

Introduction to DEXi multi criteria decision models: What they are and how to use them in agriculture

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ABSTRACT

The planning process in agriculture often requires consideration of many conflicting criteria and participation of multiple stakeholders with conflicting interests. The multi criteria decision method DEXi is therefore a viable option for decision support in farm management. This study briefly reviews basic concepts of DEXi method and possible applications in agriculture on real life decision and assessment problems.

Key words: multi criteria analysis, assessment, DEXi

INTRODUCTION

Multi criteria decision analysis can be applied when the evaluation involves several variables that cannot be easily transformed into quantitative units, and the assessment process is likely to be influenced by multiple competing criteria. Such situation often emerges in agriculture and the multi criteria analysis for different kind of assessments systems has been applied in many cases (Pavlovič et al. 2011, Žnidaršič et al. 2008, Bohanec et al. 2008, Mazetto and Bonera 2003, Griffits et al. 2008, Rozman and Pažek 2005, Rozman et al. 2006, Tiwari et al. 2009, Tojnko et al. 2009).

The most common methods like analytical hierarchical process (AHP) and multi attribute utility theory are based on quantitative assessment. On the contrary, the method DEXi (Bohanec et al. 2000) is based on discrete values of attributes and utility functions in the form of "if…then" decision rules. In particular, some methods, such as DEXi (Bohanec and Rajkovič 1990, Bohanec et al. 2000), facilitate the design of qualitative (symbolic) decision models. In contrast to conventional quantitative (numeric) models, qualitative models use symbolic variables. These seem to be well-suited for dealing with 'soft' decision problems, that is, less-structured and less-formalized problems that involve a great deal of expert judgment and where qualitative scales can be more informative than quantitative scores. The DEXi method has already been successfully used in numerous real life decision and assessment problems such as for the estimation of hotel service quality (Rozman et al. 2009).

The aim of this paper is to present the possible applications of method DEXi in agriculture on real world farm management decision problems. We present the application of DEXi methodology on assessment of farm business alternatives, tourist farm service quality and hop hybrid assessment.

DEXi METHOD

The DEX (and its windows version DEXi) is a method for qualitative multi-attribute decision modelling and support. Many real life applications of multi-attribute methods were based on DEXi (Bohanec and Rajkovič 1990). The DEXi combines the "traditional" multi-attribute decision making with some elements of Expert Systems and Machine Learning. The main characteristic of the DEXi method is its capability to deal with qualitative variables. The objectives are hierarchically ordered into a tree structure. The DEXi expert system can be used for solution of various decision problems (Leskovar 1993, Bohanec et al. 1995, Bohanec and Rajkovič 1999, Bohanec et al. 2000,) and was developed by the University of Maribor, Faculty of Organizational Sciences in collaboration with the Institute Josef Stefan. The basic approach in the DEXi methodology is a multi-objective decomposition of the problem: the decision problem is decomposed into smaller and less complex decision problems (sub-problems). In this way, we get a decision model consisting of attributes, which represent individual sub-problems. The attributes are organized hierarchically and connected with the utility functions. The utility functions evaluate each individual attribute with respect to their immediate descendant's objective in the hierarchy. Instead of numerical variables, which typically constitute traditional quantitative models, DEXi uses qualitative variables; their values are usually represented by words rather than numbers, for example "low", "appropriate", "unacceptable", etc. Furthermore, to represent and evaluate utility functions, DEXi uses *if-then decision rules.* The decision rule can be for instance: "if the net present value is negative then the alternative is not acceptable" or "if the labour usage in the investment project

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is low then the alternative is excellent". The utility function, in fact, represents a knowledge base (the complete set of "what if" decision rules), which is ultimately used for evaluation of alternatives (Bohanec et al. 1995, Bohanec and Rajkovič 1999, Bohanec et al. 2000).

The utility function is defined through the entire hierarchy for each aggregate attribute. The utility functions in DEXi are described with a set of decision rules. The decision rule describes value of an aggregate attribute for each combination of input attributes and expresses the relative importance of individual attributes. In DEXi (Bohanec 2008), the value domains are discrete; therefore, the function f maps all the combinations of values X= X1 ×X2 ×…×Xn into the values of Y. The mapping is represented in a table, where each row gives the value of y for one combination of values x∊X.

Utility functions are components of multi-attribute models that define the aggregation aspect of option evaluation. For each aggregate attribute y, whose descendants in the tree of attributes are $x^1, x^2, \ldots, x_n$, the corresponding utility function f defines the mapping:

$$f = X_1 \times X_2 \ldots \times X_n \rightarrow Y$$

Where $X_1, \ldots, X_n$ and Y denote value domains of the attributes $x_1, \ldots, x_n$ and y.

Rows are also called decision rules, because each row can be interpreted as an "if–then" rule of the form:

If $x_1 = v_1$ and $x_2 = v_2$ and … and $x_n = v_n$ then $y = v$ where $v_1 \in x_1, \ldots, v_n \in x_n$ and $v \in Y$.

For a less detailed representation of utility functions the *weights* can be used. Given a decision rule, we use some suitable method to estimate the average importance of each input attribute for determining the value of dependent variable. We then obtain weights by expressing this importance as percentages relative to each other attributes. Two methods are used to assess weights with DEXi: one is based on regression and the other on measuring attribute informatively as in machine learning methods (Bohanec et al. 2000).

Using the *regression*, a decision rule is interpreted as a set of points in a multi-dimensional space and approximated with a hyperplane in that space. Let $x_{1\ldots}x_n$ represent the input attributes and *y*, the dependent variable, which is required to be ordered. For the purpose of this method, all qualitative values of attributes are represented by their ordinal numbers. Accordingly, we can interpret a decision rule as a collection of points and approximate them by a hyperplane. That means the coefficients a_0, $a_{1\ldots}a_n$ are approximated with the least-squares optimization. The regression equation is as follows:

$$Y = a_0 + a_1 x_1 + \ldots + a_n x_n \quad (1)$$

Where:
$a_{1\ldots}a_n$ - regression coefficients
$x_{1\ldots}x_n$ - ordinal values of attributes

The weights are the calculated as shown in equation 2 (a_0 is omitted from the representation):

$$w_i = \frac{a_i}{\sum_{i=1}^{n} a_i} \quad (2)$$

Where:
wi - weight (relative importance of attribute i)

As an alternative method for the estimation of weights we can use a method used in machine learning algorithms to identify the most relevant attributes (Bohanec et al. 2000). The measure is based on the information theoretic measure of entropy, -pi log2 pi, where pi is the probability of the i-th event.

Another way of defining utility functions in the DEXi model is the so called weight-based strategy of defining decision rules (Bohanec 2008). Here, the experts explicitly define the values of only a small subset of rules but additionally specify the required weights of the attributes: the higher the weight, the more important the attribute. Using this information, DEXi constructs a linear function with which the software interpolates the values of all previously undefined rules in the table. In principle, the function is constructed so that its linear coefficients correspond to the required weights and its surface lies as close as possible to the initially specified subset of rules (Pavlovič et al. 2011). More formally, the problem is defined as shown in Figure 1 (Bohanec 2008):

Finally, the attribute values for each alternative are put into the DEXi input table and assessment is performed.

In following chapters we present three real life application of DEXi methodology in agriculture.

DEXi MODEL FOR STREUOBST STANDS ASSESSMENT

The model for "Streuobst" stands assessment was first presented by Tojnko et al. (2011). High-steam orchards (»Streuobst stands«, »Hey orchards«), traditionally grown on grassland, represent an important source of raw material for the processing industry and for traditional fruit processing on family-run farms. Near production aspects, the role of high steam orchards is also in preservation of the traditional landscape and indirectly in maintenance of the viability of rural areas. In this paper qualitative multi-attribute model for the assessment of »Streuobst stands« with respect to their multi functional characteristics, is presented. The assessment is based on four groups of attributes: Production criteria, Biological diversity, Landscape diversity and the Function of plantation.

The hierarchy of the model was established through the brain-storming of six experts involved in model development. The hierarchy is based on our previous research (see Tojnko et al. 2009). The final structure of attributes for the assessment of "Streuobst" stands and is shown in Figure 2.

Each stand that is to be assessed by the model is described by 10 basic (input) attributes. These attributes are grouped into four groups that describe 4 main functions of a "Streuobst" stand.

The aggregate attribute Production criteria consist of 2 basic attributes:
- Physiological condition of the trees: describes the trees fruit bearing potential with respect to its form and appearance
- Tree density: describes % of missing trees

1. A set of decision rules:

$$S = \{x_1 \rightarrow y_i, i = 1,2, \dots, r\}$$

Where $x_i \in X$ and $y_i \in Y$

2. With respect to required weights

$$w_1, w_2, \dots, w_n \ (w_1 \in R \ and \ \sum_{i=1}^{n} w_i > 0)$$

Construct the linear function:

$$h(x_1, x_2, \dots, x_n) = K\big(w_1 ord(x_1) + w_2 ord(x_2) + \cdots + w_n ord(x_n)\big) + N$$

So so that it best fits the rules in **S**, minimizing:

$$\sum_{i=1}^{r} (h(x_i) - ord(y_i)^2$$

3. The function coefficients are then calculated:

$$K = \frac{\sum_{i=1}^{r} y_i W_i - (\frac{1}{r}) \sum_{i=1}^{r} y_i \sum_{i=1}^{r} W_i}{\sum_{i=1}^{r} W_i^2 - (\frac{1}{r})(\sum_{i=1}^{r} W_i)^2}$$

$$N = \frac{1}{r}(\sum_{i=1}^{r} y_i - K \sum_{i=1}^{r} w_i)$$

$$where W_i = \sum_{j=1}^{n} w_j \, ord\big(v_j\big) at \ x_i = (v_1, v_2, \dots, v_n)$$

Figure 1: Formal explanation of utility function using the weight based strategy

The aggregate attribute Landscape diversity consists of 3 basic attributes:
- Visual appearance: describes the incorporation of a stand into the landscape
- Ecological diversity: describes the presence of other natural elements in the stand (such as wetland, water streams or natural tree stands)
- Erosion protection: describes the stand contribution to erosion protection (for instance the contribution of stand on slopes is greater than on a flat land)

The aggregate attribute Biological diversity consists of 3 basic attributes:
- Artificial interventions in the stand: this attribute describes the intensity of artificial interventions in the stand (such as agro meliorations or terraces)
- Diversity: number of fruit species and varieties in the stand
- Cultivation: this attribute also describes but with respect to stand management such as soil management, fertilization, pruning (for instance smaller number of mowing contributes to better biological diversity)

The last aggregate attribute describes the function of a stand (production or country side appearance) and consists of 2 basic attributes:
- Type of plantation: independent stand or stand in the settlement or special important form (such as alley or individual important tree)
- Aim of plantation: this attribute describes the arbitrary assessment of stand main contribution (county side appearance or production)

Each attribute is assigned with a set of possible qualitative values as described in Figure 2.

The selection of stands was conducted with application of the public database of the Ministry of agriculture, forestry and food land usage (http://rkg.gov.si/GERK/viewer.jsp, also see figure 6) in following stages:

a) Using the database we identified 85 stands. Using the aerial photographs in the database we checked each location for its actual usage (to compensate for the changes in the land usage).
b) Each stand was visited and the attributes at the lowest level in the DEXi model

The results show relative poor assessment of analyzed "Streuobst" stands. These results are similar to our previous research (Tojnko et al. 2009) where the also the "poor" overall assessment prevailed as result of the poor cultivation: most of the stands are mainly not pruned which results in the poor Physiological conditions of the trees.

The DEXi methodology, based on qualitative attribute values and utility functions in the form of decision rules, was applied to assess 85 stands The presented multi-criteria model enables precise estimation of contribution of "streuobst" stands to multifunctional agriculture according to the defined criteria. The value added of this approach in practice is detailed analysis of attribute values with the model features (radar charts), which can provide substantial information on possible improvements for each stand in order to ensure its ecological and landscape contribution
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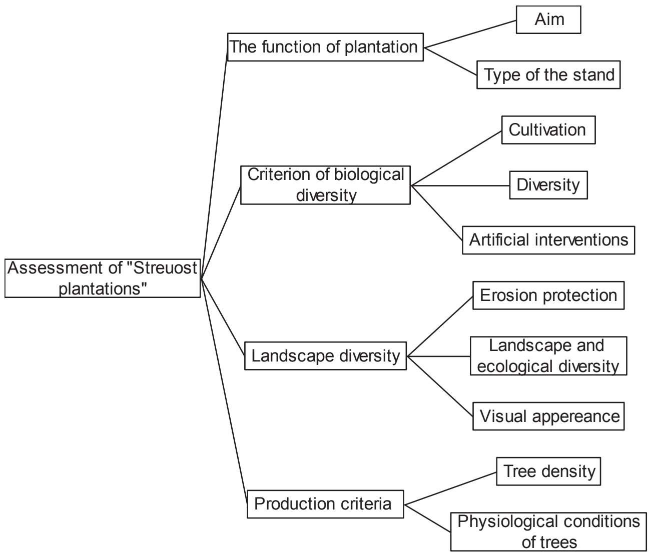

Figure 2: Attribute tree

DEXi MODEL FOR TOURIST FARM QUALITY ASSESSMENT

The model was originally published by Rozman et al. (2009) in order to assess tourist farm service quality. The model was applied to seven tourist farms with data derived from questionnaires completed by tourist farm operators and guests. The results are shown as service quality assessments for individual farms. The potential of the model for assessing the farms is demonstrated with the aim of providing a comprehensive explanation and justification of the assessment technique. It also indicates potential improvements that farms can make through "what-if" analysis and visualization. According to the developed model, two questionnaires were constructed to derive priorities and values for individual criteria. The first questionnaire was issued to tourist farm operators and staff and the second questionnaire to customers—guests of the farm. Farm operators were asked two types of questions. The first set of questions was derived from the tree of attributes (Figure 3) so that each question corresponded exactly to one input attribute (terminal node). The second set of questions consisted of general questions about the operators' satisfaction level with working in farm tourism. The guest questionnaires were set according to the recommendations of Taylor et al. (1992). They suggested multidimensional scaling of three different areas: attribute selection, number of attributes taken into account by the guests, and assessment of the relative importance of the attributes. Furthermore, the authors listed the set of attributes that influence guests' decisions and whether they select a specific vacation place according to their preferences.

Table 1: The overall DEXi assessments of 85 stands

Assessment of "Streuost plantations"	Very poor	Poor	Average	Good	Excellent
Frequency	8	40	27	10	0

Figure 3: The model hierarchy (Rozman et al. 2009)

Overall, the farms were assessed as indicated in the top data row of Figure 4 (next to *Tourist farm service quality*). The highest assessment ('very good') was obtained for Farms B, C, F, and G. This is followed by Farms A and D, which were assessed as 'good.' Farm E is a special intermediate case because, due to missing data, we could not obtain the overall value precisely as a single value; instead, we used the set 'good; very good.'

An important feature of using DEXi is the ability to "drill-down" through the tree structure of the model, look at data and assessments at the lower level of the model, and see how

Attribute	A	B	C	D	E	F	G
Tourist farm service quality	good	very good	very good	good	good; very good	very good	very good
Guest	good	very good	very good	good	very good	very good	very good
Premises	very suitable	very suitable	very suitable	very suitable	very suitable	very suitable	suitable
Landscape	very suitable	very suitable	very suitable	very suitable	very suitable	very suitable	suitable
Environment	very suitable	very suitable	very suitable	very suitable	very suitable	very suitable	suitable
Architecture	very suitable	very suitable	very suitable	very suitable	very suitable	very suitable	suitable
Order and cleanliness	good	excellent	excellent	excellent	excellent	excellent	good
Access to the farm	good	good	good	good	good	good	acceptable
Parking	acceptable	good	good	good	good	good	acceptable
House	acceptable	good	good	good	good	good	good
Equipment	suitable	very suitable	very suitable	suitable	very suitable	suitable	suitable
Homeyness	yes	yes	yes	yes	yes	yes	yes
Cleanliness	good	excellent	excellent	excellent	excellent	excellent	excellent
Spaciousness	very suitable	very suitable	very suitable	very suitable	very suitable	very suitable	suitable
Services	acceptable	good	good	acceptable	good	good	good
Food	acceptable	good	good	acceptable	good	good	good
Taste	excellent	excellent	excellent	good	excellent	excellent	excellent
Look	excellent	excellent	excellent	good	excellent	excellent	excellent
Variegation	variegated	very variegated	very variegated	variegated	very variegated	very variegated	very variegated
Serving	acceptable	good	good	acceptable	good	good	good
Drinks	acceptable	acceptable	acceptable	good	good	good	acceptable
Diversity	diversified	diversified	diversified	diversified	diversified	diversified	diversified
Serving	acceptable	good	good	good	good	good	good
Tradition	typical	typical	typical	extra	extra	extra	typical
Attitude	friendly	friendly	friendly	*	friendly	friendly	friendly
Personnel to customer	friendly	friendly	friendly	*	friendly	friendly	friendly
Personnel to personnel	friendly	friendly	friendly	*	friendly	friendly	friendly
Personnel cleanliness	suitable	suitable	suitable	*	suitable	suitable	suitable
Additional services	poor	poor	poor	poor	good	acceptable	good
Sports	not available	not available	not available	not available	available	available	available
Animation	not conducted	not conducted	not conducted	not conducted	conducted sometimes	not conducted	conducted sometimes
Souvenirs	few	not available	not available	not available	few	few	few
Repeat visits	yes	yes	yes	yes	yes	yes	yes
Farm operator	very good	very good	very good	very good	*	very good	very good
Plans for the future	yes	yes	yes	yes	*	yes	yes
Satisfaction	good	good	good	good	*	good	good
Work comparison	more pleasant	more pleasant	more demanding	more pleasant	*	more demanding	more demanding
Income	acceptable	good	good	good	*	good	good
Labor distribution	very suitable	suitable	very suitable	very suitable	*	very suitable	very suitable
Interesting work?	very interesting	very interesting	very interesting	very interesting	*	very interesting	very interesting

Figure 4: The service quality assessment of 7 tourist farms (Rozman et al. 2009)

they contribute to the overall assessment (Figure 5). This is very important for better understanding and justification of the assessment process. Furthermore, such analysis can be easily and comprehensibly visualized using various charts. As an example, Figure 6 presents radar charts that show the evaluation of service quality for each farm for the aggregate attribute *Guest,* according to the defined decision rules. Individual points other than *Guest* show values of the four attributes that influence the *Guest* attribute. The ideal guest assessment is achieved when the line is at the edge of the pentagram (Farm E). In a non-ideal assessment, the line is shifted toward the center, clearly indicating an attribute and its value contributed to a less than ideal assessment. For example, it is easy to identify the reasons why Farm D was perceived as 'good' instead of 'very good': because of 'acceptable' *Services* and 'poor' *Additional services*.

THE DEXi-HOP MODEL

The model related to a hop industry (Pavlovič et al. 2011) was developed in order to assess new potential hop hybrids. Within the hop breeding research program carried out at the Slovenian Institute of Hop Research and Brewing, thousands of hop hybrids appeared to be perspective according to research objectives (Cerenak 2006). In this research the data from four different Slovenian hop hybrids A1/54, A2/104, A3/112, A4/122 were compared with a reference German variety Hallertauer Magnum, which had the desired characteristics plant resistance and brewing value. The assessment was carried out by a qualitative multi-attribute model based on the DEX methodology (Bohanec et al. 2000). We first developed the model and then applied it to assess the aforementioned perspective hybrids. The model hierarchy is shown in Figure 6.

Among over one thousand of hybrid hop plants analyzed and eliminated stepwise through a selection procedure, the four Slovenian hop hybrids such as A1/54, A2/104, A3/112, A4/122 and a reference variety Hallertauer Magnum were involved into a comparative model assessment. The hop hybrids had been selected through a hop breeding process among sets of seedlings analysed and assessed as highly forthcoming and promising new hop varieties. Numerical data of analyses and measurements of hop cones as well as beer sensory estimation were used to describe hybrids production and brewing quality parameters. They were analyzed and

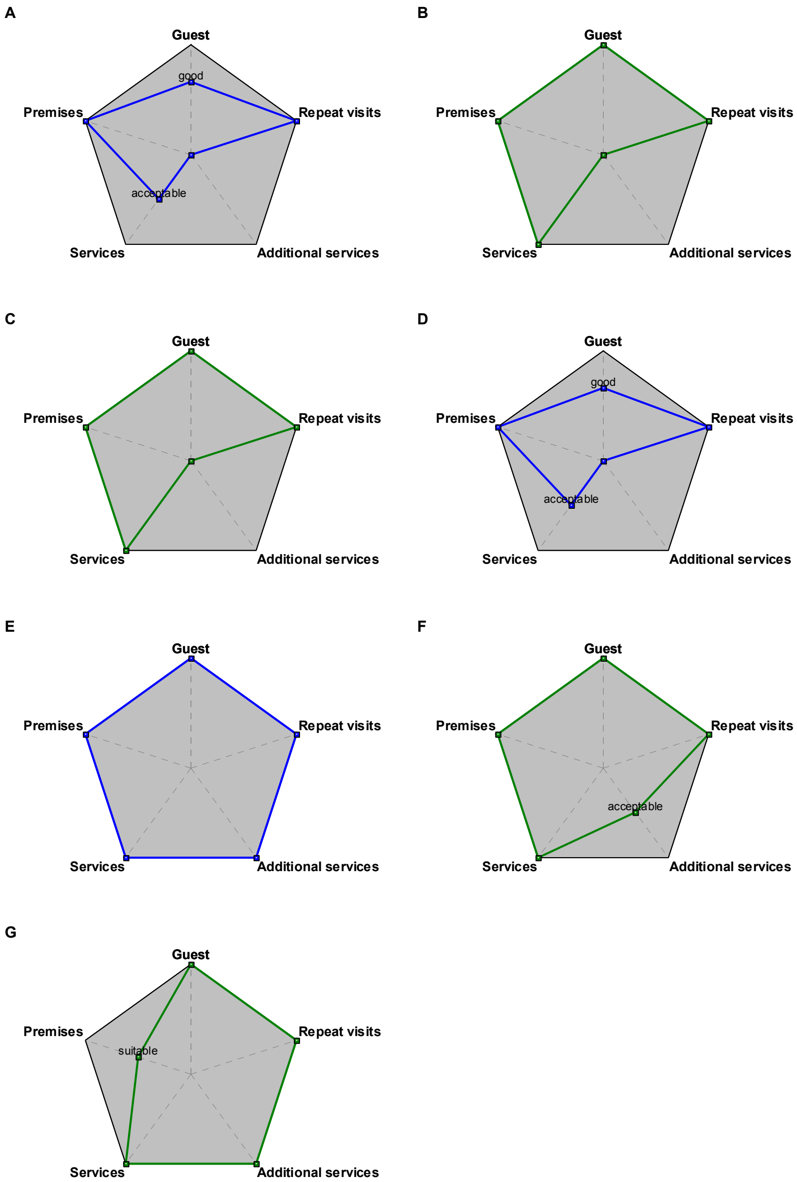

Figure 5: Graphical presentation of the assessment of the attribute Guest for individual farms

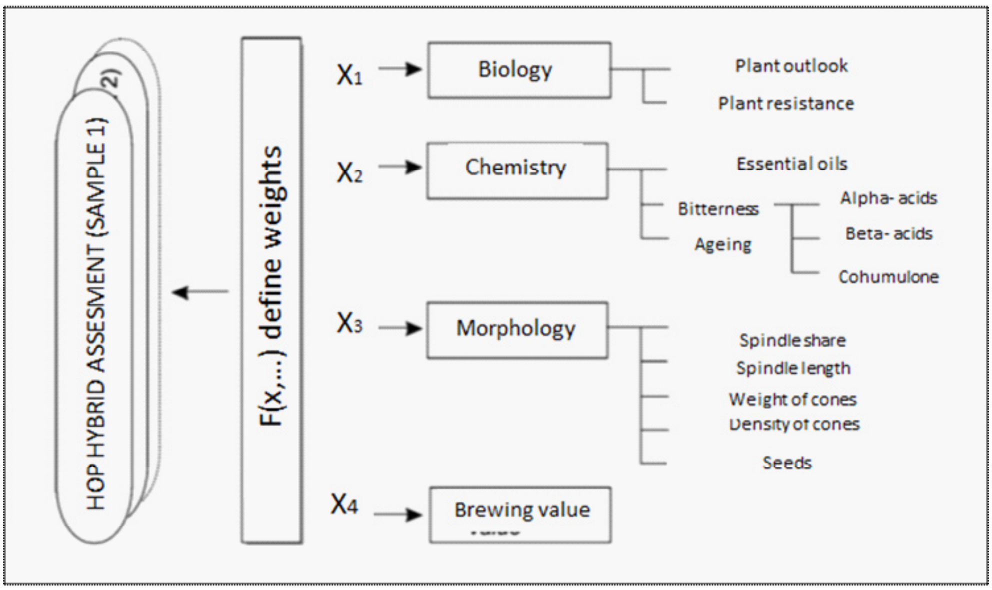

Figure 6: The hierarchical structure of the DEXi-HOP model

results were additionally discussed. The model enabled a final assessment of hybrids based on defined attributes and decision rules within defined utility functions.

Based on breeding experiences and the DEX-HOP 1.0 model results, the overall as well as individual (aggregated and derived) attributes assessments were carried out. A3/112 and A4/122 reached the overall level of reference and were thus assessed as appropriate for further breeding. On the contrary, A1/54 and A2/104 did not meet expectations in their attributes related to the reference variety. A2/104 was in overall assessed as WORSE, while A1/54 as NON PERSPECTIVE. Therefore, they were considered as hybrids with less breeding potentials.

CONCLUSIONS

In this paper, an attempt was made to present multi-criteria method DEX, based on qualitative attribute values and utility functions in the form of decision rules, and its possible application in the field of agriculture. The application of the method was presented on three real life decision/assessment problems.

Despite some deficiencies (such as the use of qualitative data only), the approach fulfills most of our expectations and reveals considerable advantages in comparison with other approaches. In particular, we emphasize the use of the qualitative multi-criteria DEXi model, which is suitable in a field where judgment prevails, thus making it difficult to give numeric answers. This kind of model is comprehensible to a wide range of users in the assessment process.

The multi-criteria DEXi model can therefore be regarded as a useful alternative tool decision support and different kinds of assessment in the field of agriculture. Further research is needed in the field of integrating quantitative data into the DEXi modeling framework, as well as comparing it other multi-criteria methods.

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