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Spatial Distribution of Grapes Sugar Content and its Correlations with Climate Characteristics and Climate Suitability in the Huși (Romania) Wine Growing Region

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Abstract

Previous studies have analyzed mainly the spatial distribution of grapes quality parameters at the plot scale, and concluded that grapes sugar content is a variable parameter, with a less predictable spatio-temporal evolution. Our study aimed to identify a pattern of spatial variation of grapes sugar content at a regional scale, under the temperate continental climate of the Huși (Romania) wine growing region. In order to do this, grapes sugar content was analyzed in relation to climate. The conditioning of grapes sugar content by climatic factors was analyzed based on regression models (Pearson correlation coefficient, coefficient of determination, linear regression). Spatial variation of grapes sugars content was achieved by the regression – kriging approach, using climate suitability as predictor. Spatial variation of obtainable wine types was achieved by classifying the spatial distribution of grapes sugar content, according to DOC wine production regulation for the Husi area. The study revealed that among climatic factors, the actual sunshine duration is the most influential one on grapes sugar content. Mapping grapes sugar content generated a coherent spatial distribution pattern at the vineyard scale, as it significantly correlates with terrain altitude. Based on grapes sugar content spatial variation, two areas with different potential for sugars accumulation into grapes were delineated. The outcomes reveal that grapes sugar content presents significant correlations with climate variables specific to vineyards and with climate suitability for wine production. Knowing these correlations allows revealing patterns that determine the spatial distribution of the grapes sugar content.

Keywords: grapevine, grapes sugar content, spatial distribution, vineyard, wine type

Introduction

Effective vineyard management and obtaining the targeted wine style require thorough knowledge of spatial variation of chemical compounds which generate grapes quality. They are mainly sugars, organic acids, phenolic compounds and aroma compounds, accumulated in berries during their growth and ripening. Among them, sugars are the most important ones (Huglin, 1986), as they determine the alcoholic content, the balance of taste and the final sensory profile of the wine.

When analyzed at a vine level, in known technological and environmental conditions, grapes sugar content is a rather easy to explore parameter, as it is specific to wine grape varieties and it reacts to viticultural practices (Champagnol, 1984; Galet, 1993). However, when analyzed in relation to

its spatial variation within the field, it proves to be, a spatially and temporally variable parameter, difficult to analyze and generating contrasting results. Studies conducted up to date on mapping grapes sugar content conclude that “maps from previous years are not useful in the management of harvest quality in the next year” (Tisseyre *et al.*, 2008), or that “soluble solids had a higher level of uncertainty for being predicted in the field” (Santos *et al.*, 2012). In contrast, Bramley (2005), referring to yield quality considers that “its variation appears to be sufficiently temporally stable to justify the identification of ‘quality zones’ within vineyards”, and also that sugar concentrations “are much less variable than total phenolics concentration”. Nonetheless, due to the variability of this parameter and the multitude of factors that influence it, no stable pattern of spatial distribution at vineyard scale has been obtained.

Spatial variability of grapes sugar content is generated by lack of uniformity of vineyard topography, soils and climate (Van Leeuwen, 2010), while its temporal variability is caused by vintage climate (Jackson and Lombard, 1993). What is more, grapes sugar content depends on grapevine variety, yield size (Huglin and Balthazard, 1976), vines age (Galet, 1993) and vineyard training system (Huglin, 1978). Therefore, there is a complex conditioning of this parameter, which requires the analysis of its correlations with a large number of biological, environmental and cultural factors in order to understand the patterns driving its spatial distribution.

The methods used to map the spatial distribution of grapes sugar content within the vineyards are not well defined, they implying yet the difficulty of sampling a large amount of berries for a pertinent depiction of the analyzed area. Taking as a model the technologies involved for in real-time anthocyanins content analysis (Lamb *et al.*, 2003), some harvest attached tools based on refractometry and spectrometry were designed (Wold *et al.* 2001; Workman and Burns 2001; Tisseyre and Taylor, 2005; Sethuramasamyraja *et al.*, 2007) but they are not yet widespread in practice. As an alternative, some authors suggest the use of spatial distribution of the yield size as an indicator, taking into account its correlation with grapes quality indicators (Bramley, 2005), while others consider NDVI (Normalized Difference Vegetation Index) to be a more relevant indicator (Agelet-Fernández *et al.*, 2009).

Unlike previous studies concerning spatial variation of grapes quality parameters at the plot scale (Bramley, 2005; Tisseyre *et al.*, 2008; Trought and Bramley, 2011; Santos *et al.*, 2012), this study analyzes spatial variation of grapes sugar content at the vineyard scale, aiming to reveal a possible model of spatial distribution. So far, grapes sugar content for the 2011 vintage has been analyzed in relation to multiannual averages of the climatic variables specific to the Huși vineyard, and mapped based on its significant correlation with climatic suitability for wine production generated by them.

Materials and methods

Study area

The study area is the Huși wine growing region, located in the eastern part of Romania, at 46°67' lat. N and 28°13' long. E, near the town of Huși (Fig. 1). It has 2139 ha and includes four vineyards: Schit (554.3 ha); Dobrina (570.6 ha); Corni (264.4 ha); and Recea (749.1 ha). The relief is like an amphitheater with an eastern opening and a decreasing altitude from 300 m above sea level (asl.) at the western limit to 40 m asl. at the eastern limit. The Schit and Dobrina vineyards are located above 150 m asl., on slopes with 10 to 30 % inclination, in the higher and hilly western part; the Recea and Corni vineyards are located below 150 m asl., mainly on flat terrains and less inclined slopes, in the lower eastern part of the area. The area is subjected to a temperate continental climate, Dfb according to World Map of the Köppen-Geiger climate classification updated (Kottek *et al.*, 2006).

Sampling the grapes sugar content

The study refers to grapes sugar content (GrSC) of the 2011 vintage. In order to ensure a representative sampling for the study area, berry samples were taken from different 26 locations (Fig. 1), each of them with a surface of about 1 ha. The geographical coordinates of the 26 sampling sites were established by using GPS. For each sampling site, GrSC (g/L) was measured for each of the 'Fetească albă', 'Fetească regală', 'Aligoté' and 'Tămăioasă românească' *V. vinifera* L. wine grape varieties, representing the established wine grape variety assortment. Each wine grape variety was represented by five vines, randomly selected, placed on different rows; from each vine, five berries per cluster were sampled, from four clusters, for a number of 20 berries per vine and 100 berries per variety. To ensure a random sample, the clusters were chosen arbitrarily, without taking into account their size or their location inside the canopy. Also, the berries were sampled from different positions and depths of the cluster. Until they were analyzed in the laboratory, the samples were kept in a freezer, at a temperature of 5 °C. The sugar concentration of grapes was determined in the laboratory, according to OIV protocol (OIV,

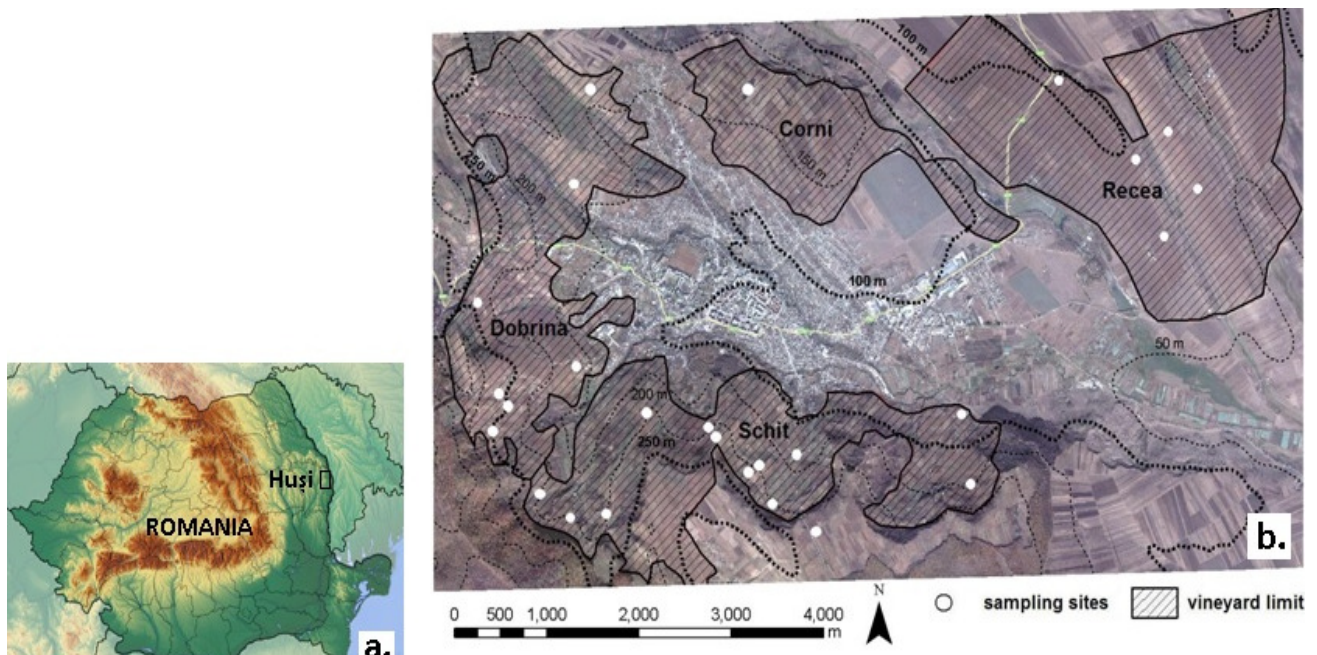


Fig. 1. Location of Huși wine growing region in Romania (a), its structure and the locations of the 26 sampling sites (b)

1990). To ensure the representativeness of the samples for the sampling sites, the GrSC was expressed as the average of the grapes sugar content for the four wine grape varieties analyzed, thus each of them having equal weight in the berries sample (Table 1). In order to have comparable berries samples, the sampling was carried out in a single day (11 September, 2011), with about 4-5 days before harvesting, from vines with the same training system (Cazenave; rather 30 shoots per vine; 25 to 30 grapes per vine; 3700 vines per ha).

Analysis of climate variables

For each of the 26 sampling sites, there were analyzed the values of nine climate variables, which characterize the climate suitability for different types of wine production in temperate continental climate conditions (Irimia et al., 2014): average annual temperature (AAT, °C); average temperature of the warmest month (TWM, °C); global radiation (GR, kcal/cm²/Apr 1st to Sept 30); actual sunshine duration (ASD, hours/Apr 1st to Sept 30); precipitation in the growing season (PP, mm/Apr 1st to Sept 30); sum of effective temperatures (Σt_{eff} , °C/Apr 1st to Sept 30); actual heliothermal index (IHa/Apr 1st to Sept 30); bioclimatic index (Ibcv/Apr 1st to Sept 30) and oenoclimatic aptitude index (IAOe/Apr 1st to Sept 30) (Table 1). The values of climate variables for each sampling site were extracted from their spatial distributions in the Huși wine growing region (Irimia et al., 2011), previously established based on multiannual averages (1961-2000) of temperature and precipitation altitudinal gradients implemented in NewLocClim software (FAO, 2003), and on values derived from DEM for the global radiation and sunshine duration (Patriche, 2007).

Analysis of climate suitability for wine production

Climate suitability was assessed in a previous phase of the study based on multiannual averages (1961-2000) of ten climate variables characterizing the Hushi wine growing region (Irimia et al., 2014). Each climate variable was mapped, and its values classified and ranked with 5 to 10 points, according to their suitability for wine production. Then the maps were combined in a GIS database, were georeferenced and the average of ranking points was computed at the pixel level (30 x 30 m). The average of ranking points (a.r.p.) expresses climate suitability and varies between 5 and 10 with the following significance: 5 a.r.p.= climate suitability for white table wines, sparkling wines and wines for distillates; 6 a.r.p.= climate suitability for white table wines, sparkling wines, and wines for distillates, as well as for quality white wines in very suitable years, in terms of climate; 7 a.r.p.= climate suitability for quality white wines; 8 a.r.p.= climate suitability primarily for quality white wines and secondarily for red table wines; 9 a.r.p.= climate suitability primarily for quality red wines and secondarily for quality white wines; 10 a.r.p.= climate suitability for quality red wines.

Analysis of the relationships between climate variables and GrSC was performed by computing regression models (Pearson correlation coefficient; coefficient of determination; linear regression) between the GrSC and the multiannual means of the nine climate variables characterizing each of the 26 sampling sites. The results were assessed according to the statistical significance of the linear regression model for a significance level of 0.05. This analysis aimed to highlight the factors driving the GrSC and also to reveal the extent to which they influence this grapes quality parameter.

Analysis of the relationships between climate suitability and GrSC was performed based on the same previously used regression models (Pearson correlation coefficient; coefficient of determination; linear regression) this time computed between the GrSC and the average ranking points (a.r.p.) revealing the climate suitability of each of 26 sampling sites. The results were also assessed according to statistical significance of the linear regression model for a significance level of 0.05. This analysis aimed to reveal the conditioning of the GrSC by local climate suitability.

Spatial distribution of GrSC within the vineyard was achieved based on its significant correlation with local climate suitability revealed by the regression models computed in the previous phase. The spatialization method was the linear regression by using climate suitability as predictor, followed by ordinary kriging of regression residuals. Subsequently, the regression and kriging spatial models were added up in order to achieve the final estimated continuous distribution of GrSC. Interpretation of results is based on: statistical analysis (Min, Max, Range, CV, STD); analysis of the "spread" index, respective the difference between the maximum and minimum values expressed as a % of the median value (Bramley, 2005); and analysis of the correlation between the GrSC and the altitude.

Spatial distribution of wine types which can be obtained in accordance with the GrSC for the 2011 vintage was achieved by classifying the spatial distribution of GrSC under the regulations of DOC wine production for the Huși wine growing region (ONIV). In addition to the requirements regarding the geographical location, wine grape variety, technological parameters of plantation and yield size, this regulation imposes a minimum content of sugar in the berries at the harvest moment, as follows: a GrSC higher than 170 g/L, up to 190 g/L is needed to produce quality wines with geographical denomination (IG); a GrSC higher than 190 g/L up to 196 g/L is required to produce high quality wines with controlled designation of origin (DOC); a GrSC higher than 196 g/L up to 213 g/L is needed to produce controlled designation of origin wines harvested at full maturity (DOC-CMD); a GrSC higher than 213 g/L is needed to produce controlled designation of origin wines late harvest (DOC-CT).

Results

Climatic variables

According to the estimates of the nine climatic variables corresponding to the 26 sampling sites, the Schit and Dobrina vineyards from the higher and hilly western part are characterized as poor in heliothermic resources and wetter, while the Corni and Recea vineyards from the lower and plain part as richer in heliothermic resources and slightly less humid (Table 1). Thermal parameters record minimum values in the Dobrina vineyard (AAT = 9.0 °C; TWM = 20.4 °C; Σt_{eff} = 1203.4 °C) and maximum ones in the Recea vineyard (AAT = 10.1 °C; TWM = 21.7 °C; Σt_{eff} = 1427.1 °C). In a sampling site of the Schit vineyard, thermal parameters record absolute maximum values for the Huși wine growing region (AAT = 10.2 °C; TWM = 21.8 °C; Σt_{eff} = 1449.0 °C), but they are not representative for this

Table 1. The values of climate variables, climate suitability and grapes sugar content (GrSC, g/L) characterizing the 26 sampling sites from the Huși wine growing region

Sampling sites	Vineyard	Altitude	Aspect	Climate variables*									Climate suitability (a.r.p.)		GrSC (g/L)
				AAT (°C)	TWM (°C)	Σtu (°C)	ASD (hours)	GR (kcal/cm ²)	PP (mm)	IAOe	Ibcv	IHa	site	vineyard	
1	Schit	60.1	N	10.2	21.8	1449.0	1461.6	87.9	342.2	4702.9	7.8	2.1	9.4		228.9
2	Schit	161.3	NV	9.6	21.2	1333.3	1383.3	83.3	353.9	4477.8	6.8	1.8	8.0		190.0
3	Schit	129.3	NE	9.8	21.4	1369.6	1383.3	85.9	350.2	4503.6	7.0	1.9	8.3		209.8
4	Schit	211.8	NE	9.4	20.8	1276.5	1383.3	79.4	359.7	4359.8	6.5	1.8	7.0		194.6
5	Schit	236.9	N	9.2	20.7	1248.5	1479.0	88.3	362.6	4411.9	6.8	1.8	8.3		217.3
6	Schit	205.0	NV	9.4	20.9	1284.1	1470.3	81.3	358.9	4458.6	6.9	1.9	8.1		223.8
7	Schit	196.1	NV	9.4	20.9	1294.0	1435.5	81.9	357.9	4439.3	6.8	1.9	7.8	8.0	198.0
8	Schit	202.5	V	9.4	20.9	1286.9	1383.3	89.1	358.6	4376.0	6.5	1.8	8.3		211.5
9	Schit	198.8	V	9.4	20.9	1291.0	1287.6	89.5	358.2	4286.7	6.1	1.7	7.7		190.6
10	Schit	219.5	N	9.3	20.8	1267.9	1322.4	80.6	360.6	4285.6	6.2	1.7	6.9		179.7
11	Schit	207.4	SE	9.4	20.9	1281.4	1374.6	92.3	359.2	4358.9	6.5	1.8	8.0		205.7
12	Schit	201.2	NE	9.4	20.9	1288.3	1418.1	85.5	358.5	4413.1	6.7	1.8	8.1		231.8
13	Schit	198.1	NE	9.4	20.9	1291.8	1400.7	84.3	358.1	4401.1	6.6	1.8	8.1		209.3
14	Dobrina	263.7	E	9.1	20.5	1218.8	1365.9	89.0	365.7	4252.5	6.1	1.7	7.4		173.0
15	Dobrina	277.7	E	9.0	20.4	1203.4	1383.3	88.7	367.3	4245.6	6.1	1.7	7.4		195.6
16	Dobrina	276.7	E	9.0	20.4	1204.5	1383.3	88.9	367.2	4247.4	6.1	1.7	7.4		202.8
17	Dobrina	182.8	E	9.5	21.0	1309.0	1400.7	88.6	356.4	4427.6	6.7	1.8	8.5	7.9	214.8
18	Dobrina	215.7	E	9.3	20.8	1272.1	1392.0	91.8	360.2	4361.7	6.5	1.8	8.0		220.5
19	Dobrina	158.5	SV	9.6	21.2	1336.5	1287.6	92.6	353.6	4356.9	6.3	1.7	8.5		209.4
20	Dobrina	161.2	S	9.6	21.2	1333.3	1392.0	90.6	353.9	4456.5	6.8	1.9	8.5		212.1
21	Corni	157.2	S	9.7	21.2	1337.9	1374.6	92.0	353.4	4446.2	6.7	1.8	8.5	8.5	219.0
22	Recea	104.1	SV	9.9	21.5	1398.3	1487.7	90.3	347.3	4651.9	7.6	2.1	9.0		221.4
23	Recea	89.3	E	10.0	21.6	1415.3	1409.4	90.1	345.6	4599.6	7.3	2.0	8.9		220.3
24	Recea	83.4	S	10.0	21.7	1422.1	1470.3	90.7	344.9	4670.8	7.7	2.1	9.4	9.0	217.6
25	Recea	79.1	SV	10.1	21.7	1427.1	1383.3	91.2	344.4	4591.3	7.2	2.0	8.9		213.6
26	Recea	80.2	SV	10.1	21.7	1425.8	1392.0	90.7	344.5	4598.1	7.3	2.0	8.9		197.3

* AAT = average annual temperature (°C); TWM = average temperature of the warmest month (°C); Σtu = sum of effective temperatures (°C/Apr 1st to Sept 30); ASD = actual sunshine duration (hours/Apr 1st to Sept 30); GR = global radiation (kcal/cm²/Apr 1st to Sept 30); PP = precipitation in the growing season (mm/Apr 1st to Sept 30); IAOe = oenoclimatic aptitude index (Apr 1st to Sept 30); Ibcv = bioclimatic index; IHa = actual heliothermal index (Apr 1st to Sept 30) (Apr 1st to Sept 30); (Irimia et al., 2014).

vineyard, as for all the other 12 sampling sites from this area the thermal parameters are much lower (Table 1).

GR values are the highest in the sampling sites from the Dobrina, Corni and Recea vineyards (90.1 - 92.0 kcal/cm²), which are exposed mainly to south and east, and the lowest in the sampling sites from Schit (80.6-87.9 kcal/cm²), exposed mainly to north (Table 1). ASD varies significantly in the Schit and Dobrina vineyards located on uneven relief and are much homogeneous on the flat terrains of the Recea vineyard; overall, the sampling sites from Recea are characterized by values of about 1400 hours (1383.3-1487.7 hours), while those of the Schit, Dobrina and Corni present very dissimilar values, ranging in a large interval, from 1287.6 to 1479.0 hours. PP values vary in a narrower range, from 342.2 mm to 367.3 mm, with minimum values in the sampling sites from Recea and maximum ones in those from Dobrina and Schit (Table 1). The bioclimatic indices IAOe, Ibcv and IHa reveal poor heliothermal resources in the sampling sites from Dobrina and Schit, and maximums in the sampling sites from Recea and Corni, thus revealing enhanced heliothermal resources (Table 1).

Climate suitability

The estimates of climate suitability for wine production of the 26 sampling sites vary between 6.9 a.r.p. and 9.4 a.r.p. (Table 1). It is a wide range of variation that shows climatic resources suitable for the production of different types of wine, from sparkling wines to quality red wines. However, the overall averages of the Schit and Dobrina vineyards of the higher zone are of 8.0 a.r.p. and 7.9 a.r.p. respectively, indicating climatic suitability for quality white wines and red table wines; the overall averages of the Corni and Recea vineyards of the lower zone are

higher, by 8.6 a.r.p. and 9.0 a.r.p. respectively, revealing the climate suitability for quality red wines production primarily and quality white wines production in secondary.

Correlations between climate variables and GrSC

The analysis of the correlation coefficients between the estimates of climate variables and the GrSC for the 26 sampling sites, reveals the climatic variables driving GrSC, the way they influence GrSC and their representativity in the assessment of the spatial variation of GrSC.

The Pearson correlation coefficient ranging from 0.28 to 0.60 shows the conditioning of GrSC by the local climatic factors (Fig. 2a to Fig. 2i). Climatic conditioning of GrSC is best represented by IHa, Ibcv and IAOe ($r = 0.57 - 0.60$) (Fig. 2a, 2b, 2c). The climatic factor which is most influential in GrSC is ASD which strongly correlates with the GrSC ($r = 0.57$) while the least influential is GR which weakly correlates with GrSC ($r = 0.28$) (Fig. 2g). The temperature, characterized by AAT, TWM and Σtu (Fig. 2d, 2e, 2f), as well as the PP, moderately correlate with GrSC ($r = 0.43$). All correlations are significant for $p < 0.05$, except for the one for the GR.

The coefficient of determination (R^2) reveals that of all climatic factors, the ASD explains best, rather 33 % of the GrSC variance (Fig. 2h), while temperature (AAT, TWM, Σtu) and PP explain only 18 % of the GrSC variance (Fig. 2d, 2e, 2f, 2i).

The simple linear regression shows that, except for PP, the increase of all the other climate variables is associated with the increase of the GrSC (Fig. 2). For the climatic factors, which vary from one year to another, the increase by one unit of the multiannual mean is associated with the increase of GrSC by:

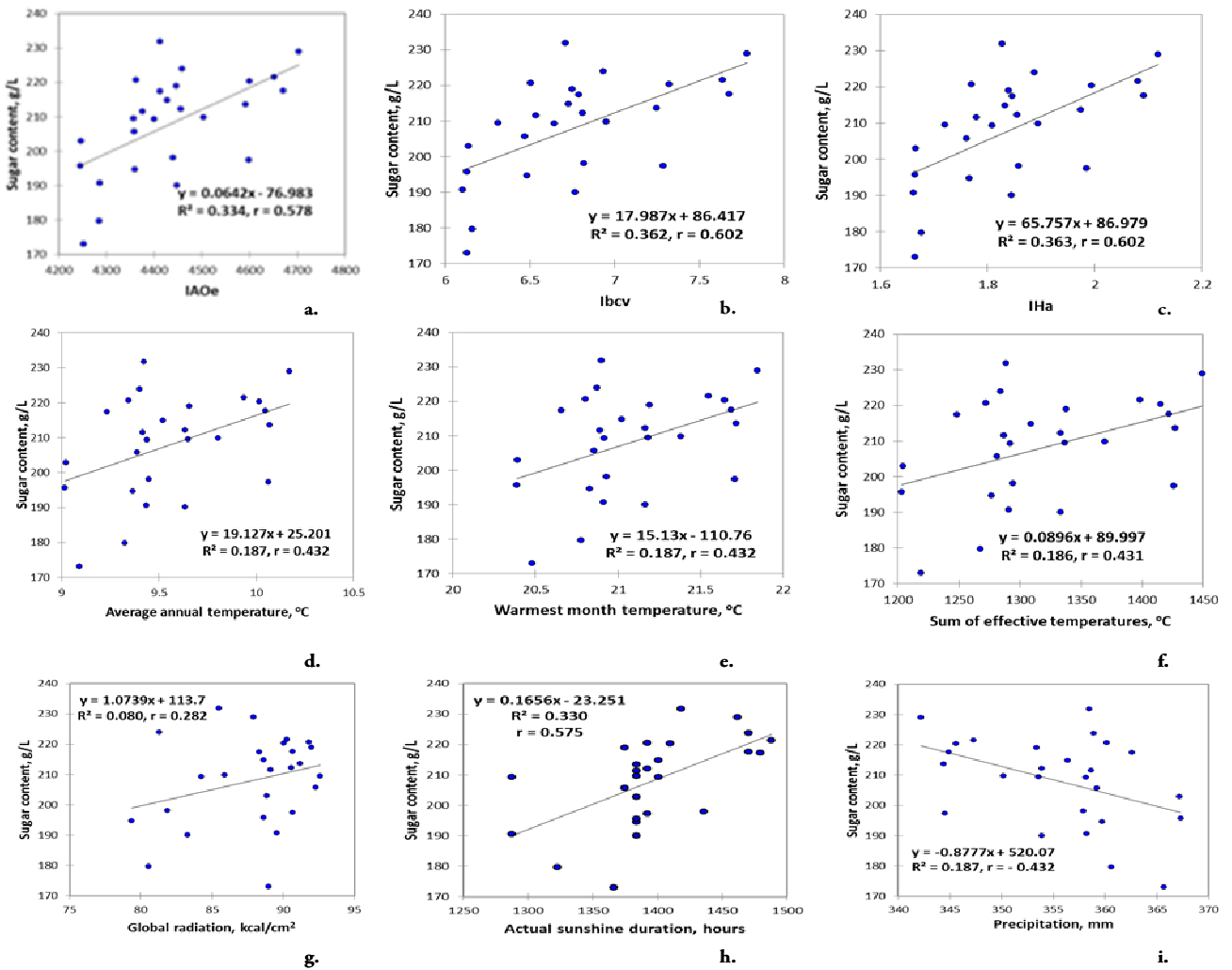


Fig. 2. Regressions between multiannual climate variables and GrSC (g/L) for the 2011 vintage in the Huși wine growing region

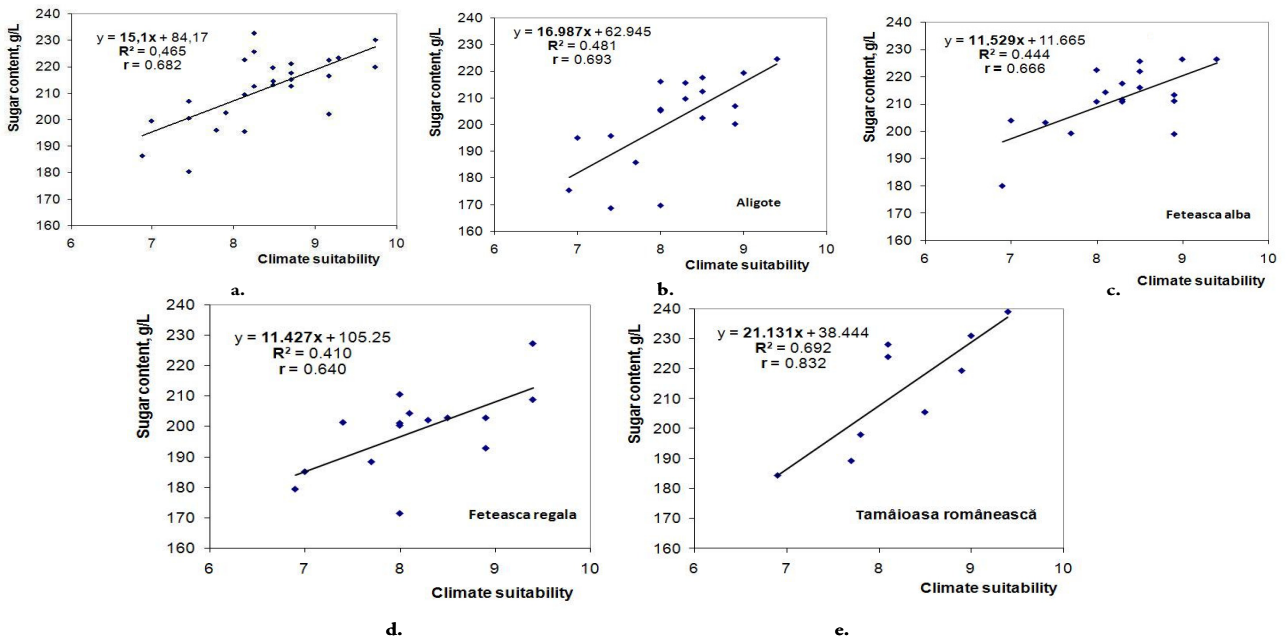


Fig. 3. Regressions between climate suitability for different types of wine production and the GrSC (g/L) for the 2011 vintage in the Huși wine growing region: a. for the mean of GrSC on 26 sampling sites; b. for 'Aligoté' variety; c. for 'Fetească albă' variety; d. for 'Fetească regală' variety; e. for 'Tămâioasă românească' variety

19.12 g/L in the case of AAT (Fig. 2d); 15.13 g/L in the case of TWM (Fig. 2e); 1.07 g/L in the case of GR (Fig. 2g); and 0.16 g/L in the case of ASD (Fig. 2h). For the PP, the increase by 1 mm of the multiannual mean is associated with the decrease by 0.87 g/L of the GrSC (Fig. 2i).

Correlations between climate suitability and GrSC

Pearson correlation coefficient reveals a strong positive relationship ($r = 0.68$) between the climate suitability and the GrSC (Fig. 3a); what is more the R^2 shows that climate suitability explains 46.5% of the GrSC variance, and the increase by one unit of the climate suitability/a.r.p. is associated with the increase by 15.1 g/L of the GrSC. These correlations are significant for $p < 0.05$.

When it comes to wine grape variety some differences can be noticed: Pearson correlation coefficient (r) ranges between 0.64 (strong positive correlation) for the 'Fetească regală' variety and 0.83 (very strong positive correlation) for the 'Tămâioasă românească' variety (Fig. 3); the R^2 shows that climate suitability explains 41% of the GrSC variance for the 'Fetească regală' variety up to 69% for the 'Tămâioasă românească' variety. The increase by one unit of the climate suitability is associated with the increase of the GrSC from 11.4 g/L for the 'Fetească regală' variety up to 21.1 g/L for the 'Tămâioasă românească' variety (Fig. 3).

Spatial variation of the GrSC

The map of GrSC for the 2011 vintage shows that it ranges between a maximum of 227.5 g/L in the Recea vineyard and a minimum of 165.3 g/L in the Dobrina and Schit vineyards (Fig. 4). This spatial variation reveals the correlation of GrSC with altitude ($r = 0.42$; $R^2 = 0.18$), and the altitudinal decrease of the GrSC, from the lower zone towards the higher zone of the study area. The linear regression between the altitude and the GrSC shows that the increase by one m of the altitude is associated with the decrease by 0.10 g/L of the GrSC (Fig. 5), a difference of about 21 g/L for the 2011 vintage between the lowermost sampling point (60.1 m asl.) and the uppermost sampling point (277.7 m asl.).

Statistical data show that the means of the interpolated GrSC values for the study area vary in a narrow range, between 205.9 g/L for the Schit vineyard and 216.9 g/L for the Recea vineyard (Table 2). The most uniform in terms of GrSC spatial distribution and hence in terms of grapes quality spatial distribution is the Corni vineyard (CV= 1.2), while the less uniform is the Schit vineyard (CV= 4.3). The *spread* index

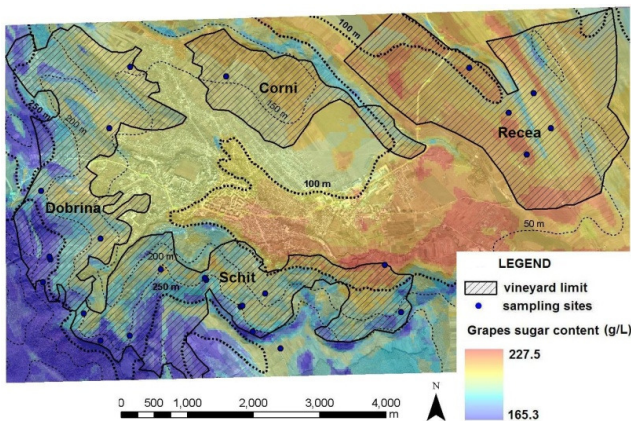


Fig. 4. Spatial distribution of GrSC (g/L) for the 2011 vintage in the Huși wine growing region

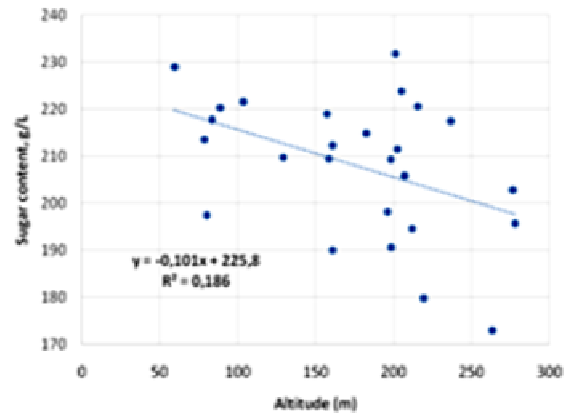


Fig. 5. Regressions between altitude and GrSC (g/L) for the 2011 vintage in the Huși wine growing region

reveals the same variability: a spread by 7.6 % for the Corni vineyard and by 27.9 % for the Schit vineyard, with an overall average by 16.9 % for the entire study area.

Spatial distribution of wine types which can be obtained depending on spatial distribution of GrSC of 2011 vintage

By classifying the spatial distribution of GrSC of the 2011 vintage according to ranges of GrSC required by the DOC wine production regulation for the Huși region, it can be noticed that it allows obtaining mainly two types of wine: DOC-CT wine on 52 % of the wine growing region surface and DOC-CMD wine on 41.0 % of the wine growing region surface (Table 3); the GrSC adequate to DOC and IG wines production had insignificant shares, of 3.9 % and 2.8 % respectively of wine growing region area.

The analysis of spatial distribution of GrSC classified according to DOC wine production requirement reveals that the wines types obtainable differentiate according to terrain altitude (Fig. 6): the DOC-CT wine production area extends in the lower zone, up to 150 m asl.; the DOC-CMD wine production area stands between 150-250 m asl.; the DOC and IG wine production zones correspond to high areas at above 250 m asl.

Table 2. Statistics for the spatial distribution of the GrSC within the Huși wine growing region

Vineyard	Surface (ha)	Sugar content (g/L)						
		Min	Max	Range	Mean	STD	CV	Spread ^a
Schit	554.3	168.5	226.1	57.6	205.9	8.8	4.3	27.9
Dobrina	570.6	172.6	214.5	41.9	206.2	7.9	3.8	20.3
Corni	264.4	204.6	220.9	16.3	215.0	2.6	1.2	7.6
Recea	749.7	199.8	225.6	25.7	216.9	3.9	1.8	11.8

^a spread is the difference between the maximum and minimum values, expressed as a % of the mean value (Bramley, 2005).

Table 3. The structure of wine types which can be obtained in the Huși wine growing region, depending on spatial distribution of GrSC for the 2011 vintage

GrSC (g/L)	Wine type ^a	Vineyard								Total surface	
		Schit		Dobrina		Comi		Recea		ha	%
< 190	IG	35.3	6.3	26.6	4.6	0.0	0.0	0.0	0.0	62.0	2.8
190-196	DOC	39.6	7.1	44.2	7.7	0.0	0.0	0.0	0.0	83.9	3.9
196-213	DOC-CMD	387.8	69.9	356.6	62.4	34.8	13.1	99.3	13.2	878.6	41.0
> 213	DOC-CT	91.4	16.4	143.1	25.0	229.5	86.8	650.3	86.7	1114	52.0
Total		554.3	100	570.6	100	264.4	100	749.7	100	2139	100

^a IG = quality wines with geographical denomination; DOC = high quality wines with controlled designation of origin; DOC-CMD = controlled designation of origin wines harvested at full maturity; DOC-CT = controlled designation of origin wines late harvest.

Comparing the spatial distributions of wine types which can be obtained (Fig. 6) and climate suitability specific to the Husi area (Fig. 7), a similitude of two spatial distributions can be noticed. Supported by the strong

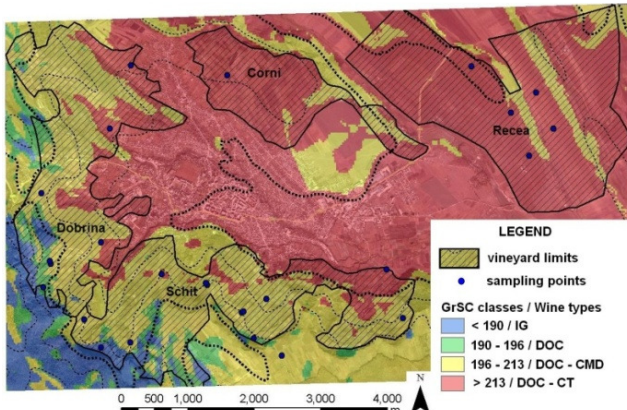


Fig. 6. Spatial distribution of the wine types obtainable within the Husi area according to spatial distribution of the GrSC for the 2011 vintage

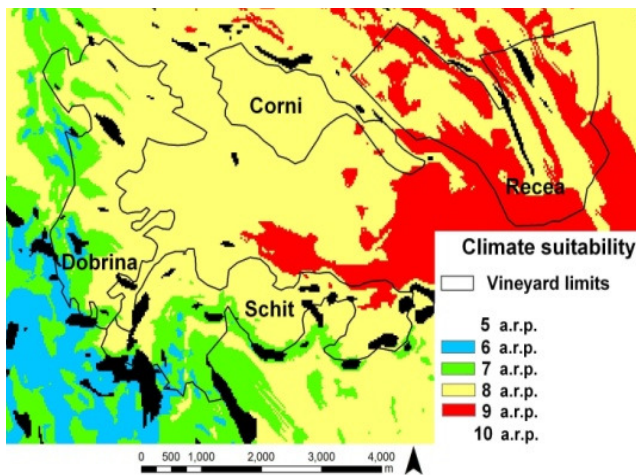


Fig. 7. Map of climate suitability (a.r.p. distribution) within the Husi wine growing region (Irimia *et al.*, 2014)

correlation of GrSC with climate suitability ($r = 0.68$) this similarity may reveal a pattern driving the spatial distribution of GrSC within the Husi wine growing region.

Discussions

This study analyzed the correlations of the GrSC of the 2011 vintage with the averages of climate variables characterizing the Husi wine growing region and also with the climate suitability for wine production they generate. Based on regression – kriging analysis, the spatial distribution of GrSC of the 2011 vintage was developed, and by its classification, the map of wine types which GrSC provides was achieved. The two maps show a potential pattern of spatial distribution of GrSC at the vineyard level. This may be a new result given the fact that the research which has been conducted so far (Bramley, 2005; Tisseyre *et al.*, 2008; Santos *et al.*, 2012) has focused mainly on spatial variation of grapes

quality parameters at plot scale. Although the analysis at the plot scale provides very accurate results, it reveals only local distribution patterns generated by the soil influence, while at vineyard scale the factor driving the variability is the climate (Van Leeuwen, 2010).

The study revealed strong correlations, statistically significant for $p < 0.05$, between multiannual averages of climate variables which define the climate of the Husi wine growing region and the GrSC of the 2011 vintage. The ASD, which closely correlates with GrSC ($r = 0.57$) turned out to be a very influential climatic factor of the GrSC. These results are in accordance with the ones of previous studies (Teodorescu *et al.*, 1987) emphasizing that the years with an exceeding of ASD of 8.9 % are suitable for wine quality, while those with a deficit of ASD of 9.8% are unsuitable for wine quality. Temperature, whose influence was expressed in this study by AAT, TWM and Σtu variables, slightly correlates with GrSC ($r = 0.43$); although this correlation is weaker compared to the values communicated by Huglin (1978) ($r = 0.71-0.83$), it indicates that the temperature should be taken into account when analyzing and modelling the spatial distribution of GrSC.

The close correlation ($r = 0.68$) between the GrSC for the 2011 vintage and climate suitability of the Husi wine growing region, identified in our research, reveals one of the relations of yield quality dependence which functions at vineyard level. Climate, together with grapevine variety determine differences of grapes composition at regional level (Van Leeuwen, 2010). Climate also determines the type of wine specific to a certain vineyard (Jones *et al.*, 2005). However, the study revealed that the correlation GrSC – climate suitability has a distinct value for each wine grape variety. This requires a customization of the analysis and modelling of the GrSC for each wine grape variety.

Mapping the GrSC based on its correlation with climate suitability ($r = 0.68$) revealed a coherent pattern of spatial variation at vineyard level. The study showed a significant correlation of the GrSC with altitude ($r = 0.42$, $p < 0.05$) and that under temperate continental climate conditions of the Husi wine growing region, an increase by 1 m of the altitude, is associated with a decrease by 0.10 g/L of the GrSC. This decrease of the GrSC can be related with the retarding effect of altitudinal increasing on grapes maturation, highlighted by previous studies (Calame *et al.*, 1977). Linearity of the altitudinal distribution of the GrSC is disrupted by the ASD variation that generates local variation of GrSC regardless of the altitude. GrSC variability is characterized by an average of 16.9 % of the *spread* index, value which is comparable with the one provided by other authors (Bramley, 2005).

The map of GrSC allowed revealing, as practical utility, the spatial distribution of wine types that can be obtained within the area. Differentiation of wine types in relation to altitude has been highlighted for other wine growing regions too (Shanmuganathan, 2010). Also, classification of spatial distribution of grapes quality parameters in order to delineate areas of wine quality within the vineyards is already practiced (ASAE, 2007). In our study two areas with different potential for wine production were delineated: an area situated below 150 m asl. where the GrSC records high values which ensure DOC-CT wines obtaining; and an area ranging between 150 and 250 m asl. where the GrSC records lower values which ensure DOC-CMD wines obtaining.

Since vineyards' climate is specific, temporally stable (Jones *et al.*, 2005) and less affected by vintage climate, its influence on grapes quality parameters should generate rather similar consequences from one year to another. Thus, the map of GrSC and also the map of wine types that it provides should present a certain spatio-temporal stability. By knowing the regression coefficients which characterize the relationship between climate variables and GrSC, the impact of their annual variation on wine production zones can be predicted. However, the lack of information on yield quality over several vintages prevents us from considering the study's outcomes as indisputable. Moreover, accurate setting of the spatial distribution of GrSC would require the representation of pedological and biological factors influence. Yet, given the significance of the statistical correlations between climate and GrSC, the map of spatial distribution of the GrSC for the 2011 vintage and the map of obtainable wine types, based on it, can be considered as guidance tools for site specific management within the Huși wine growing region.

Conclusions

The study provides new information on the factors that determine the spatial variation of grapes sugar content within vineyards. Although it is a spatially and temporally variable parameter, grapes sugar content shows significant correlations with climate variables specific to vineyards and with the climatic suitability for wine production they generate. Knowing these correlations allows revealing patterns that determine spatial distribution of grapes sugar content within the vineyard. In the case of the Huși wine growing region, based on the significant correlation of GrSC with climate suitability ($r = 0.68$), the map of GrSC for the 2011 vintage and the map of wine types that can be obtained were drawn up. The two maps reveal a coherent pattern of spatial distribution of grapes sugar content at vineyard scale, significantly correlated with terrain altitude. Such maps can be improved by integrating the influence of technological, biological and pedological factors on GrSC and can be used as tools for vineyard site-specific management. Based on grapes sugar content of a single vintage, this study did not allow the assessment of spatio-temporal stability of the obtained pattern of GrSC spatial distribution. By mapping the grapes sugar content for many years and analyzing its correlations with other factors which determine it, a clear pattern of GrSC spatial distribution within the Huși wine growing region can be achieved.

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