The relation between the expression of characteristics and the scale levels of data for the assessment of distinctness and uniformity is summarized in Table 6.

Table 4: Statistical procedures for the assessment of distinctness

<table>
<tr><th>Type of scale</th><th>Distribution</th><th>Observation method</th><th>Procedure[1] and further Conditions</th><th>Reference</th></tr>
<tr><td rowspan="2">ratio</td><td>continuous</td><td rowspan="4">MS<br>MG<br>(VS)[2]</td><td rowspan="4">R: COY-D<br>Normal distribution, df >=20<br><br>R: long term LSD<br>Normal distribution, df<20<br><br>NR-P: 2 out of 3 method (LSD 1%)<br>Normal distribution, df>=20</td><td rowspan="4">TGP/9.7</td></tr>
<tr><td>discrete</td></tr>
<tr><td rowspan="2">interval</td><td>continuous</td></tr>
<tr><td>discrete</td></tr>
<tr><td>ordinal</td><td>discrete</td><td>VG<br><br>VS</td><td>R: minimum distance>=1<br><br>NR-D: threshold model</td><td><br><br>TWC/14/12</td></tr>
<tr><td>Combination of ordinal or ordinal and nominal scales</td><td>discrete</td><td>VG<br>(VS)[3]</td><td>R: state-by-state-comparison</td><td></td></tr>
<tr><td>nominal</td><td>discrete</td><td>VG<br>(VS)[3]</td><td>R: each state-is clearly different from the other</td><td></td></tr>
</table>

1) R - recommended
NR-P - not recommended (previous method)
NR-D - not recommended (method under development)
2) see remark in chapter 6
3) normally VG but VS would be possible

Table 5: Statistical procedures for the assessment of uniformity

| Type of scale | Distribu-tion | observa-tion method | Procedure[1)] and Further Conditions | Refe-rence |
|---|---|---|---|---|
| ratio | continuous | MS | R: COY-U<br>Normal distribution<br>NR-P: 2 out of 3 method<br>($s^2_c$<=1.6$s^2_s$))<br>Normal distribution<br>NR-D: LSD for untransformed percentage of off-types | TGP/ 10.3.1 |
| | discrete | MS | | |
| interval | continuous | VS | | |
| | discrete | | | |
| ordinal | discrete | VS | NR-D: threshold model | TWC/ 14/12 |
| Combina-tion of ordinal or ordinal and nominal scales | discrete | | There is no case where uniformity is assessed on combined scaled data | |
| nominal | discrete | VS | R: off-type procedure for dichotomous (binary) data | TGP/ 10.3.2 |

1) R - recommended
NR-P - not recommended (previous method)
NR-D - not recommended (method under development)

Table 6: Relation between expression of characteristics and scale levels of data for the assessment of distinctness and uniformity

| Example | Name of characteristic | Distinctness | | | Uniformity | | |
|---|---|---|---|---|---|---|---|
| | | Unit of assess-ment | Description (states of expression) | Type of scale | Unit of assess-ment | Description (states of expression) | Type of scale |
| 1 | Length of plant | cm | assessment in cm without digits after decimal point | ratio scaled continuous quantitative data | cm | assessment in cm without digits after decimal point | ratio scaled continuous quantitative data |
| | | | | | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |
| 2 | Number of stamens | counts | 1, 2, 3, ... , 40,41, ... | ratio scaled discrete quantitative data | counts | 1, 2, 3, ... , 40,41, ... | ratio scaled discrete quantitative data |
| 3 | Intensity of anthocyanin | 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9 | very low<br>very low to low<br>low<br>low to medium<br>medium<br>medium to high<br>high<br>high to very high<br>very high | ordinally scaled qualitative data (with an underlying quantitative variable) | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |
| 4 | Sex of plant | 1<br>2<br>3<br>4 | dioecious female<br>dioecious male<br>monoecious<br>unisexual monoecious<br>hermaphrodite | nominally scaled qualitative data | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |

| Example | Name of characteristic | Distinctness | | | Uniformity | | |
|---|---|---|---|---|---|---|---|
| | | Unit of assess-ment | Description (states of expression) | Type of scale | Unit of assess-ment | Description (states of expression) | Type of scale |
| 5 | Leaf blade: variegation | 1<br>9 | absent<br>present | nominally scaled qualitative data | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |
| 6 | Time of beginning of flowering | date | e.g. May 21, 51st day from April 1 | interval scaled discrete quantitative data | date | e.g. May 21, 51st day from April 1 | interval scaled discrete quantitative data |
| | | | | | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |
| 7 | Shape | 1<br>2<br>3<br>4<br>5<br>6<br>7 | deltate<br>ovate<br>elliptic<br>obovate<br>obdeltate<br>circular<br>oblate | combination of ordinal and nominal scaled discrete qualitative data | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |
| 8 | Flower color | 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9<br>10 | dark red<br>medium red<br>light red<br>white<br>light blue<br>medium blue<br>dark blue<br>red violet<br>violet<br>blue violet | combination of ordinal and nominal scaled discrete qualitative data | True-type<br><br><br>Off-type | Number of plants belonging to the variety<br>Number of off-types | nominally scaled qualitative data |

[End of document]