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Application of multicriteria analysis for assessment of wheat quality in trade and processing

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RESEARCH ARTICLE

Abstract

The quality related value of grains, especially wheat is defined with a number of quality parameters. Numerous parameters that are often mutually inconsistent result in the fact that decision making related to selection of wheat lots based on their quality is a complex multidimensional problem. The aim of the research was to test the possibility of application of multicriteria analysis for ranking of wheat lots in respect to their overall quality and its variation. A modified version of the preference ranking organisation method for enrichment evaluation, MODIPRIM, was used for multicriteria analysis of wheat intended for sales and processing purposes. The results of determining the quality parameters of wheat lots in six consequent crop years were used to form the input database. Multicriteria analysis was conducted with developed optimisation criteria and assessment of the significance coefficients resulted in a reduction of the complexity of the decision making problem involving numerous quality parameters to the differentiation of observed wheat crops based only on their quality level and variability with simultaneous possibility of wheat alternative evaluation in respect of defined final purpose. Newly introduced cubic and square preference functions in MODIPROM method gave the best fits for multicriteria ranking of the supplied input data, emphasizing its suitability for tested purposes.

Keywords: cereal quality, socio-economy, wheat

1. Introduction

Contemporary decision-making related to the management of agricultural products based on their quality is a complex multi-dimensional process that requires simultaneous consideration of large number of quality parameters. In practice, the quality of agricultural products, especially grains, is determined during harvest based on a number of indirect quality parameters that can be easily analysed with rapid methods. The quality of grains as raw materials for different processing purposes is evaluated further by determining the quality parameters related to the behaviour of raw materials in the production process, yields of final products, the potential to obtain final product at desired quality and safety level (Pojić and Mastilović, 2013).

In the case of wheat, quality evaluation during the harvest is performed based on parameters obtained with rapid methods such as moisture content, test weight, protein content, Hagberg falling number and the content of separable and inseparable admixtures by categories (Mastilović *et al.*, 2008a). In the process of storage, trade and processing, wheat is further evaluated on the basis of processing value parameters, such as gluten content, amylograph, farinograph, and extensograph parameters (Torbica *et al.*, 2008) resulting in a complex decision-making process in managing the segregation, blending, standardisation, commercialisation and processing of wheat (Mastilović *et al.*, 2008b). Obtaining sets of dozens of values puts the decision makers in the wheat production, trade and processing chain in the position of making decisions related to the optimisation of operations in wheat trading and processing based on large number of quality parameters that are often mutually inconsistent with optimal values of some parameters in relation to less favourable values of the others.

The methods of multicriteria analysis have been applied in solving practical multi-dimensional decision making problems, in many areas in which management is faced with the problem of decision-making based on large number of criteria and alternatives (Bartolini and Viaggi, 2010). The methods usually used in solving such problems are the weighted sum method, weighted product method, analytical hierarchy process, elimination and choice translating reality, technique for order preference by similarity to ideal solutions, compromise programming, multi-attribute utility theory and preference ranking organisation method for enrichment evaluation (PROMETHEE) (Radojičć and Žižović, 1998). Multicriteria analysis methods have been successfully applied in the fields of sustainable energy planning, environmental management, evaluation of sustainable concepts, evaluation of different products for observed end use purposes and other areas (Pohekar and Ramachadran, 2004; Sultana and Kumar, 2012; Vinodh and Jeya Girubha, 2012; Zhang *et al.*, 2009).

In order to apply a multicriteria ranking method for solving multi-dimensional problems, the ranking criteria have to be defined and a database consistent with established objectives has to be formed (Bertsimas and Freund, 2000). The goal of multicriteria problem solving is to enable decision making which is based on the ranking of alternatives and thus can be substantiated based on the analysis of the results.

One of the frequently used multicriteria analysis methods, PROMETHEE, has been applied in areas environment management, business and financial management, hydrology and water management, chemistry, logistics and transportation, energy management, manufacturing and assembly, social sciences and other topics (Behzadian *et al.*, 2010). The application of PROMETHEE for ranking of wheat lots according to their quality has not been reported, but it has been successfully used for the ranking of rice in relation to origin and variety in dependence of mineral elements content (Kokot and Phuong, 1999).

The aim of this research was to test the possible application of a modified PROMETHEE method, MODIPROM, for multicriteria analysis of wheat intended for sales and processing purposes.

2. Materials and methods

Upgraded PROMETHEE method MODIPROM

For ranking wheat, the multicriteria analysis procedure MODIPROM, based on improvement of PROMETHEE, was used. The authors of PROMETHEE (Brans and Vincke, 1985) developed six variants of this method (Brans and Mareschal, 1992), out of which for the research presented in this paper the following options were used:

- PROMETHEE I to determine the partial order of alternatives;
- PROMETHEE II to determine the complete order of alternatives; and
- PROMETHEE III for determining the interval order of alternatives.

A modified version of PROMETHEE, MODIPROM was designed at the Faculty of Mechanical Engineering in Kraljevo. Compared to the original PROMETHEE method, this modified version is characterised by a number of advantages including ease of calculation, coverage by testing of data for all types of preference functions, utilisation of parameters that have an economic explanation and importance and possibility of complete elimination of adverse effects following the rankings (Kolarević, 2004).

Improvements that have been introduced in MODIPROM relate primarily to the change of type of used preference functions. Some preference functions of PROMETHEE are retained also in MODIPROM (usual function, quasi function, function with linear preference, stepwise function and Gaussian function), while instead of the linear and area preference indifference functions cubic and square functions are introduced. The preference functions used and the parameters describing them are provided in Table 1.

For each $(d_{ik})_i$, in the normalised coordinate system $\{(d_{ik})_j, P_{jik}[(d_{ik})_j]\}$ values of approximation errors are calculated with Equation 1:

$$\varepsilon_i = [p_j(x_{jl}) - y_{jl}] \qquad (1)$$

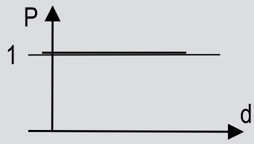
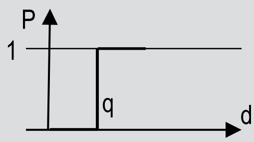
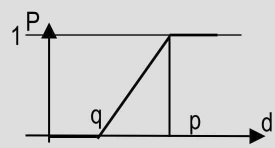
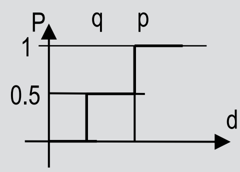
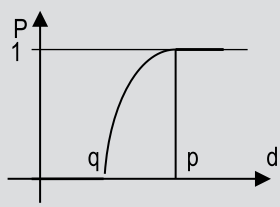
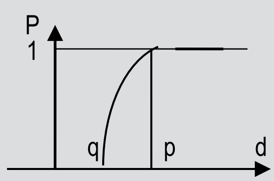
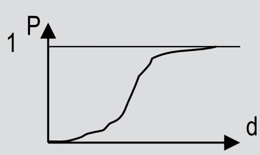
where ε_i is the error of approximation of the empirical values; y_{jl} is the theoretical value of the function $p_j(x_{jl})$ for l^{th} data; $p_j(x_{jl})$ is the theoretical value for the function l^{th} data; y_{jl} is the value of the preference functions for l^{th} data; l is the combinations of alternatives a_i and a_k which is $(d_{ik})_j = f_j(a_i)\cdot f_j(a_k) > 0$.

From listed preference functions the function for which for a given set of points, $\{(d_{ik})_j \cdot P_{jik}[(d_{ik})_j]\}$, the sum of squared deviations is the smallest was selected:

$$S = \sum_{l=1}^{s} \varepsilon_l^2 = \sum_{l=1}^{s} [p_j(x_{jl}) - y_{jl}]^2 \qquad (2)$$

MODIPROM provides the possibility of solving specific problems of ranking of alternatives based on sub-criteria within each ranking criterion through the introduction of sub-criteria functions with enabling of multi-level parsing of functions. In addition, weighting of the significance of selected criteria and sub-criteria according to the objectives

Table 1. Types of preference functions used for multicriteria analysis by MODIPROM.

Type	Name	Form	parameters	$P_j(x)$	
I	Usual criterion			$P_j(x)=1$	
II	Quasi (U shape) criterion		q	$P_j(x) = \begin{cases} 0 \\ 1 \end{cases}$	d<q d≥q
III	Criterion with linear preference (V shape)		q, p, b_0, b_1	$P_j(x) = \begin{cases} 0 \\ b_0 + b_1 x \\ 1 \end{cases}$	d<q q≤d<p d≥p
IV	Stepwise (level) criterion		q, p	$P_j(x) = \begin{cases} 0 \\ 0.5 \\ 1 \end{cases}$	d<q q≤d<p d≥p
V	Square criterion		q, p, b_0, b_1, b_2	$P_j(x) = \begin{cases} 0 \\ b_0 + b_1 x + b_2 x^2 \\ 1 \end{cases}$	d<q q≤d<p d≥p
VI	Cubic criterion		q, p, b_0, b_1, b_2, b_3	$P_j(x) = \begin{cases} 0 \\ b_0 + b_1 x + b_2 x^2 + b_3 x^3 \\ 1 \end{cases}$	d<q q≤d<p d≥p
VII	Gaussian criterion		σ	$P_j(x) = \begin{cases} 0 \\ 1 - e^{\frac{x^2}{2\sigma^2}} \end{cases}$	d≤0 d>0

b_0, b_1, b_2, b_3 = coefficients of the regression analysis; p = boundaries of strict preference; q = boundary indifference; σ = standard deviation of normal distribution.

of the decisions made based on multicriteria ranking was enabled.

The general mathematical formulation of a structured model with multiple levels of criteria is described with the mathematical model:

$$\max/\min\,[f_1(x), f_2(x),\ldots, f_p(x)],\ p\geq 2 \quad (3)$$

with the constraints $g_i(x)\leq 0$, $i=\overline{1,m}$ and $x_j\geq 0$, $j=\overline{1,n}$, where n is the number of variables; p is the number of preference functions, m is the number of limitations; x-n is the dimensional vector of variables x_j, $j=\overline{1,n}$, f_k is the objective criteria, $k=\overline{1,p}$, $g_i(x)$ is the set of constraints and $i=\overline{1,m}$.

Further the minimisation criteria are translated into the criteria of maximisation, in order to maximise the objective function vector by the given limitations, as shown in the expression:

$$\max f_r(x) = -\min[-f_r(x)],\ r\in(1,p) \quad (4)$$

By solving the above model, a set of acceptable solutions is obtained, i.e. the vector X that belongs to a set of natural numbers $X \in R^n$, for which $X = [x|g_i(x)\leq 0,\ i=\overline{1,m},\ xj\geq 0,\ j=\overline{1,n}]$. The set of solutions X corresponds to a set of values of preference function, i.e. the vector $f(x)$, so that the set of eligible solutions *X* can be mapped in the criterion set $S{:}\ f(x) = [f_1(x), f_2(x),\ldots, f_p(x)];\ S = [f(x)|x\in X]$.

In further analysis of the problem of multiple criteria for decision-making based on choice among multiple alternatives is solved by using the mean values of the net flow Φ. The problem is solved as follows:

- the actual preference functions are used only on the last r^{th} level;
- for lower levels of ranking the transformed values of net flow Φ from k^{th} level of the (k-1) ranking level are introduced with repetition of the process until the basic (l^{th}) level;
- transformation of the mean net flow is performed using the formula: $e_i = (\overline{\Phi}(a_i) - \min\overline{\Phi})/R$ where $R = \max \overline{\Phi} - \min \overline{\Phi}$ represents the 'range', i.e. the difference between the highest and the lowest values of the net flow.

The values e_i, representing transformed values of average net flow Φ, are formed for further analysis in the interval [0,1], where the best alternative has value 1, and the worst value 0.

In order to take into account both, the levels of wheat quality parameters and their variation, multicriteria analysis included the optimisation for the mean values and for standard deviation of selected wheat lots.

For the analysis, a software package MODIPROM version 1.0 developed in Microsoft Excel (Redmond, WA, USA), supported by Windows environment, developed at the Faculty of Mechanical Engineering in Kraljevo, Serbia was used. The method was previously successfully applied in the fields of logistics and transportation (Gašić and Savković, 2006), quality management (Mijailović and Marić, 2011) and evaluation of suppliers (Mijailović, 2010; Mijailović *et al.*, 2011).

Input data

The objective to obtain input data with a wide variety of combinations of levels and ranges of wheat quality parameters was met by using the results of testing of quality parameters of wheat lots from different production regions from different crop years, with previously proven high variability of input data (Torbica and Mastilović, 2008; Torbica *et al.*, 2007). In this way the starting data corresponded to those with which the decision makers in wheat production, trade and processing chain are faced when selecting wheat lots for sales, purchase or different end-use processing procedures.

Wheat crops originated from six different production years (2005-2010). In every crop year during the harvest at least 100 wheat lots were sampled from different wheat growing regions in Serbia (Pannonian plane in the north, hilly part and river valleys of central Serbia), representing influence of growing and climatic conditions in wheat growing regions in Serbia with relevant role in forming of annual wheat crop. Quality parameters relevant for wheat trade and processing were tested after the period of wheat postharvest ripening of two months.

The quality parameters included moisture content (ICC, 1976), test weight content and structure of admixtures (ICC, 1972), protein content (ICC, 1994a), wet gluten content (ICC, 1984), Zeleny sedimentation value (ICC, 1994b), falling number (ICC, 1995), farinograph (ICC, 1992b), extensograph (ICC, 1992a) and amilograph (ICC, 1992c) parameters tested according to the appropriate methods adopted in wheat quality testing.

Defining of input criteria

In the process of selecting the criteria to be used for decision making, a number of different criteria defining the problem comprehensively and fairly, in accordance with the established requirements should be selected. The matrix which contains a vector of input/output consists of a large number of functions that have the following characteristics:

- features/criteria are different and reflect different measuring units;
- the requirements for maximizing /minimizing functions are different;

- the relative importance of certain functions is different;
- the basic objective function is parted to sub-criteria functions resulting in a problem of the need to analyse preference functions at many levels.

Defining of ranking criteria

The first step in application of multicriteria analysis for ranking wheat according to its quality is to define the criteria based on which ranking and sub-ranking within each of the selected criteria will be performed. Bearing in mind that in practice, the evaluation of wheat lot quality is performed in terms of its trade, market and processing values (Mastilović *et al.*, 2008b), these aspects of wheat value were adopted as the criteria by which multicriteria ranking of wheat will be performed:

Q_t: trade value of wheat representing the value defined with quality parameters used for reduction of wheat price to standard quality, including moisture content, test weight and content of admixtures easily separable from wheat (shrivelled and broken kernels and weed seeds);

Q_m: market value of wheat representing the value defined with quality parameters used as price determinants in contracts at wheat market globally including protein content, wet gluten content, Zeleny sedimentation value, Hagberg falling number and content of admixtures inseparable from wheat (sprouted, wheat bug damaged, *Fusarium* and black spot kernel content);

Q_p: processing value of wheat representing the value defined by quality parameters highly correlated with wheat processing properties, including the most frequently used amylograph (maximum viscosity) farinograph (water absorption, degree of dough softening, farinograph quality number) and extensograph (energy, resistance and extensibility) parameters.

The quality parameters defining each aspect of wheat value represent the sub-criteria for the multicriteria ranking of wheat. The objective function representing optimisation of selected criteria can be mathematically expressed as follows:

$$\text{Opt}\{Q_t(q_{t1},q_{t2},\ldots,q_{tk}),\ Q_m(q_{m1},q_{m2},\ldots,q_{mk}),\ Q_p(q_{p1},q_{p2},\ldots,q_{pk})\} \quad (5)$$

A summary of selected criteria and sub-criteria for multicriteria ranking of wheat are presented in Table 2.

Table 2. Summary of quality parameters representing sub-criteria for multicriteria analysis of wheat with defined criteria for optimisation and adopted significance coefficients.

Designation and name of ranking criteria		Designation and name of ranking sub-criteria		Significance coefficient in terms of		Criteria for optimisation	
				sales	processing	AVG[1]	SD[2]
Q_t	Trade value	Q_{t1}	Moisture content (%)	5	2	min	min
		Q_{t2}	Test weight (kg/hl)	5	2	max	min
		Q_{t3}	Shrunken and broken kernels content (%)	4	2	min	min
		Q_{t4}	Weed seed content (%)	3	2	min	min
Q_m	Market value	Q_{m1}	Protein content (% dmb)	5	4	max	min
		Q_{m2}	Wet gluten content (%)	2	5	max	min
		Q_{m3}	Zeleny sedimentation value (ml)	1	3	max	min
		Q_{m4}	Hagberg falling number (s)	5	3	max	min
		Q_{m5}	Sprouted kernels content (%)	2	4	min	min
		Q_{m6}	Wheat bug damaged kernels content (%)	5	5	min	min
		Q_{m7}	Fusarious kernels content (%)	3	2	min	min
		Q_{m8}	Black spot kernels content (%)	1	2	min	min
Q_p	Processing value	Q_{p1}	Amilograph viscosity (BU)	2	2	max	min
		Q_{p2}	Farinograph water absorption (%)	2	2	min	min
		Q_{p3}	Farinograph degree of softening (BU)	4	5	max	min
		Q_{p4}	Farinograph quality number	3	3	max	min
		Q_{p5}	Extensograph energy	5	5	max	min
		Q_{p6}	Extensograph resistance	3	3	max	min
		Q_{p7}	Extensograph extensibility	4	4	max	min

[1] Mean value for lots from the observed crop year.
[2] Standard deviation for lots analysed in observed crop year.
BU = brabender units; dmb = on dry matter basis.

Defining of optimisation criteria

The next step in the preparation of input data for multicriteria analysis was to define the optimisation criteria for quality parameters adopted as sub-criteria for wheat ranking, assuming virtually the selection of a maximum or a minimum as the objective for achievement of optimum quality regarding each of quality parameters selected as a sub-criteria for wheat ranking. For quality parameters for which the minimum or maximum value is at the same time the optimal value defining of optimisation criteria was not a problem. Among the parameters that might conditionally be characterised in this manner are: test weight, shrivelled and broken kernels content, weed seed content, protein content, sedimentation value, gluten content, water absorption, energy, extensibility and degree of softening. It is important to emphasise that even for these parameters the adopted definition of the minimum and maximum as optimisation criteria (Table 2) is only conditional and applicable in the case of wheat intended for bread production. In the case of ranking of wheat for special purposes (for example for cakes, puff-pastry or other purposes) different definition or criteria of optimisation should be used, and certain parameters might be included under those where the minimum or maximum value cannot be identified as the optimal value.

For wheat quality parameters such as falling number, extensograph resistance and amylograph maximum viscosity, the optimum values cannot invariably be attributed to a minimum or maximum value. Optimal values of these parameters are in certain ranges, and minimal and maximal values represent the deviation from optimal performance quality. For multicriteria ranking purposes values of these parameters are defined as the maximum (Table 2), based on the fact that for high values the deviation from the optimum quality is less problematic than is the case with low values.

Regarding the standard deviation as a measure of deviation from the optimum conditions of quality, the optimisation criteria is for all cases to achieve a minimum (Table 2) because wheat lots with minimal standard deviations express the tendency of the lowest deviation from the established average.

Assessment of significance of selected criteria

A further step in defining the input criteria for multicriteria ranking of was the definition of the significance coefficients for the quality parameters adopted to represent sub-criteria for ranking. In practice, when decisions related to the ranking of wheat lots are made, different importance is attributed to the observed quality parameters. The importance attributed to each parameter in the decision making process depends on the purpose for which wheat lots are being ranked and the significance of variations of observed quality parameter for the concerned purpose. In practice wheat is most frequently ranked for purposes of its (a) sales/purchase aiming at the best price/value ratio; or (b) processing aiming at the highest effects with regard to quality and yield of products and processing costs (Mastilović *et al.*, 2008b). Thus the sales and processing aspects of decision making in wheat ranking were adopted as two approaches from which the significance of individual quality parameters, used as sub-criteria in multicriteria analysis could be tested.

The significance coefficients were assigned to quality parameters in the range from 1 to 5, where 1 was assigned for the lowest level of significance, and 5 for the highest. Assigned values (Table 2) were assessed conditionally by the authors based on significance and relations of each quality parameter to observed evaluation aspect reported in the authors' previous work (Janić-Hajnal and Mastilović, 2007; Janić-Hajnal *et al.*, 2010; Mastilović *et al.*, 2008a; Torbica *et al.*,2008).

3. Results and discussion

Ranking of wheat for sales and processing purpose

Transformed net flow Φ values for the mean values and standard deviation obtained by multicriteria analysis are presented in Table 3. The multicriteria analysis was performed alternatively (a) without significance coefficients; (b) with significance coefficients defined from the aspects of importance of parameters in wheat sales; and (c) with significance coefficients defined from the aspect of importance of parameters in wheat processing (Table 2).

The results for net flow Φ for mean values and standard deviations for the observed crop years are presented in Table 3. They will be discussed from the aspects of input information that they provide to a manager confronted with selecting the most convenient wheat for a given purpose: (a) sales/purchase with the best price value ratio at the market; or (b) the most effective processing into bread and bakery goods.

When significance coefficients defined from the aspect of sales are applied (Table 3, third column) wheat from crop year 2006 is ranked as the best, followed closely by wheat from 2007, and 2005 and 2008. On the other hand, wheat from 2010 with the lowest net flow value is ranked as the worst, while 2009 is in between four favourable years and this unfavourable one. Such an order enables the clear selection of wheat from any of the years 2005-2008 as the crops which will accomplish favourable market position. Further ranking of the selected four crop years can be performed based on the ranking of their standard deviations (Table 3, sixth column). Out of the four years,

Table 3. Values of calculated transformed net flow values obtained with different significance coefficients for the mean values and standard deviations of quality parameters of wheat from different crop years.

Crop years	Mean value (quality level)			Standard deviation (variation of quality)		
	Without significance coefficients	With significance coefficients in terms of sales	With significance coefficients in terms of processing	Without significance coefficients	With significance coefficients in terms of sales	With significance coefficients in terms of processing
2005	0.93^{3}	0.87^{3}	0.84^{4}	0.87^{2}	0.97^{2}	0.93^{2}
2006	1.00^{1}	1.00^{1}	0.93^{2}	0.44^{4}	0.55^{4}	0.28^{5}
2007	0.99^{2}	0.96^{2}	0.90^{3}	0.08^{5}	0.13^{5}	0.51^{3}
2008	0.51^{4}	0.87^{4}	1.00^{1}	0.66^{3}	0.69^{3}	0.33^{4}
2009	0.00^{6}	0.47^{5}	0.40^{5}	1.00^{1}	1.00^{1}	1.00^{1}
2010	0.04^{5}	0.00^{6}	0.00^{6}	0.00^{6}	0.00^{6}	0.00^{6}

Superscript numbers = ranks in the complete order of alternatives calculated by MODIPROM.

in spite of the fact that it is not ranked as the first based on mean value ranks, the crop of choice would be 2005 for which the standard deviation is, with Φ=0.87, ranked as the crop year with the lowest variations of average quality level. Quite a lower ranking based on the standard deviation is obtained for 2008, and even lower for 2006, which was the best ranked from the aspect of the means of the quality parameters. In the case of 2007, the results of multicriteria analysis indicate that, in spite of high quality, managers dealing with wheat sales should be careful due to high variability of quality among individual wheat lots. Clear differences in respect to quality variation in terms of sales can be seen also between two crops with low quality, with 2009 being characterised by the lowest and 2010 the highest variations out of all observed crop years.

In the case of ranking with application of significance coefficients defined from the aspect of processing (Table 3, fourth column) the first four years (2005-2008) again stand out as more favourable ones, with 2008 ranked as the best. Although ranked as the fourth, or the worst out of four favourable years, 2005 again stands out due to its low variability of quality (Table 3, seventh column) which is in the case of processing even more important. The other three years with favourable quality are ranked lower with respect to the variability of quality among wheat lots. Crop year 2010 is again ranked as the least favourable in terms of both, quality level and its variability.

Based on the above explanations, the crop of choice for both those engaged in wheat trade and wheat processing would be 2005 with quality close to the highest and its low variability, while 2010 with the lowest quality and highest variability is to be avoided. These conclusions are consistent with a comprehensive analysis of wheat quality presented in studies from Serbia available in academic literature and/or on-line (Torbica *et al.*, 2005, 2006; A. Torbica, personal communication) confirming thereby applicability of PROMETHEE in its modified version MODIPROM, for fast and reliable ranking of wheat based on its quality.

When no significance coefficients are applied (Table 3, second and fifth columns) the ranking order is more or less the same but the absence of significance coefficients ranks 2008 lower, out of the group of favourable crop years, and 2009 falls to the very bottom of the list indicating that these two crop years had unfavourable values of parameters with lower assessed importance for sales and/or processing. Such conclusions point to the importance of the application of significance coefficients in order to avoid misleading conclusions based on multicriteria analysis.

Comparison of PROMETHEE I, II and III ranking

In the previous section the complete ranking of alternatives, in this case wheat from different crop years, obtained with PROMETHEE II and based on a score of the net preference flow was discussed. The analysis of ranking of wheat from different years based on raw input data using the methods of partial (PROMETHEE I) and interval (PROMETHEE III) alternative ranking in comparison to the already presented complete (PROMETHEE II) ranking for the mean value and standard deviation with the use of different significance coefficients is presented in Tables 4 and 5, respectively.

The method of complete ranking (PROMETHEE II) enables full consideration of the sequence of alternatives, for both mean values, as indicators of quality level and standard deviations as indicators of variability of the quality. The application of partial (PROMETHEE I) alternative ranking results in the same order of alternatives but enables also indication of alternatives indifferent to each other which

Table 4. Multicriteria ranking of crop year mean values (quality level) depending on PROMETHEE I, II or III method ranking of alternatives with different significance coefficients.

No coefficients of significance			Coefficients of significance in terms of sales			Coefficients of significance in terms of processing		
I	II	III	I	II	III	I	II	III
2006^{c}	2006^{a}	2005^{c}	2006^{b}	2006^{a}	2006^{b}	2006^{c}	2008^{a}	2008^{c}
2007^{c}	2007^{b}	2006^{c}	2007^{c}	2007^{b}	2005^{d}	2008^{c}	2006^{b}	2005^{d}
2005^{d}	2005^{c}	2007^{c}	2005^{d}	2008^{c}	2007^{d}	2005^{d}	2007^{c}	2006^{d}
2008^{e}	2008^{d}	2008^{d}	2008^{d}	2005^{d}	2008^{d}	2007^{d}	2005^{d}	2007^{d}
2009^{f}	2010^{e}	2009^{e}	2009^{e}	2009^{e}	2009^{e}	2009^{e}	2009^{e}	2009^{e}
2010^{f}	2009^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}

Superscript letters = ranks in the partial, complete and interval order of alternatives calculated by MODIPROM.

Table 5. Multicriteria ranking of crop year standard deviations (quality variability) depending on PROMETHEE I, II or III method ranking of alternatives with different significance coefficients.

No coefficients of significance			Coefficients of significance in terms of sales			Coefficients of significance in terms of processing		
I	II	III	I	II	III	I	II	III
2009^{a}	2009^{a}	2009^{a}	2005^{b}	2009^{a}	2005^{b}	2005^{b}	2009^{a}	2005^{b}
2005^{b}	2005^{b}	2005^{b}	2009^{b}	2005^{b}	2009^{b}	2009^{b}	2005^{b}	2009^{b}
2008^{c}	2008^{c}	2008^{c}	2008^{c}	2008^{c}	2008^{c}	2007^{c}	2007^{c}	2007^{c}
2006^{d}	2006^{d}	2006^{d}	2006^{d}	2006^{d}	2006^{d}	2006^{e}	2008^{d}	2006^{e}
2007^{e}	2007^{e}	2007^{e}	2007^{e}	2007^{e}	2007^{e}	2008^{e}	2006^{e}	2008^{e}
2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}	2010^{f}

Superscript letters = ranks in the partial, complete and interval order of alternatives calculated by MODIPROM.

have the same values of positive and negative flows, meaning that sum of vectors of unfavourable and favourable conditions is the same. Interval ranking of alternatives (PROMETHEE III) enables insights as to which alternatives are ranked in the same quality interval.

The decision that the 2010 crop was the least favourable in terms of both quality and variability was confirmed by the application of partial and interval ranking with both providing clear differentiation of this year as the least favourable one.

The selection of 2005, as discussed previously, as the crop year with the most favourable characteristics of the examined wheat crops is by partial and interval ranking somewhat challenged, based on the fact that neither in the case of sales nor for processing purposes the assumption that the quality of four best ranked crops does not differ significantly, must be based on results of both partial (Table 4, fourth and seventh column) and interval ranking (Table 4, sixth and ninth column) be discarded. On the other hand the decision that this year should be selected as the best due to its low variability in quality is confirmed by the ranking of 2005 is equal to that of 2009 as the best crop year, in both cases because of applied significance coefficients and for both partial and interval ranking.

Selection of optimal preference function

Testing was performed for all seven preference functions shown in Table 1. Deviation of the analysed data in relation to the preference functions is shown in Figure 1 for the mean values and standard deviations.

The results presented indicate that for both mean values and standard deviations, the best fit was achieved in the case of application of cubic and square criteria (Figure 1, rows V and VI) as the newly introduced criteria in MODIPROM method in relation to the basic PROMETHEE method. An adequate fit was achieved also when the Gaussian criterion (Figure 1, row VII) was applied, while all other

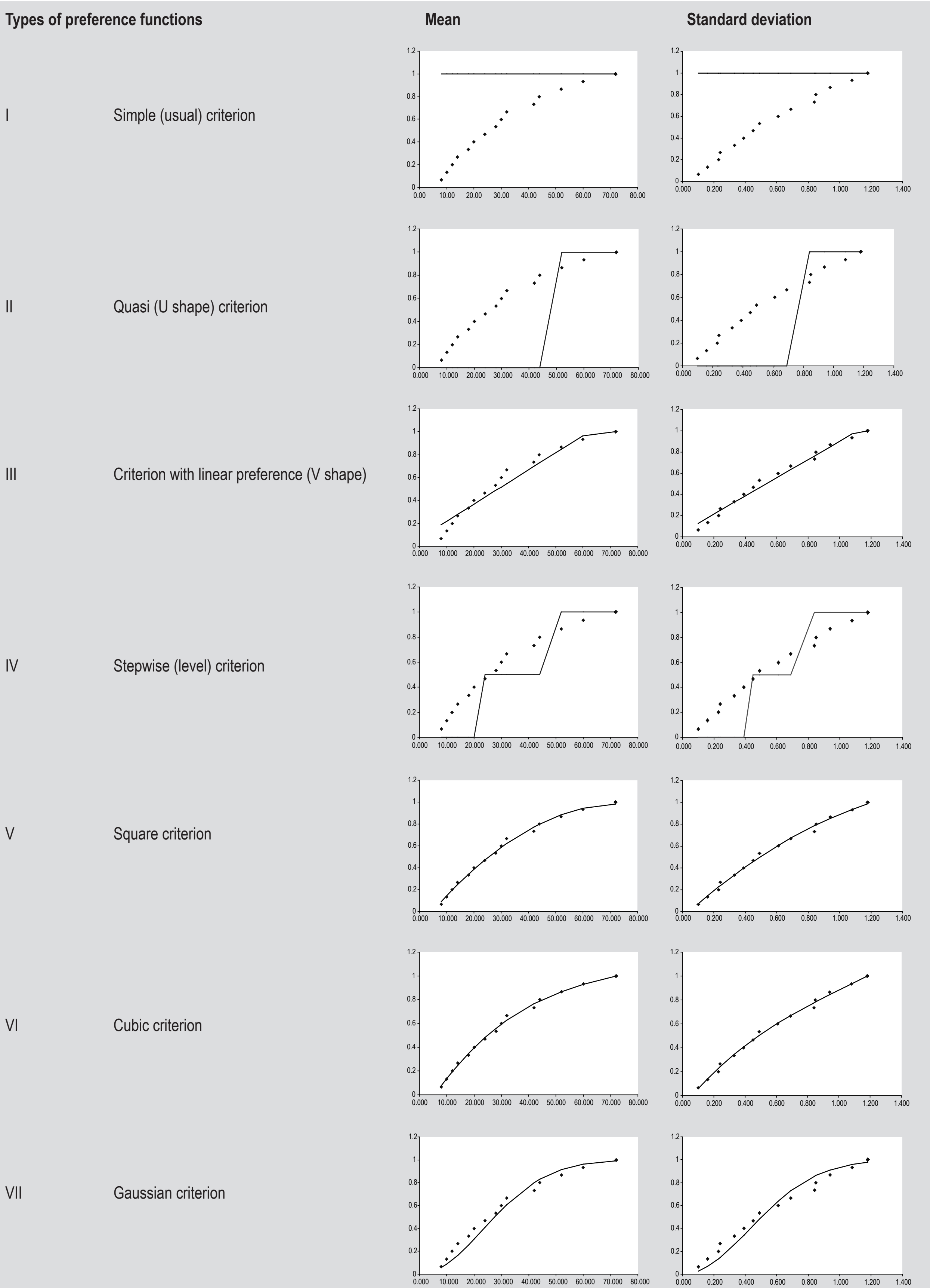


Figure 1. Deviations of analysed input data from examined preference functions for the mean values and for standard deviations (diamonds = data, line = preference function).

tested preference functions deviations are significantly higher (Figure 1, rows I, II, III and IV) and thus they are not applicable. This statement indicates the suitability and preference of MODIPROM for multicriteria ranking of wheat based on their quality in relation to the basic PROMETHEE.

Considerations which were conducted for all other tested combinations of input data and coefficients of significance suggest the same conclusions regarding the selection of the most suitable preference functions.

4. Conclusions

The application of the PROMETHEE method and its modified version MODIPROM for ranking wheat samples with regard to quality (tested on the wheat lots from different crop years) was proven to be possible and reasonable for ranking by its quality in order to make decisions directed at the selection of optimum quality wheat lots. The best fit was achieved using square and cubic preference functions as newly introduced functions in the MODIPROM method, which indicates the suitability and preference of the MODIPROM application methods in multicriteria ranking of wheat by its quality in relation to the basic PROMETHEE method.

By defining of the coefficients of significance it is possible to rank wheat in terms of target-oriented selection of quality aspects. The combined use of alternative methods of complete (PROMETHEE II) partial (PROMETHEE I) and interval (PROMETHEE III) ranking allows the simultaneous consideration of the exact sequence of ranking of wheat from different crop years and indication of crop years which are regarding quality level or variability mutually indifferent.

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