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Fuzzy logic tool for wine quality classification

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ABSTRACT

Wine quality is a complex attribute, thus single berry parameters are not adequate to define grape suitability for the production of specific wines. Fuzzy logic systems are particularly suited for aggregating multiple data to feed multi-variables decision support systems. The aim of the present study was the development of a simple in use and reliable tool based on fuzzy logic multi criteria decision making to objectively classify wine quality based on selected grape attributes. For this purpose, representative berry samples were harvested and vinified for two consecutive years from thirteen commercial vineyards in Nemea, Greece planted with Vitis vinifera cv. Agiorgitiko. Total soluble solids, pH, berry volume, botrytis infection, grape seed colorization, anthocyanin extractability, optical density (OD 520) and skin phenolics (Dpell) were measured at harvest and were used in the tool as inputs. Moreover, the produced wines were sensory evaluated by an experienced and trained panel. The ranking of the vineyards, according to the tasting panel, was compared to the ranking made by the tool and the results showed high general agreement between them suggesting that the latter was able to model expert knowledge successfully. According to the results, the fuzzy logic multi criteria decision making tool could allow the incorporation of grape quality parameters at harvest into a single index providing grape growers and wine producers with a valuable tool for classifying wine quality.

1. Introduction

Viticulture and wine making in Greece have been widely practiced since antiquity. There exist a plethora of important native cultivars (*Vitis vinifera* sp.), with various distinct enological properties and organoleptic characteristics. Agiorgitiko is an indigenous Greek red grape variety that gives Protected Designation of Origin (PDO) wines. Agiorgitiko is dominant in Nemea region (Peloponnese, Greece), and it is characterized by its fruity aromas and "velvet tannins" (Koussissi et al., 2009). Although Nemea is a well-known and reputed grape producing area in Greece, grape quality zones cannot be identified due to the lack of a simple commercial index for assessing grape quality.

Several grape parameters have been associated with wine quality. It is generally accepted that grape maturity is important to the overall quality of red wine (Ough and Alley, 1970), which is strongly related to the concentration of most aroma-active compounds (Fang and Qian, 2006), phenolic composition and colour parameters (Pérez-Magariño and Gonzalez-San Jose, 2006). Significant changes in phenolic composition occur with respect to maturity indicating a greater potential to elaborate high quality red wines (Ferre-Gallego et al., 2012). Moreover, acidity and pH are very important parameters affecting directly the sensory properties of the wine and regulating the chemical reactions that take place between the wine components. In red wine, phenolic compounds are one of the most important wine quality parameters since they are strongly related to mouth-feel, structure, colour, bitterness and astringency. Anthocyanins are a family of phenolic compounds directly related to red wine colour (Somers and Evans, 1977). Proanthocyanidins (or condensed tannins), which are located in grape seeds and skins, are another large family of phenolic compounds that make an important contribution to wine quality by stabilizing red colour

Abbreviations: PDO, Protected Designation of Origin; MCDM, Multi Criteria Decision Making methodology; AHP, Analytic Hierarchy Process; TSS, total soluble solids; SC, seed colorization; BV, berry volume; OD, optical density; EA, anthocyanin extractability; PA, potential anthocyanins; Dpell, tannin content of the skins; ANOVA, analysis of variance; MISO, multiple input – single output system; FMCDM, fuzzy logic multi criteria decision making

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through combination with anthocyanins, directly affecting astringency and bitterness and participating in colloidal stability (Chira et al., 2011; Souquet et al., 1996). Berry size is another important parameter for wine quality since it is generally accepted that the increased skin/pulp ratio in smaller berries has a positive effect on wine sensory characteristics (Hardie et al., 1997). Finally, botrytis infection (*Botrytis cinerea*) is responsible for one of the most serious grapevine diseases related with quantitative and qualitative deterioration of the grapes (Ky et al., 2012). In an attempt to estimate wine quality based on grape parameters, Sinton et al. (1978) and du Plessis and Van Roouen (1982) proposed various grape parameters as quality indicators (e.g. total soluble solids, pH). However, soon it became evident that single parameters are not adequate to define grape and wine quality and more complex descriptions are required (Cozzolino et al., 2006; Dambergs et al., 2006; Guidetti et al., 2010).

A method to combine multiple parameters, in this case grape characteristics, to rank grape quality for wine production is the Multi Criteria Decision Making methodology (MCDM). It constitutes a decision support approach that was developed to synthesize an amount of information for the reception of a decision, constantly and logically (Chai et al., 2013; Gal et al., 2013; Yu, 2013). MCDM methods have seen significant use in agricultural and environmental issues. Kiker et al. (2005), provided recommendation for applying MCDM techniques in environmental projects, Okeola and Sule (2012) used MCDM to study urban water supply systems in Nigeria, Jaber and Mohsen (2001) developed a MCDM system for the evaluation of non-convectional water resources supply in Jordan, Kabir et al. (2014) presented MCDM methods for infrastructure management, Baourakis et al. (1996) presented a methodology which combines multi-criteria preference and data analysis in order to design new agricultural products, Balafoutis et al. (2014) used MCDM techniques to evaluate biofuels derived from sunflower oil produced and consumed within a farm and Krassadaki and Siskos (2000) proposed a MCDM technique to evaluate proposals for rural development projects.

There are several MCDM methods such as (a) Multi-Attribute Utility Theory, (b) Analytic Hierarchy Process (AHP), (c) Fuzzy Set Theory, (d) Goal Programming, (e) ELECTRE, (f) PROMETHEE etc. (Velasquez and Hester, 2013). Between the MCDM approaches available, fuzzy set theory is an efficient tool to model and deal with the imprecise and nonlinear nature of practical decision making and classification problems (Bellman and Zadeh, 1970; Zimmermann, 1978; Mardani et al., 2015). The major advantage of fuzzy logic based systems over traditional techniques, is their efficiency in handling complex and non-linear problems due to their inherent non-linear character, their capability of adaptation and integration of expert knowledge. Human beings are involved in the decision analysis since decision making should take into account human subjectivity, rather than employing only objective probability measures. They can be used either in addition to other approaches or as self-reliant methodologies providing thereby a plethora of alternative schemes to work out. In contrast to other approaches that are mostly quantitative approaches, fuzzy logic addresses the problem of data classification in a rather unified qualitative and quantitative manner (Casillas et al., 2013).

The use of fuzzy logic functions has the advantage of reaching solution based on linguistic fuzzy rules and variables which have clear physical meanings. Therefore, fuzzy logic in agriculture would provide more clear results when using data sets from agricultural systems that are very variable and dependent on numerous environmental (soil and water resources, meteorological data) and agronomic (soil tillage, irrigation, fertilization, etc.) parameters. A variety of fuzzy algorithms for data classification in agricultural systems has been proposed. Morlat and Guilbault (2001) proposed an algorithm to estimate the vigour potential conferred by soil based on soil depth and the degree of weathering of the parent rock and Coulon et al. (2010) completed this algorithm by using a fuzzy expert system. Kaufmann et al. (2009) proposed and developed a fuzzy logic expert system to evaluate the potential plant productivity of restored soils based on measured physical soil parameters. De Gruijter et al. (2011) used fuzzy logic for digital soil assessment, resulting in maps that are broadly similar with the ones produced with Boolean models, but more informational as they indicate areas representing a transition between two original Boolean classes. Kolhe et al. (2011) worked on an intelligent multimedia interface based on a novel approach of rule promotion with fuzzy logic for drawing intelligent inferences for crop disease management, providing highly-effective interactive user interface on web for live interactions and giving solutions of plant pathological problems in short spell. Chang and Sie (2012) have developed a multi-staged fuzzy logic scheme to calculate the growth rate of crops using environmental factors such as light, temperature and water availability. Papadopoulos et al. (2011) used fuzzy logic to design a decision support system for site-specific nitrogen fertilization based on characteristics of the soil, weather and farming practices. Ashraf et al. (2014) used type-II fuzzy set to develop a fuzzy decision support system of fertilizers application taking cropping time and soil nutrients in the form of spatial surfaces into consideration. A self-adaptive fuzzy inference system for the evaluation of agricultural land in China was developed by Liu et al. (2013). Murmu and Biswas (2015) reviewed all work done on fuzzy logic systems for crop classification showing their advantage to classify crops without a definitive decision about the land cover class to which each pixel belongs. Zareiforoush et al. (2015) used fuzzy logic to develop a hybrid intelligent approach for the quality of milled rice and to design an automatic control system for grading of milled rice in the processing industry.

There have been also some attempts to use fuzzy logic systems in the viticulture and wine-making sector. Raptis et al. (2000) proposed a fuzzy classifier and a neural network for the classification of wine distillates with regard to two distinct features of the products, the aroma and the taste, while Tagarakis et al. (2013) applied fuzzy clustering techniques to develop a simplified procedure for the delineation of management zones in vineyards using soil electrical conductivity, soil depth, topography, NDVI, yield and grape composition (must sugar content, total acidity). Tagarakis et al. (2014) designed, developed and validated a fuzzy inference system to model grape quality in vineyards based on selected grape attributes (total soluble solids, titratable acidity, total skin anthocyanins and berry fresh weight). Furthermore, many studies use fuzzy logic in order to handle uncertain data. Grelier et al. (2007) built a set of rules in order to explain the relationship between vintage quality, reduced to sugar content, and other available variables.

As stated above, wine quality is based on grape quality and its estimation based on grape composition is a priority. However, such estimation should rely on simple and rapid physicochemical analysis, covering multiple aspects of wine quality without advanced laboratory equipment. A tool that could be able to objectively evaluate grape composition and correlate it with wine quality could be of practical interest to winemakers and was not previously developed. The benefits from establishment of such tool would be multiple: Specific grape producing zones could be identified and classified with respect to grape quality. These grape quality zones (which may not be the same every year) could further determine the commercial value of the grapes and be used by the winemakers to improve control over the winemaking processes according to grape quality. Today, overall quality evaluation of wine is primarily based on the results of sensory analysis. Chemical analyses are inefficient for quality determination, however if they are performed in combination with sensory analysis they could provide information only on specific quality aspects.

In this work, a tool based on fuzzy algorithms is proposed for classification of Agiorgitiko wines produced by grapes from selected vineyards in Nemea with regard to quality using as indicators specific grape parameters. To achieve this objective, simple grape parameters were selected by viniculture and wine-making experts for construction of the fuzzy model and the overall wine quality was evaluated by